CHAPTER ONE

EXECUTIVE SUMMARY

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This document summarizes the results of a study to assess the potential of advanced ceramic-based materials to help the Industries of the Future (aluminum, chemicals, forest products, glass, metals casting, and steel) meet their long-range visions of energy efficiency and pollution reduction, improved capital effectiveness, and increased productivity. The report has three primary objectives: (1) provide to the Industries of the Future a review of the status and potential of key advanced ceramic-based materials, including examples of specific application challenges these materials already are solving in other industries; (2) provide to ceramic materials suppliers a review of key materials needs in each Industry; and (3) provide recommendations of specific ceramic material candidates for specific applications in each Industry. The study has identified that all of the Industries of the Future have similar materials needs, plus additional specialized needs. Table1.1 lists ar eas that ceramic-based materials are especially suited to benefit and illustrates the commonality of these needs to all of the Industries. Many of these crosscutting needs are addressed by the superior resistance of ceramics to wear, corrosion, and elevated temperatures. Other specialized needs that the ceramic-based materials can address include

- controlled surface behavior (very smooth surfaces for papermaking and synthetic fiber production);
- dimensional stability (tooling for metals forming, joining, heat treating, and measurement);
- electrical conductivity plus stability in a molten salt or molten metal (electrodes for aluminum smelting);
- high thermal conduction (heat exchangers, quench blocks); and
- filtration (chemical separations, molten metal filtration, hot-gas cleanup).

Ceramic-based materials already are satisfying some of the needs and have potential to provide further benefits, as discussed in this report.

Four categories of ceramic-based materials were identified in the study to be critical to meeting the needs of the Industries of the Future: refractories, monolithic ceramics, ceramic composites, and coatings. Refractories (the high-temperature linings and thermal insulation for furnaces and process vessels) are a necessity in all of the Industries of the Future and have continually been the subject of incremental improvements. Refractories remain the limiting factor in many high-temperature processes and are an important priority of the Industries.

Monolithic ceramics, especially ones with improved strength and toughness, have been a focus of development by the Department of Energy (DOE), other government agencies, and the ceramics industry for the past 20 years. Several of these advanced ceramics (silicon nitride, silicon carbide, and toughened oxides) have now reached production status and are demonstrating substantial increases in life and reliability for applications similar to those used in the Industries of the Future. Important advances in understanding how to design with brittle ceramics and in refining analytical design methods have also evolved. The timing is good for considering monolithic ceramics, especially for small-to-medium size parts where improved wear resistance, corrosion resistance, low friction, and high-temperature stability are required.

Monolithic ceramics are not optimum for all applications. Engineered ceramic composite materials are under development and represent a new generation of materials that can be tailored for specific applications. These engineered composites include continuous fiber ceramic composites (CFCCs) and particulate or whisker-reinforced ceramics. Supported by DOE Office of Industrial Technologies funding, CFCCs have

Table 1.1. 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

undergone extensive development during the past six years and appear to have potential to solve many especially difficult Industry challenges. However, CFCCs are still at an early-to-intermediate stage of development and are just starting to be evaluated under industrial application conditions. Developments are focused on achieving high-toughness materials that do not fracture in a catastrophic mode and that thus assure high reliability. A further objective has been to achieve larger size components than are currently possible or cost-effective for monolithic ceramics. Large size and high reliability are required for Industry components such as process vessels, heat exchanger tubes, and radiant burners.

The fourth category of ceramic-based materials important to the Industries of the Future is coatings. Ceramic coatings can sometimes offer the superior wear and corrosion resistance of ceramics combined with the ductility and toughness of the underlying metal. New diamond and diamond-like coatings are especially promising, having demonstrated greater than 20 times reduction in wear rate for some applications. Other coating technologies have been refined in recent years and have reached a level of maturity consistent with use in selected Industry applications. Examples include plasma spray, electron beam physical vapor deposition, chemical vapor deposition, and ion implantation.

The remainder of this report is divided into eight chapters (2–9) plus an appendix. Chapter 2 has been prepared primarily to update Industry individuals on ceramic materials advances that might benefit their specific Industry applications. This chapter includes many examples of successful applications of these advanced ceramics to solve needs similar to those of the Industries of the Future. Chapters 3–8 review each Industry of the Future and discuss needs and potential applications for ceramics. These chapters have been prepared to introduce materials suppliers to the Industries and also to stimulate the thinking of Industry individuals regarding potential uses of ceramics. Chapter 9 contains some brief concluding remarks and recommendations for future studies and interactions.