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**State of the Art—Alumina Ceramics for
Energy Applications**

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STATE OF THE ART—ALUMINA CERAMICS FOR ENERGY APPLICATIONS

by

Willard E. Hauth
Stephen D. Stoddard

ABSTRACT

Prominent ceramic raw materials and products manufacturers were surveyed to determine the state of the art for alumina ceramic fabrication. This survey emphasized current capabilities and limitations for fabrication of large, high-density, high-purity, complex shapes. Some directions are suggested for future needs and development.

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This report is primarily concerned with the definition of industrial capability for the fabrication of large, high-purity ceramic products in commercial quantities. This information was provided by a survey of ceramic manufacturers which focused on commercial fabrication capabilities for large, high-purity alumina shapes and technologies that can expand current fabrication capabilities.

Modern energy production concepts, including thermonuclear fusion, coal gasification, and magnetohydrodynamic systems, require containment materials that resist elevated temperatures, erosion and corrosion, thermal shock, and in some cases, radiation damage. Additional desirable characteristics are electrical insulation, imperviousness to gases, and low creep under stress. Ceramic materials provide several candidates that could fulfill some or all of these requirements. The additional parameter which raises some significant questions is the fabrication of large, high-density, high-purity, often complex parts. The large sizes suggested include linear dimensions between one and three meters and large curved shapes such as a cylinder one-half meter in diameter integral to a base plate one meter in diameter. Monolithic parts with these large dimensions are required to test the feasibility of many of the proposed energy systems.

Current industrial capabilities and limitations for fabrication of such containment systems were determined by selecting alumina as a material that is commercially manufactured for sufficient applications to represent the state of the art of fabrication of large, high-density, high-purity ceramic shapes. Although there are technologies for fabricating large parts from

several ceramic materials, alumina is the predominant commercial material. Accordingly, a survey of prominent ceramic raw materials and products manufacturers was conducted to determine the state of the art concerning alumina ceramic fabrication (see Appendix A). The list of survey respondents is presented in Table I.

The five primary concerns for which this survey sought industrial input are presented in Table II. The survey was also designed to obtain information about the relation between raw data points. For example, it would be useful to know if fabrication of large plates is limited more by composition than by fabrication or firing system size.

Capabilities for fabrication of rectangular plates were reported with regard to the fabrication equipment system. Table III provides the current size limitations for plates produced by dry pressing, slip casting, and isostatic pressing systems. When these sizes were limited by equipment capacity it was because of size limitation imposed by the manufacturer or because of a lack of consumer interest in larger sizes. The fired densities reported for these parts range from 3.40 to 3.94 Mg/m³ (i.e., 90 to 97% theoretical density). Hot isostatic pressing has been proposed as having advantages for the fabrication of large shapes but is, as yet, unavailable on a commercial scale, although large equipment is available in this country.

Table IV presents the limiting sizes on commercial right cylinders. Most cylindrical shapes are fabricated by isostatic pressing; however, some are slip cast. The density and fabrication limitations are essentially the same as those reported for plate fabrication. It should be noted that an increase of one of the cylinder dimensions is always done at the expense of at least one of the other two dimensions.

Responses generated by questions concerning large, complex shape fabrication indicate a general lack of experience in this area. Complex shapes, e.g., cones, elbows, and flanged tubes, are fabricated by most manufacturers by pressing (most frequently isopressing) and machining to the required shape in the green state. Parts "hogged" out of pressed stock are currently limited in size of the finished part to about 130 by 130 by 130 mm. This small size is probably dictated by the difficulty in removing the organic binders without damaging the part.

It is apparent that the primary factor limiting fabricated part size capability is the lack of past commercial interest in large, high-purity parts. The consensus among survey respondents is that dimensions of one-half to one meter would involve very little extension of existing technology, particularly for relatively simple shapes. This attitude presupposes significant interest and financial support for purchase of larger size capacity forming and firing equipment. Significant increases above about one-meter dimension and/or increase in complexity will require a well-designed development program as well as the procurement of large-size-capacity forming and firing equipment and ample raw material and energy supplies.

The primary high-alumina bodies available commercially contain 85% or more alumina. Of these, most contain between 94% and 99.9% alumina. The

most prominent additive present in all compositions is silica along with small amounts of alkaline earth oxides which are introduced coincidentally by the raw material or intentionally as fluxes, grain-growth inhibitors, etc.

The commercial alumina materials of primary interest for use as containment systems are at least 99% alumina. This requirement has been based on the need to minimize material additions that would reduce the chemical or physical stability of the containment system in harsh environments. This report is therefore limited to industrial fabrication of alumina bodies with greater than 95% alumina.

It should be noted that significant increases in current part size capability could be applied to some of the proposed ceramic requirements if a concession could be made in favor of lower purity ceramic bodies. Slip cast parts as large as 250 by 460 by 920 mm and isostatically pressed parts as large as 230 by 200 by 1300 mm have been fabricated from less than 95% alumina bodies for noncommercial use. Many products including thick-walled tubes up to 3000 mm long, extruded and machined insulators as large as 2400 mm long by 600 mm in diameter and entire furnace linings have been fabricated from mullite-based and other alumina-containing materials and commercial castable systems. It is likely that some of this fabrication technology could be translated to higher purity systems, given the necessary support.

Several materials and fabrication areas have shown promise for extension of technologies to the fabrication of large shapes. These are forming and firing systems, reactive materials, energy requirements, and component assembly.

Two common manufacturing process steps that are major determinants of size limitation are wet ball milling and the addition of organic binders. Ball milling alumina in the presence of water results in the formation of an alumina gel which can cause stress and steam-removal problems during sintering. Organic binders, commonly used to enhance green strength, must be oxidized during the firing process to be removed completely. The elimination of the gel and binders during firing becomes very difficult as the size of the fabricated part increases. We should evaluate the alteration of materials and fabrication techniques that would minimize the problems caused by these practices while maintaining green strength and machinability.

Investigations are also necessary to improve conventional firing systems. The stresses generated by shrinkage and nonuniform distribution of temperature during firing are magnified by increasing part size. Improved design and materials for kilns will be one of the first steps toward production of larger parts. However, the availability and/or cost of fuels is of increasing concern because of the long firing schedules required. The subject of natural gas availability and cost has been reviewed recently in the report "The Need for Natural Gas: The Alumina Ceramics Industry," sponsored by The Alumina Ceramics Manufacturers Association (this report is presented here as Appendix B with the permission of the Alumina Ceramic Manufacturers Association).

The single most promising technique for large-shape fabrication is isostatic pressing. It was universally suggested to enhance development

of impervious, large shapes, and to concentrate efforts on compositions with lowered firing temperatures and lower firing shrinkage. Advances in surface-active "sinterable" alumina powders are recognized as beneficial in lowering required sintering temperatures in high-purity bodies. The use of such powders and fabrication techniques in a hot isostatic pressing environment also warrants further evaluation.

Other areas of materials technology that have shown promise in the production of large ceramic shapes are ceramic-to-ceramic and glass-to-ceramic bonding. Many manufacturers have worked on these seals using small-to medium-size parts. Although the technology should be transferrable to large sizes, the limiting factor has been experience governed by prior customer demands.

Several projects requiring the assembly of large high purity, vacuum-tight ceramic shapes have been pursued successfully at the Los Alamos Scientific Laboratory (see Figs. 1 and 2). The assembly of complex monoliths by means of bonding of prefired subassemblies could also minimize the energy requirements for fabrication of large ceramic parts in the future.

TABLE I
SURVEY RESPONDENTS

<u>Manufacturer</u>	<u>Respondent</u>
Battelle Columbus Laboratories	Dale E. Niesz
Coors Porcelain Company	David G. Wirth
Corhart Refractories Company, Div. of Corning Glass Works	Robert F. Patrick
Diamonite Products, Div. of Spartex Inc.	Richard L. Marion
3M Company	Joseph T. Bailey
Plessey/Frenchtown Incorporated	John D. Fredericks
McWorrel Refractory Porcelain Company	Ronald K. Francis
Reynolds Metals Company	David R. Watson
Saxonburg Ceramics Incorporated	William Golya
Western Gold and Platinum Company	William S. Smith

TABLE II
EXAMPLES OF INFORMATION REQUESTED

1. Variety of chemistry in commercial bodies including alumina content and major impurities.
2. Maximum sizes of regular and irregular shapes within fabrication capability.
3. Types of fabrication, firing, and finishing facilities.
4. Areas of current technology that show potential for large shapes.
5. Vital factors in future capability development.

TABLE III
SIZE LIMITS FOR PLATE FABRICATION

<u>Process</u>	<u>Max. size (mm)</u>
Dry pressed	25 by 500 by 560
Slip cast	13 by 460 by 600
	25 by 200 by 300
Isostatic pressing	25 by 500 by 560

TABLE IV
SIZE LIMITS FOR CYLINDER FABRICATION

<u>Composition (wt%)</u>	<u>Size Limitation (mm)</u>		
	<u>Diameter</u>	<u>Length</u>	<u>Wall Thickness</u>
<99.5% Al ₂ O ₃	660	305	50
	510	460	25
	460	510	40
	360	685	40
99.5% Al ₂ O ₃	510	460	25
	460	305	40
	200	610	25
99.9% Al ₂ O ₃	100	250	20

Fig. 1.

An 85% alumina monolithic pump-out assembly was fabricated by attaching a slip cast right cylinder to a slip cast elliptical right cylinder using high alumina slip of the same composition. This assembly is fired to form a monolith that is vacuum tight. The stepped surfaces are lapped to a 4 RMS finish to provide a sealing surface for O-rings to join them hermetically to quartz toroidal segments. These assemblies are currently being used in thermonuclear fusion research.

Fig. 2.

A 99.5% alumina torus sector was assembled by means of glass sealing the joints between alumina subassemblies. Twelve of these monolithic assemblies have been connected using O-rings for use as a plasma container for thermonuclear fusion experiments. A series of glass compositions melting between 500 and 1450°C have been successfully used for this application.

APPENDIX A

SURVEY OF ALUMINA FABRICATION CAPABILITIES

The United States Department of Energy (DOE) projects for the development of energy sources are beginning to focus on requirements for large ceramic shapes. The ceramics, for use in fusion and MHD reactors and coal gasification systems, will provide resistance to high temperature, erosion, corrosion, and thermal shock as well as electrical insulation, imperviousness, and low creep under stress. As the fabrication techniques for large alumina shapes are relatively well developed, Los Alamos Scientific Laboratory has been asked to survey the primary alumina manufacturers to determine the state of the art of producing large alumina shapes. This information will be used by DOE systems design scientists to develop prototype systems that are realistic as well as to define the limitations to large-part fabrication for which future work is required.

State Of The Art--Al₂O₃

Do you have any objection to being identified as source for the answers given (personally and/or by company)?

1. What product compositions are available with 50% or more Al₂O₃? If we discuss impervious, large-shape capability, what per cent Al₂O₃ contents bodies are your principal lines?
2. What are the major impurities in the above compositions with less than 97% Al₂O₃?
3. How large a rectangular plate can be made of each composition? How thick?
 - 3a. What method of fabrication is used? Does this change with composition?
 - 3b. What is the relative density? Is this affected by composition or fabrication method?
4. Is this capability limitation a function of composition (i.e., difficulty imposed by decreasing the level of product impurity)?
5. Is this limiting size smaller than your optimum fabrication or kiln capacity?
6. How large a cylinder can be made of each composition? Diameter, thickness, length?
7. What method of fabrication is used? Does this change with composition? What is the relative density? Is this affected by composition or fabrication method?

Is this capability limitation a function of composition (i.e., difficulty imposed by decreasing the level of product impurity)?

Is this limiting size smaller than your optimum fabrication or kiln capacity?
8. What are the maximum dimensions which can be achieved for complex shapes (e.g., a top hat, a cone, an elbow, etc.)?

9. What method of fabrication is used? Does this change with composition? What is the relative density? Is this affected by composition or fabrication method?
Is this capability limitation a function of composition (i.e., difficulty imposed by decreasing the level of product impurity)?
Is this limiting size smaller than your optimum fabrication or kiln capacity?
10. What tolerances to required dimensions do you expect to achieve on as-fired large pieces? Is this highly dependent on composition?
11. What as-ground tolerances would you be able to provide for large pieces? How large a shape can you grind - i.d. - o.d. on rings, flats, etc.
12. Because the gas-tight requirement as well as large size is important for many systems, is it feasible to fabricate large monolithic structures via glass-to-ceramic or ceramic-to-ceramic sealing? Is this within your capability on any size level?
13. What compositions, fabrication methods, and/or heat treating systems do you feel have the most promise for further development of impervious large shapes?
14. Do you have any comments or proposals concerning factors which you consider vital to present or future individual company or industry advancement in fabrication of large, high-purity alumina?

APPENDIX B

THE NEED FOR NATURAL GAS: THE ALUMINA

CERAMICS INDUSTRY

The alumina technical ceramics industry is relatively small and is highly specialized, concentrating on the production of custom-built components used in the manufacture of a wide range of essential industrial and commercial products. The Alumina Ceramics Manufacturers Association* has as its members** a significant proportion of those companies that manufacture alumina technical ceramics.

The alumina technical ceramics industry has a significant impact on the American economy. Total estimated sales last year were \$170,000,000; 1976 estimated sales will be approximately \$194,400,000. Manufacturers of alumina ceramics employ approximately 6,600 workers and maintain payrolls of more than \$69,000,000 per year. Alumina technical ceramic plants are located in many states; in areas that have experienced severe natural gas curtailments, and in other sections of the country where the prospect of curtailment is real. The impact of the industry is more widespread than these figures, taken alone, suggest. Because alumina ceramics are used as components of sophisticated products in many industries, shut-down due to natural gas shortages would have a ripple effect throughout the economy.

An alumina technical ceramic has been defined as "a ceramic product utilizing sophisticated high purity Alumina (Al_2O_3) and other ingredient materials, fired by unusual techniques."*** Equipment designers utilize alumina technical ceramics because they have certain unique qualities that are required to build more durable and maintenance-free equipment. These characteristics include the following: (1) The hardness, density, mechanical strength, inertness and heat resistance of alumina make it an excellent abrasion and wear-resistant material. (2) This inorganic

* The Association, which aids its members by establishing technical standards for alumina ceramics, has also served as a clearinghouse for obtaining energy usage information from its members. Eighty-seven percent of the products manufactured by Association members are alumina technical ceramics.

** The members of the Association are as follows: Alberox Corporation, Industrial Park, New Bedford, Mass. 02745; American Feidmuehl Corp., P.O. Box 2090, Hendersonville, N. C. 28739; Coors Porcelain Company, Golden, Colorado 80401; Diamonite Div., Spartek, Inc., Shreve, Ohio 44676; DU-CO Ceramics Co., Saxonburg, Pennsylvania 16056; Krohn Ceramics Corp., 221 Seventh Avenue, Hawthorne, N. J. 07507; McDanel Refractory, Porcelain Company, P.O. Box 560, Beaver Falls, Pennsylvania 15010; Materials Research Corp., Orangeburg, New York 10962; Plessey, Frenchtown, Frenchtown, New Jersey 08825; Western Gold and Platinum Co., 555 Harbor Boulevard, Belmont, California 94002.

*** J.T. Jones and M.F. Berard, "Ceramics - Industrial Processing and Testing."

material can resist attack by most chemical compositions.* (3) High alumina has excellent electrical insulating properties even at elevated temperatures.** (4) It retains most of its mechanical strength characteristics at elevated temperatures, which makes it an excellent refractory material. (5) High alumina is unaffected by most equipment operating environments. Used in place of metal or plastic, it sharply reduces equipment maintenance and the time during which machines are idle for repairs. (6) Finally, high alumina can be fabricated to extremely tight tolerances using diamond grinding techniques.***

Members of the Alumina Ceramic Manufacturers Association have projected a continued, dramatic growth in alumina technical ceramics production. The demand for these sophisticated components increases with each innovation in the highly technical industries, such as computer and electrical industries, on which modern American prosperity has been based. Association members estimate their future rates of expansion to average 20 percent a year. An important side effect of this growth -- which may well be more startling in the future because of technical developments unforeseen today -- is that the amount of natural gas required to sustain the industry will double by 1980, for a total estimated natural gas consumption of 6,221,325**** Mcf, instead of the 1976 estimated consumption of 3,354,420 Mcf.*****

Alumina ceramics manufacturers have an inadequate supply of gas today, and prospects for the future are not good. Association members have had up to 50 percent of their supply curtailed every day.***** Other members have been curtailed by more than 10 percent most of the year. For others, curtailment was a real possibility but because of the warm weather this past winter a serious crisis was avoided. Association members have been informed that they may not increase their consumption of natural gas; this severely curtails use of gas in an expanding industry.

* Its use provides some protection against corrosion in pollution control and medical and chemical processing equipment.

** It is therefore used, for example, in microwave tubes, radomes and microwave windows.

*** Precision applications include cutting tools, needle valves, gyroscope parts, computer tape guides and nuclear reactor components.

**** The estimated consumption of propane, oil, and electricity will also increase as the industry grows and as it eliminates the present (very small) use of natural gas as a boiler fuel.

***** Association members have made serious and expensive efforts to conserve natural gas. Kilns have been redesigned and re-insulated to increase ware load per kiln cars. Analyses of firing schedules have allowed more products to be packed into each firing. Other steps have been taken to lower temperatures in the plants and to lessen the amounts of heat lost.

***** Most manufacturers of alumina ceramics have been placed in category 2 of the curtailment priority system established by the Federal Power Commission.

NATURAL GAS IS REQUIRED FOR THE PRODUCTION OF ALUMINA CERAMICS

Natural gas is an essential process fuel used to fire the special kilns used for the manufacture of alumina ceramics.* Neither fuel oils, nor electricity, can replace natural gas in the manufacturing process for the foreseeable future. The firing process -- through which the ceramic material acquires the special qualities that make technical alumina ceramics uniquely suited to a wide range of industrial uses -- requires the use of a fuel which will attain extremely high temperatures** without disturbing the carefully balanced atmosphere needed to produce the matured ceramic.***

The high temperature kilns required to produce technical alumina ceramics, therefore, utilize gaseous fuels. They cost from \$150,000 to \$500,000 installed, and cannot be converted to electric or fuel oil firing even if those fuels were suitable. Clearly, the economic impact of having to replace the existing kilns would be serious for the entire industry -- and might force some of the smaller manufacturers to shut down entirely.

The temporary curtailment of gas supply, which would necessitate shutdowns, might permanently damage some of the kilns which are constructed to operate continuously. With shutdown, the kiln becomes cold, and the arch of the kiln will sag or collapse and must be repaired.

Association members have indicated, in response to an Energy Usage Survey, that propane can be used by some of them as an alternative fuel. Propane, however, is an expensive fuel which is in very short supply. Although the FPC will consider propane an appropriate alternate fuel for temporary use, the FPC recognizes that propane, as a byproduct of natural gas, is also in short supply and the capability to convert to the use of propane is therefore not considered to give the consumer alternative fuel capability. (18 C.F.R. §2.78(c) (10))

* 95 percent of the natural gas consumed by Association members is used as a process fuel.

** Alumina technical ceramics are fired at temperatures as high as 3200°F (1760°C).

*** Fuel oil is not a practicable firing agent because sulfur dioxide is formed during its combustion. Sulfur dioxide changes the atmosphere and damages the matured ceramic. Furthermore, the volume of combustion space required for the release of an equal quantity of fuel oil is 400 times greater than the volume required for a gaseous fuel. The size -- and consequently the cost of kilns -- would have to be increased enormously. (Bricks used to build the kiln cost more than \$5 apiece.) Electrically heated kilns are precluded because they do not have the versatile capacity necessary to attain high temperatures in the required oxidizing atmosphere.

It is estimated that the use of propane -- if it were available -- would increase manufacturing costs by 20 percent or more. Furthermore, some manufacturers have no stand-by propane system nor storage facilities.

NATURAL GAS CURTAILMENTS IN THE ALUMINA
CERAMICS INDUSTRY WILL SERIOUSLY AFFECT THE
ECONOMIC WELL-BEING OF LOCAL COMMUNITIES
THROUGHOUT THE NATION

The shutdown of any alumina ceramics manufacturing plant would have a serious effect on the plant's local suppliers and businessmen that serve not only the plant but its employees. Each plant employs a skilled workforce that might well add to local unemployment rolls in case of plant shutdown. Each alumina ceramics manufacturer also contributes to community well-being through the payment of taxes. For some communities, the tax base would be seriously weakened: tax payments to one community, for example, amounted to a quarter of a million dollars. A second company estimated that it provided 5 percent of the total tax base of its local community, and another company was the third largest taxpayer in its town.

Plant shutdowns, in this industry as in others, would increase unemployment. For some communities, the loss of employment at the alumina ceramic plant would amount to disaster. One plant employs 20 percent of the local work force, and supplies 15 percent of the total wages paid in the community. Alternative sources of employment in the immediate area are extremely limited. In another community, 14 percent of the available workforce are employed in the plant: present unemployment exceeds 15 percent and a shutdown would only add to that figure.

In one case, the impact of plant shutdown would be drastic. The plant payroll accounts for 16 percent of the total payroll received by community residents, and local purchasing on behalf of the plant contributes 10 percent of the local economy. There is no alternative source of employment. With shutdown, tax revenues would be reduced 35 percent, and welfare costs to the community could increase 38 percent.

These serious local effects of plant shutdown are merely the beginning of the nation-wide impact that would inevitably occur.

THE RIPPLE EFFECT

Curtailement of natural gas to this unique industry will have a "ripple" effect on a wide variety of American industries. The special characteristics of alumina technical ceramics make them the preferred, if not the essential components for a wide range of products, from precision tool-making equipment to the ceramic block over which telephone wire is drawn. Aluminum products are used in power conversion and generators: the cost of the alumina ceramic component may be less than \$50,000, but it is sub-assembled into metal hardware and then becomes part of a \$40 million nuclear power plant. A \$380,000 power conversion installation will not function without \$1,600

worth of alumina ceramic components that are supplied by an Association member, as a second tier supplier, to the subassembly manufacturer. Temporary shutdown would affect not only the subassembly manufacturer but the builder of the installation as well. This impact would be felt almost immediately: it would be rare to have inventory on hand to meet the custom needs of the end-product manufacturer.*

One case study will illustrate the point for the entire industry. Alumina ceramic parts are used as windows, envelopes, insulators and spacers in the power transmitting tubes used in radar applications. The shutdown of the alumina ceramics manufacturer because of natural gas curtailments, would have the following immediate effects:

a. There would be a rapid shutdown of production facilities for power transmitting tubes, since these tubes cannot be made without alumina;

b. At least 10,000 workers in the various tube plants would be out of work;

c. A crash program to find a substitute material would take a minimum of one year and probably three years, and would cost \$35 to \$50 million, since it would require changes in the physical size of the tubes and development of new manufacturing processes;

d. A catastrophic ripple effect would be felt by the military, space, communications and transportation users of radar systems. Well over 100,000 workers would be affected. The cost to radar users of re-engineering their systems might be as much as \$250 to \$500 million.

* In some instances, foreign ceramic products could be substituted, or the end product could be re-engineered, at a substantial cost, to use inferior substitutes. The end product would then also be inferior.

Alumina technical ceramic products are essential parts of portable radio equipment; bio-medical equipment; radar sets and television output signals.*

* A partial list of "essential end products" was supplied to the Association by its members:

1. Oil and gas production
2. Medical equipment, e.g., blood transfusion analysis equipment
3. Nuclear power generators
4. Coal mining equipment
5. Coal disulfurization plants (pilot)
6. Space programs - insulators for temperature control in space units
7. Electrical industry operations
8. Fast fire - low fuel consuming kilns for manufacturing glass and ceramic tiles
9. Temperature measurement and controls
10. Avionic systems - commercial, private and military
11. Telephone equipment
12. Fume scrubbers
13. Missile Radomes
14. Radar antennas
15. Computers
16. Wire drawing equipment
17. Metal cutting tool machinery
18. Textile machinery
19. Semi-conductors
20. Stand-off insulators for precipitators
21. Electronic substrates and package components
22. Electrostatic precipitators
23. Electronic transmitting tubes
24. Telecommunications - thin film hybrid circuitry
25. Paper production
26. Corrosion resistance programs
27. Electronics products that are used in commerce, industry and national defense

Alumina ceramics also have a number of vital defense related uses, as is indicated by the use of alumina ceramics in all radar systems and by the presence of numerous Defense Department sub-contracts held by Association members. Alumina technical ceramics are also used in much experimental work; their manufacturers play a key role in furnishing prototype parts to designers of new equipment.

RECOGNITION OF THE ALUMINA CERAMIC
INDUSTRY'S SPECIAL NEED FOR NATURAL GAS
WOULD PREVENT SEVERE DISLOCATION OF THE
ECONOMY AT A MINIMAL COST

We have demonstrated that the alumina technical ceramics industry requires natural gas for process uses. Because the unique properties of alumina ceramics can only be achieved by the use of natural gas as the firing fuel, no substitute fuel can be used. Curtailments in the supply of natural gas will not only cause shutdowns in the alumina ceramics industry, but, if the curtailments are severe, the dislocation will be felt throughout the economy.

On the other hand, the national cost of changing the allocation priority for the members of the Association, and other manufacturers of alumina ceramics, will be so slight as not to exist at all. The members of this industry use, and will use in the future, an insignificant amount of this nation's natural gas. The return on additional gas allocated to the industry will be many times greater than the cost of the allocation, and will be greater than the return that could be obtained from an allocation to any other industry.