CHAPTER NINE

CONCLUSIONS AND RECOMMENATIONS

9.1 CONCLUSIONS

This study identified a variety of metal alloys and refractory ceramics that are currently being used by the Industries of the Future (IOFs) and that are candidates for replacement with advanced ceramic materials. While these conventional materials have gained widespread acceptance, their continued use is a source of high maintenance, lost productivity, and low energy efficiency. Key material challenges for replacement materials include wear, corrosion, degradation at elevated temperatures, creep, mechanical and thermal fatigue, and impact and thermal shock. Ceramics are well known to have superior wear resistance, corrosion resistance, and high-temperature stability, but they are often not selected for IOF applications because of their higher cost and reliability concerns associated with mechanical stresses or thermal shock. The study determined that while major improvements have been achieved in ceramic materials in recent years in their mechanical and thermal properties and in design knowledge, costs remain high and user confidence remains low. In many cases, lack of awareness on the part of the IOFs prevents advanced ceramics from even being considered as a potential solution.

Four categories of ceramics offer benefits: monolithics, coatings, refractories, and ceramic matrix composites. The first three are well-established industries, whereas ceramic matrix composites are relatively new and are just beginning to be qualified for industrial applications. Competing technologies also exist and include continued advances in metal alloys and their composites to reduce weight, increase corrosion resistance, and improve temperature capability and hybrid systems that combine the reliability of metals with the wear and corrosion resistance of plastics or the temperature capability of refractories. Because all the IOFs are placing increased emphasis on maintenance, productivity, energy efficiency, quality, and regulatory compliance, now appears to be an opportune time for the IOFs to explore the potentials of advanced ceramic materials.

The study concludes that the four categories of ceramic materials provide many opportunities to meet the material needs of the IOFs. Figure 9.1 lists a representative cross-section of these opportunities and shows how they crosscut the Industries. Examples of other important opportunities relative to specific industries include anodes and cathodes for aluminum smelting, molten metal filters, and microporous ceramics for chemical separations.

9.2 RECOMMENDATIONS

The following recommendations were developed to provide a meaningful and achievable path forward to assure advanced ceramics will be used to save energy and reduce emissions in the immediate future. Recommendations are provided in three areas: education/increased awareness, partnership facilitation, and technical challenges.

Education/Increased Awareness

Two conclusions of the study are that representatives of the IOFs generally lack the knowledge required to consider advanced ceramics as a potential solution and that the advanced ceramics industry generally lacks an understanding of the problems within the IOFs that advanced ceramics could solve. Specific recommendations for further action follow:

- Dissemination of the results of this study through direct mailing to IOF partners and advanced ceramic companies and, more widely, by electronic distribution on the Department of Energy's (DOE's) Office of Industrial Technologies (OIT) Web site: http://www.oit.doe.gov.

Table 9.1. Application areas where ceramic-based materials can benefit multiple Industries and provide high return on investment

	Chemical	Refinery	Forest Products	Steel	Glass	Aluminum	Metalcasting
Burners	X	X	X	X	X	X	X
High-temp. insulation	X	X	X	X	X	X	X
Heat recovery	X	X	X	X	X	X	X
Sensor shields	X	X	X	X	X	X	X
Separations	X	X	X	X	X	X	X
Handling/transport	X	X	X	X	X	X	X
Rollers	X		X	X	X	X	
Gas injection				X	X	X	X
Gates/vanes/seals	X	X	X	X	X	X	X
Fans/stirrers	X	X	X	X	X	X	X
Molds/tooling					X		X
Supports	X	X	X	X	X	X	X
Pumps	X	X	X			X	X
Bearings	X	X	X			X	
Liners	X	X	X	X	X	X	X

- Increased knowledge by the advanced ceramics industry on the vision, roadmaps, projects, and solicitations for funding currently being addressed under each of the Vision Industries. The OIT's informative Web site provides much of this information, including the OIT Resource Catalog from which over 450 OIT publications can be ordered or viewed in HTML format.
- Increased participation on the part of the advanced ceramics industry at IOF conferences and expositions both in the form of displays and presentations on the status of advanced ceramic materials and their past and potential uses in the respective IOFs. Information about upcoming events within the Vision Industries can also be found on the OIT Web site.
- Establish a Web site that provides easy access to information on advanced ceramics for use by the IOFs. Much of this information exists within various sources on the Internet, but a centralized source with links and expanded information on specific problems would be a valuable communication resource. In addition, data that exist throughout the advanced ceramics industry but not currently on the Internet would need to be collected, logically organized, and made available on this specialized Web site.
- Develop new and creative ways to communicate information and data relevant to ceramics performance and properties in the uses that are identified in this report. This should include, but not be limited to, articles in industry trade publications, World Wide Web sites, papers and lectures at trade gatherings, and video and CD ROM reports.

Arrange tours of IOF plants by the advanced ceramics industry. The goal of these tours is to see first hand what the problems are and furnish immediate feedback as to how advanced ceramics could provide a potential solution. Presentations should be included at these meetings on the status of monolithic and composite ceramic materials that could be considered by the IOFs.

Partnership Facilitation

The study identifies opportunities that could benefit from partnerships among the IOFs and advanced ceramics industry. Specific recommendations for further action follow:

- Encourage the interaction and formation of partnerships among the advanced ceramics community and IOFs. Many opportunities identified in this study are considered

precompetitive to specific industry groups and are of sufficient complexity that a consortium or partnership between the specific IOF and advanced ceramics industry will be required to develop solutions in an acceptable period of time.

- Review the results and outcomes from the recent joint meetings of the Chemical and Glass Industries with the advanced ceramics industry. Specific recommendations for the remaining Vision Industries should be made based on lessons learned for improving and building on future joint interactions.

Technical Challenges

Another conclusion of the study is that a number of crosscutting technical challenges remain before the widespread application of advanced ceramic materials will occur in the IOFs. Some of these challenges include reduced cost, improved reliability, scale-up, increased design knowledge, and expanded design databases. Specific recommendations for further action follow:

- Continue support for crosscutting programs like the Continuous Fiber Ceramic Composite Program that are vitally important in ensuring that early-stage research efforts support many of the energy-intensive IOFs.
- Perform regular reviews of remaining crosscutting barriers to the insertion of advanced ceramics. Consider using new crosscutting research and development programs that impact the ceramics industry for the demonstration of key technology platforms for improving energy efficiency and reducing environmental problems.
- Develop improved databases, test methods and design guidelines for use by the IOFs through increased coordination with ASTM, ASME, Mil-Hdbk-17, and other related activities. Current databases are generally inadequate and do not allow IOF experts to make favorable design decisions on advanced ceramics. Test methods are frequently lacking, and design guidelines are not well understood when applied to advanced ceramic materials.