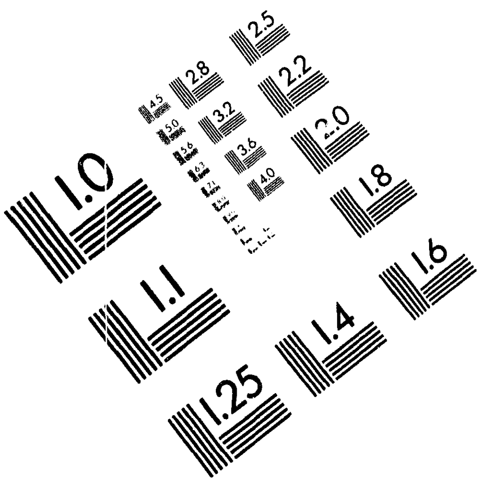

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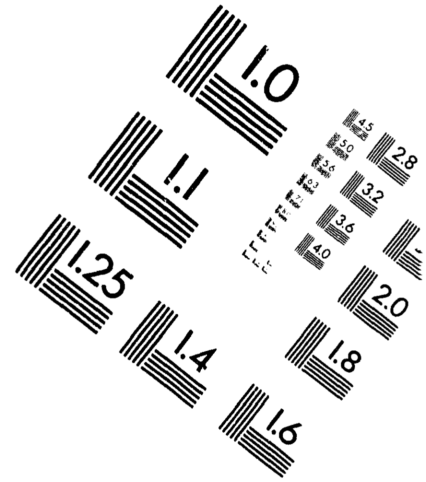

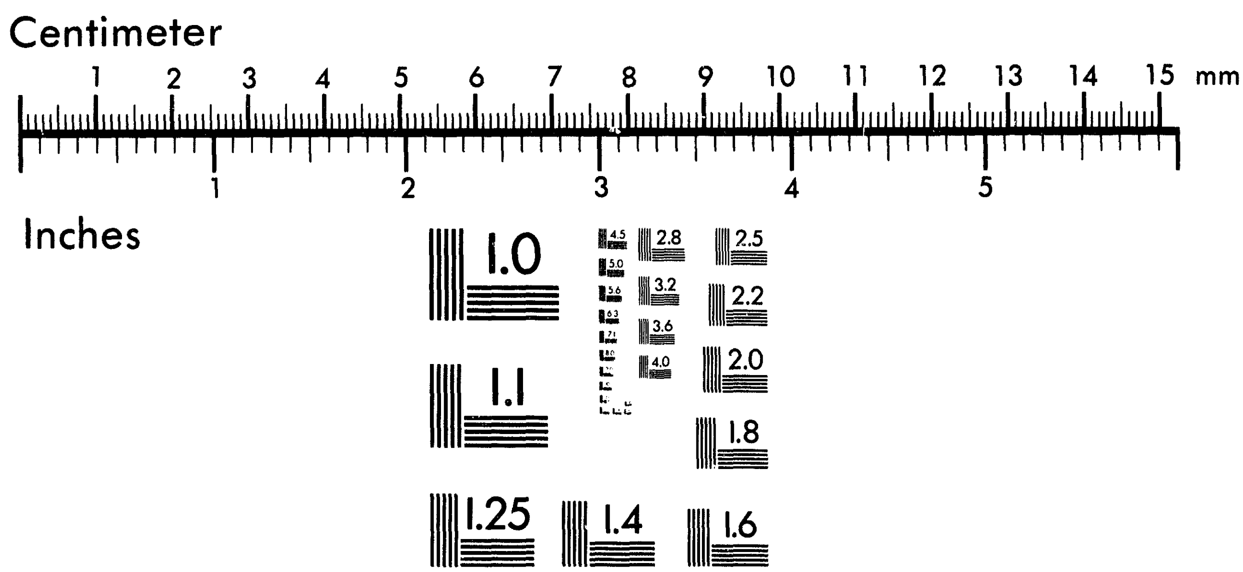

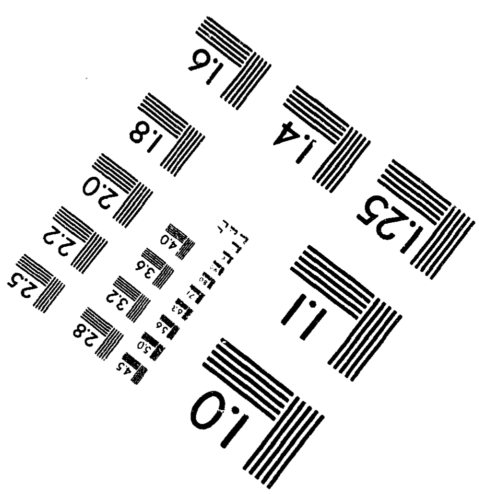

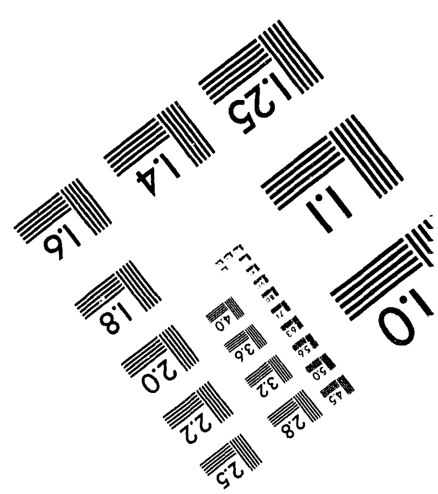

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COMPOSITES (CFCCs) FOR LOW COST ENERGY AND A CLEANER ENVIRONMENT

Prepared for:

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Office of Industrial Technologies
Under Contract DE-AC01-91CE40956

December 15, 1993

Prepared by:

Research Management Consultants, Inc.
Washington, DC

EXECUTIVE SUMMARY

U.S. industry currently consumes approximately $110 billion worth of energy each year, and expends at another $45 billion annually to deal with the pollutants and wastes industry generates.[1] Furthermore, between 1990 and 2010, the real price of energy for the industrial sector is estimated to rise 1.4% annually; and real increases in environmental costs will likely be greater than energy costs.[2] Hence, key technologies must be developed to reduce energy consumption and waste generation in the industrial sector. Such technologies will not only reduce energy and environmental costs for U.S. industry, enabling them to compete in an increasingly tough global market, but will also (because of lower industrial energy demand) reduce the cost of energy to the public and provide a cleaner environment. In addition, if the United States develops such technologies, jobs will be created for U.S. workers and this country will avoid increased reliance on foreign suppliers.

One such enabling technology is *continuous fiber ceramic composites* (CFCCs). These materials are being evaluated across a broad spectrum of applications and industries. The potential for using CFCCs is very substantial, due to the material properties that CFCCs feature. CFCCs are lightweight, tough, and corrosion-resistant; and exhibit high-temperature strength. These properties will enable industry to use energy more efficiently and reduce emissions associated with both energy consumption and industrial production. As an added benefit, CFCCs will also allow the United States to achieve greater energy independence and improve its environment.

This document characterizes the expected applications where CFCCs will be used. Specifically, employing CFCCs in U.S. industry and power generation can result in the following benefits:

- Energy savings of at least 2.16 Quadrillion Btus (Quads) annually by the year 2010, with an energy cost savings of at least $8.1 billion.
- Environmental progress in the form of emissions reduction, with minimum reductions for the following pollutants by the year 2010:
    - 917,000 tons annually of nitrous oxide (NO_x) emissions.
    - 118.9 million tons annually of carbon dioxide (CO_2) emissions.
- Cost savings from reduction in regulated emissions, principly NO_x and to a lesser extent, SO_x. With current environmental regulations and the expectation of stricter regulations, potential annual savings could be several billion dollars.
- Improved component performance and lifetime, resulting in reduced downtime, high-quality and low-cost products; allowing greater domestic and international competitiveness and a positive impact on U.S. employment.
- The competition for an estimated near-term market of between $700 million and $1.4 billion annually, with an identified market of over $6.4 billion by 2010.[3]
- The potential to create or save at least 64,000 industrial sector jobs for U.S. citizens, and a similar amount from multiplier effects, from identified applications where estimates were available.

In addition, CFCCs will be a valuable, cross-cutting technology in non-industrial applications, including the military, residential, commercial, and transportation sectors. The material properties that make CFCCs so valuable to industry are also beneficial in these sectors, and can result in the following:

- Energy savings of at least 0.06 Quads by the year 2010.
- Minimum emissions reduction of 113,000 tons of NO_x and 3.4 million tons of CO_2 by the year 2010.
- Reduction in particulate emissions from diesel engines.
- Improved fuel economy for some internal combustion engines.

These benefits will flow to U.S. consumers in the form of lower-cost electricity, higher quality and lower-cost manufactured products, and a cleaner environment. State and local governments will also benefit by the use of CFCC products, as these products will help meet Federal standards for air quality based on the Clean Air Act Amendments of 1990, in particular for NO_x and particulate matter. This will allow state and local governments to retain Federal funding for various uses, such as infrastructure repair.

CFCCs are currently being developed by other countries, and will be the material of choice in numerous applications. With both industrial and non-industrial applications, the estimated worldwide market for CFCC products is estimated to be at least $10 billion annually by the year 2010 ($6.4 billion identified in this document).[4] U.S. consumers will purchase a large percentage of the CFCC products sold. Thus, if the United States does not domestically develop this technology, the United States will become dependent on foreign producers for CFCCs and the end products that use CFCC components. Finally, a $10 billion market represents roughly 100,000 industrial sector jobs which will be actively competed for by many countries. Including multiplier effects, the number of affected jobs could be around 200,000.

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INTRODUCTION

For many industrial applications, materials are desired which combine light weight, high temperature strength, and stability in corrosive environments. Among competing materials, ceramics are noteworthy candidates for such applications. The use of ceramics is often constrained, however, by brittleness; i.e., low toughness. Ceramic composites are being developed to overcome this limitation. With recent advances in ceramic fiber technology, it is possible to design a composite material based on continuous ceramic fibers embedded in a ceramic matrix.

The use of ceramic composites in industrial applications will result in reduced fuel consumption, but will also prevent airborne pollution (principally NO_x, SO_x, CO_2, and particulates), and economically benefit the end user through energy and environmental savings and increased competitiveness. Industry will also benefit through increased productivity and consumers will benefit through lower energy and environmental costs and a cleaner environment.

The development and use of CFCCs could become an important factor in the international competitiveness of U.S. industry. CFCCs will be a critical enabling material in the design and engineering of advanced components, systems, and processes. If CFCC technology is developed outside the United States, domestic users of these materials may be forced to rely on foreign suppliers of the products fabricated from CFCCs, as well as the materials themselves. Foreign countries, including Japan and France, have embarked on government-supported CFCC development efforts. With the market for CFCC products expected to be a $10 billion dollar market by 2010, CFCC development will be important for the competitiveness of U.S. industry and for retaining and creating jobs for U.S. citizens.

The U.S. Department of Energy has embraced the potential that *continuous fiber ceramic composites* (CFCCs) can contribute to increased energy efficiency, and the Department's Office of Industrial Technologies has initiated a research and development program to develop the technologies necessary to entice industry to adopt these materials. As part of the program, an applications assessment element that identifies and defines the potential end-use applications has been included.

This document attempts to summarize the potential energy, environmental, and economic benefits that CFCCs will have for various application areas in the U.S. economy, and particularly for the industrial sector. A summary table is included at the end of this document for industrial applications. Estimates have been taken from many sources, and unless otherwise noted, numbers are assumed to be for the year 2010 in constant (early 1990s) dollars. The average cost of energy is assumed to be $5 per million Btus, which is below the Department's baseline estimate for industrial energy costs, but close to the cost of natural gas (which is the primary energy source for many CFCC applications).[2] Unless provided by another source, estimates for CO_2 emission reduction from energy savings were taken from the Department's Industrial Waste Reduction Program, assuming fossil fuels were used, and using natural gas as the fuel saved (since natural gas has the lowest emissions of CO_2 between coal, oil, and natural gas). Most energy savings numbers are for the United States alone, although a few may be worldwide numbers.

The domestic environmental savings that may result from CFCCs will heavily depend on future legislation and regulation. However, the costs of emitting are definitely increasing, at least in several areas. Some examples are as follows:

- California requires offsets from one industrial source if a new source will also emit. One recent offset yielded a minimum $17,500 per ton of NO_x. The South Coast Air Quality Management District (SCAQMD) is attempting to reduce NO_x emissions by 87% by the year 2007.[5,6]

- The Illinois Environmental Protection Agency is in the process of setting up an emissions trading scheme for NO_x for the Chicago area in order to reduce emissions and meet Federal standards. Included are large stationary emitters - i.e., industrial and utility sources.[7]
- Massachusetts plans to issue an emissions trading, banking, and averaging program for NO_x during the fall of 1993. Included are boilers that emit at least 50 tons/yr of NO_x.[8]
- Several states, including New York and Massachusetts, now require utilities to incorporate estimated costs for several pollutants, including NO_x, into their planning process. The monetized value of these externalities for various states ranged from $1,800 per ton in New York to $7,100 per ton of NO_x in Nevada, with even higher values in California.[9]
- Potential costs of non-compliance with EPA regulations (i.e., potential fines of several thousand dollars per day).

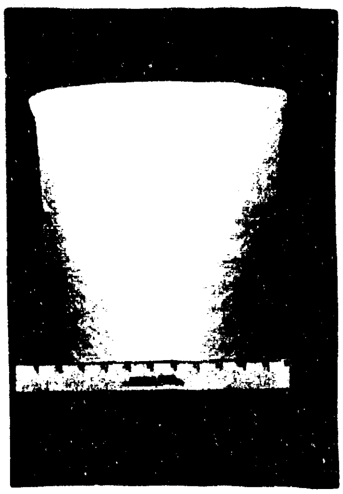
CFCCs will have to compete with alternative technologies and materials for many of the various applications that are being considered. Alternate materials include metal matrix composites, monolithic ceramics, and whisker and particulate reinforced ceramic composites. Alternate technologies may include new production processes, such as advanced glass melters. CFCCs will be used, but the extent of use will depend somewhat on the speed of development and commercialization of CFCCs relative to other materials and technologies.

GAS TURBINES - LARGE INDUSTRIAL

Turbines are a source of power for many sectors of the economy. The most recognized example of a turbine would be a jet engine. Utilities also use large, natural gas-powered turbines (greater that 20MW) to generate electricity for consumers. These turbines are relatively clean-burning, and installation costs for a gas turbine power plant are relatively low compared with other options, such as nuclear and coal. The large gas turbine power generators used by utilities and industry are advanced heat engines that experience thermal stresses primarily because of transient temperature distributions that occur when there are changes in power output. The efficiency of these turbines can be increased by operating them at higher temperatures, thus requiring materials with high temperature capabilities.

Description:[5,10]
CFCCs are candidates for numerous components, including the rotors, stators, combustion chamber liners (see illustration), cross fire tubes, combustor-to-turbine transition piece, turbine shrouds and blade tip seals, first-stage nozzles and buckets, and regenerators in power systems. CFCC materials would allow turbines to operate at higher inlet temperatures, increasing the thermodynamic energy-conversion efficiency by up to 4%. The power output increases by almost 2% by using CFCC turbine tip shrouds and combustor liners alone.

Energy Benefits:[5]
Application of CFCC components will reduce fuel use by 13% for gas turbines over current technology, saving 0.4 Quads of energy per year in the year 2010.



Environmental Benefits:[5]
Environmental emissions can be reduced by 75% compared with conventional technology, eliminating 300,000 tons per year of NO_x. Reduction in emissions due to the energy savings include 22.6 million tons per year of CO_2.

Economic Benefits:[10,11]
With projected market demand, this CFCC application will save $1.3 billion per year in energy costs, plus savings due to reduced environmental emissions. Fuel savings from the shrouds and liners alone will save $83 million per year by the year 2000 in the United States alone. Energy savings will be passed onto consumers due to lower rate increases for utilities.

Market Potential:[3,5,12,13]
The utility industry is projected to need 135,000 MW of additional capacity between the years 2000 and 2009. If mature CFCC technology were applied to gas turbines, CFCC component sales could be around $150 million per year, with a near-term market of $60-110 million. One estimate for worldwide sales in 2000 is $3 billion for gas turbines over 20MW in power generation. This would affect roughly 30,000 industrial sector jobs.

Relevant Markets:
Utility industry; international markets

GAS TURBINES - SMALL INDUSTRIAL

Turbines are a source of power for many sectors of the economy. The most recognized example of a turbine would be a jet engine. Natural gas-powered turbines are used in other applications, with small industrial gas turbines (1 to 20 MW) used for electric power generation, oil and gas production, oil and gas transmission, and hydrocarbon processing. The efficiency of these turbines can be increased by operating them at higher temperatures, thus requiring materials with high temperature capabilities.

Description:[14]
Many components (i.e., rotors and stators) that make up the turbine need to have the capacity to operate in a high-temperature environment. Ceramics, including CFCCs, operate in high temperatures, and are under development for use in these turbine components, and the benefits listed below are not for CFCCs alone, but also for the use of monolithic ceramics as well.

Energy Benefits:[14]
Worldwide estimated energy savings are estimated to be 0.36 Quads, or 350 billion cubic feet (BCF) of natural gas, annually in the year 2010. U.S. savings are estimated at 0.12 Quads (120 BCF). By 2015, worldwide savings are 0.52 Quads (500 BCF) annually.

Environmental Benefits:[14]
Environmental benefits will consist of reductions in NO_x emissions, which will be reduced by at least 90%, of 137,000 tons annually in the United States by 2010, and of 400,000 tons annually by 2010 and 700,000 tons annually by 2015 worldwide. Emissions of CO_2 will also be substantially reduced, including 44.5 million tons per year in the United States by the year 2010, with projections of a 130 million ton annual reduction by 2010 and 220 million ton annual reduction by 2015 worldwide.

Economic Benefits:[2,14]
Based on $5 per thousand cubic feet of natural gas, energy savings of $600 million are projected for the United States in 2010. Savings from NO_x reductions would also be significant.

Market Potential:[14,15]
Worldwide electric generating capacity is projected to increase substantially between 1990 and 2010, along with increased production of oil (24% increase) and gas (50% increase), giving a substantial market potential. One estimate for sales in the year 2000 for industrial and power generation gas turbines is nearly $1 billion. Assuming similar demand in the year 2010 would mean that nearly 10,000 industrial sector jobs would be affected.

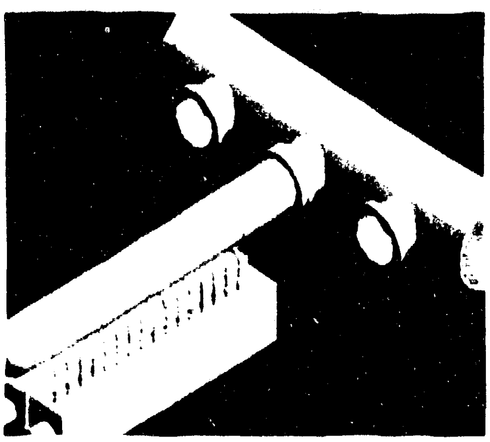
Relevant Markets:
Petroleum refining, chemical, utility, and oil and gas industries; international markets

HIGH PRESSURE HEAT EXCHANGERS (HIPHES)

Almost every industrial process utilizes heat exchangers in some capacity to transfer heat from one process stream to another. Heat exchangers are a very large energy consumer, with an annual heat duty of 12 quads.[16] The efficiency and performance of heat exchangers can be improved substantially with advanced technology. High-temperature and corrosion-resistant materials are one area where improvements in the performance of heat exchangers can be obtained; CFCCs have this capability.

Description:
High pressure heat exchanger systems (see illustration of system parts) can be coupled with gas turbines for power generation systems, waste streams, and other hot gas streams to recover energy, which is then used in preheating combustion gases or synthesis gases in the production of energy, or of chemicals such as methanol (See separate entry on Reformers). Heat exchangers are also an integral part of cogeneration systems and combined cycles for utilities, delivering high temperature air to the gas turbine at pressures up to 200 psi.

Energy Benefits:[14]
Advanced combined cycles offer potential for significant increases in overall efficiency. In one example, the high performance power cycle system (HIPPS), use of a CFCC air preheater would enable overall efficiency of 47% versus the current 35% for conventional coal-fired power plants. Annual energy savings of 0.5 Quads of energy are possible at full commercialization.



Environmental Benefits:[5]
Emissions of 100,000 tons per year of NO_x will be eliminated from reduced fuel use, along with a minimum 28.3 million tons per year of CO_2. One example, the HIPPS cycle, would yield emissions 75% below allowable limits under current New Source Performance Standards.

Economic Benefits:[5,16]
With projected market demand, this CFCC application will save $1.8 billion per year in energy costs, plus reduced costs from environmental emissions. This will allow manufacturers to have lower cost electricity and products.

Market Potential:[3]
With increased efficiency demands, stricter environmental regulations, and new electricity generating plants, this application will result in significant markets. A near term market of $150-300 million annually is expected, or the equivalent of 1,500-3,000 industrial sector jobs.

Relevant Markets:
Chemical, metals, utility, pulp & paper, and petroleum refining industries

WASTE INCINERATION

Some of the solid and liquid waste generated in the United States is disposed of through incineration, and more could be incinerated for energy instead of landfilled. Concerns about the airborne emissions that result from incineration creates a need for materials that can withstand high temperatures and corrosive environments, thus allowing more complete combustion. The material incinerated has a large energy value, which can be recovered during the incineration and displace some fossil fuel use.

Description:
High temperature incineration of industrial and municipal waste will be made more efficient in CFCC based systems. CFCC components in burners, handling equipment, firing chamber liners, and furnace internals will have excellent corrosion resistance, important in the harsh environments of incineration systems.

Energy Benefits:[5]
More than 0.5 Quads of energy can be saved annually by using waste incinerators to generate power and recover heat energy through the improved efficiency CFCCs exhibit.

Environmental Benefits:[5,17]
CFCCs will allow an increase in process temperature and reduce the solid waste burden, currently being landfilled, by up to 90%. CFCCs will reduce toxic waste emissions, as complete breakdown of complex molecules like dioxin and PCBs will occur, and the solid liner design will reduce harmful gas leaks. These factors should even help reduce health care costs.

Economic Benefits:[5]
Annual energy savings of $2.5 billion from displaced energy use; reduced life cycle costs due to the better corrosion resistance. Reduced disposal costs for residential consumers and other waste generators.

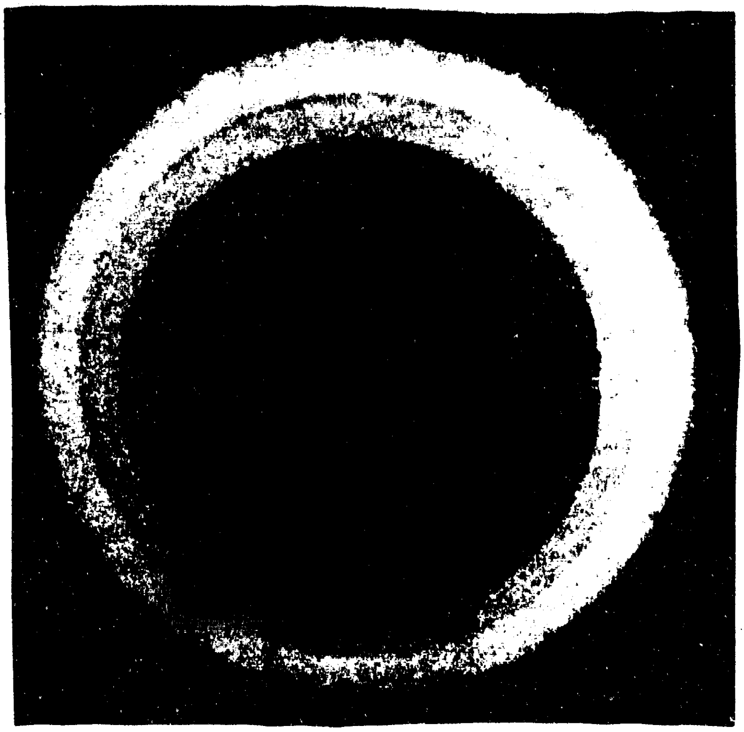
Market Potential:[3,5,17]
A near term market of $30-60 million per year for CFCC components is expected. The potential market for hazardous waste disposal firing chamber liners alone is estimated at $550 million in annual sales, which would affect roughly 5,500 industrial sector jobs. The total equipment market for waste incineration is expected to be $3.5-4.5 billion per year.

Relevant Markets:
Petroleum refining, chemical, metals, and waste incineration industries

RADIANT BURNERS (STEAM GENERATION)

The use of burners for heating accounts for a large amount of industrial energy use. The industrial steam generation sector consumes around 6.5 Quads annually.[18] Conventional flame type industrial burner technologies rely heavily on convective (i.e., air or fluid movement) heat transfer from hot flue gases to meet process heating requirements. In contrast, radiant burners transfer as much as 50% of their energy input directly to the process load in the form of infrared radiation. The use of CFCC components in radiant burners will allow for greater market acceptance. Currently, the use of radiant burners is limited because they cannot meet performance requirements.

Description:
Radiant burners (see illustration), which include fire tubes and water tube boilers, will be used in new and retrofit industrial boiler applications in several energy intensive industries. CFCC radiant burners are of a reduced size, have increased durability, and higher radiant output, which allay concerns currently limiting radiant burners. The primary benefit for this application is emission reductions of NO_x



Energy Benefits:[18]
Efficiency gains of 1-2% are anticipated. Potential savings of 0.066 Quads are predicted for this application are expected.

Environmental Benefits:[18]
Around 240,000 tons of NO_x emissions will be eliminated, along with a minimum 3.7 million tons of CO_2, annually. Emissions of carbon monoxide will also be reduced.

Economic Benefits:[18]
Energy savings of $330 million per year, along with the potential for large savings for NO_x reduction, with one source estimating a multi-billion dollar savings based on SCAQMD values.

Market Potential:[18]
Due to stringent regulations for NO_x emissions of industrial boilers, this application will be a large near-term opportunity, especially for fire tube and water tube boilers. There are roughly 37,000 industrial boilers installed nationwide that could be retrofitted, plus an annual new boiler market of roughly $300-400 million (300-400 units). Assuming a 25% market penetration would yield a market for CFCC products at $75-100 million, representing roughly 750-1,000 industrial sector jobs.

Relevant Markets:
Chemical, food, pulp & paper, metals, and petroleum refining industries

HOT GAS FILTERS

Filter systems are necessary in many applications, such as coal combustion and refinery processing, in order to filter particles from a process. Hot gas filters, or hot gas cleaning systems, are used for very high efficiency particulate and contaminant removal in the temperature range of 300°C to 1000°C. The currently available technologies (i.e., wet scrubbers, electronic precipitators, and baghouses) all have limitations, such as lower efficiencies or smaller temperature ranges, when compared to CFCCs.

Description:[5]
The use of CFCC filters will be in the form of tubular sheets and/or plenums. For example, ceramic components are being developed for hot gas filters to be installed ahead of the turbines in industrial systems to protect the turbines from impingement of particulates. The cleaning system would help industries and utilities meet stringent emission control regulations, and increase the efficiency of processing and power generating facilities. Candle filters will be used in advanced coal combustion combined cycle plants.

Energy Benefits:[19]
Annual energy savings of 0.1 Quads per year are possible by using candle filters for the combustion of coal alone.

Environmental Benefits:[19]
Estimated NO_x emissions reduction of 23,000 tons per year, along with a minimum CO_2 reduction of 5.7 million tons annually based on the energy savings. CFCC filters will also help prevent erosion of turbines and help meet Clean Air Act requirements.

Economic Benefits:[19]
Energy savings of $500 million annually, along with savings from reduced NO_x emissions. Hot gas filters will help increase the use of low cost coal, thus insulating consumers from electric rate increases.

Market Potential:[5,20]
Hot gas filters have a potential international market of $7 billion over the next 10-15 years. The U.S. market for this hot gas filters is estimated to be around $200 million in 1998, and a 20% penetration for CFCCs is anticipated, or $40 million and 400 industrial sector jobs.

Relevant Markets:
Petroleum refining, pulp & paper, metals processing, chemical, and utility industries

RADIANT BURNERS (DRYING AND LOW-TEMPERATURE HEATING)

The use of burners for heating accounts for a large amount of industrial energy use. The drying and low-temperature heating applications consume around 3 Quads annually.[18] Conventional flame type industrial burner technologies rely heavily on convective (i.e., air or fluid movement) heat transfer from hot flue gases to meet process heating requirements. In contrast, radiant burners transfer as much as 50% of their energy input directly to the process load in the form of infrared radiation. The use of CFCC components in radiant burners will allow for greater market acceptance.

Description:
Radiant burners (see illustration) will be used in low and moderate temperature industrial furnaces, used for fluid heating and non-fluid heating (including drying) applications. CFCC radiant burner sales will be benefitted by the smaller size and increased durability of CFCCs.

Energy Benefits:[18,21]
Efficiency gains of 1-2% are anticipated for fluid heating applications, and 50-60% for non-fluid heating applications. Energy savings of 0.15 Quads per year are estimated with projected market penetration; with universal market acceptance, savings of 0.39 Quads could be possible.

Environmental Benefits:[18]
Annual NO_x emissions will be reduced by 75%, or 117,000 tons, along with a minimum 8.5 million tons of CO_2. Emissions of carbon monoxide will also be reduced.

Economic Benefits:[18]
Energy savings of $750 million per year are expected, along with possible savings from NO_x reduction, with one source indicating the potential for nearly a billion dollar savings based on SCAQMD values.

Market Potential:[18]
Due to the efficiency gains and emissions savings, a near-term market will exist for drying applications. A 20% market penetration is expected for drying applications by 1997. There are roughly 120,000 units in the United States in the drying and low-temperature heating applications, with the majority of units in the drying area. Thus, a substantial market exists for new CFCC radiant burners in this area.

Relevant Markets:
Food and pulp & paper industries

REFORMERS

To make cleaner gasoline, in order to meet Clean Air Act requirements, several "additives" must be blended with the intermediate gasoline product. Methanol, which is produced by a reforming process, and methanol derivatives are major "additives". In reforming processes, such as steam reforming, desulfurized methane feedstock is pumped through metallic tubes in the convection section of the furnace, where it is preheated by a heat exchanger. Steam is added to the methane, and as the hot steam/methane mixture enters and travels through the catalyst filled reformer tubes, the steam and methane react, producing synthesis gas. The synthesis gas is used in downstream processes to produce methanol, hydrogen, or ammonia as the final product. Materials used in reforming processes must be able to withstand hazardous and corrosive environments, and high temperature and high pressure conditions.

Description:
There is substantial potential for using CFCC components, primarily for tubes, in the reforming process due to intrinsic material properties of CFCCs.

Energy Benefits:[5]
Improvement in operating efficiency of up to 25% is expected, translating into reduced feedstock consumption, improved production yields, and reduced energy costs. Annual energy savings of 0.25 Quads per year are possible.

Environmental Benefits:[5,22]
Reduced greenhouse gases from the reforming plants due to increased yields, reduced vehicle emissions from burning cleaner fuels in vehicles. A minimum reduction of 1.4 million tons of CO_2 is expected.

Economic Benefits:[5]
Since demand for methanol is growing rapidly for production of cleaner gasoline, there will be a smaller need for automobile manufacturers and other industries to spend money developing or using other technologies to meet environmental regulations. This will help keep the cost of automobiles and cleaner gasoline to the lowest amount possible.

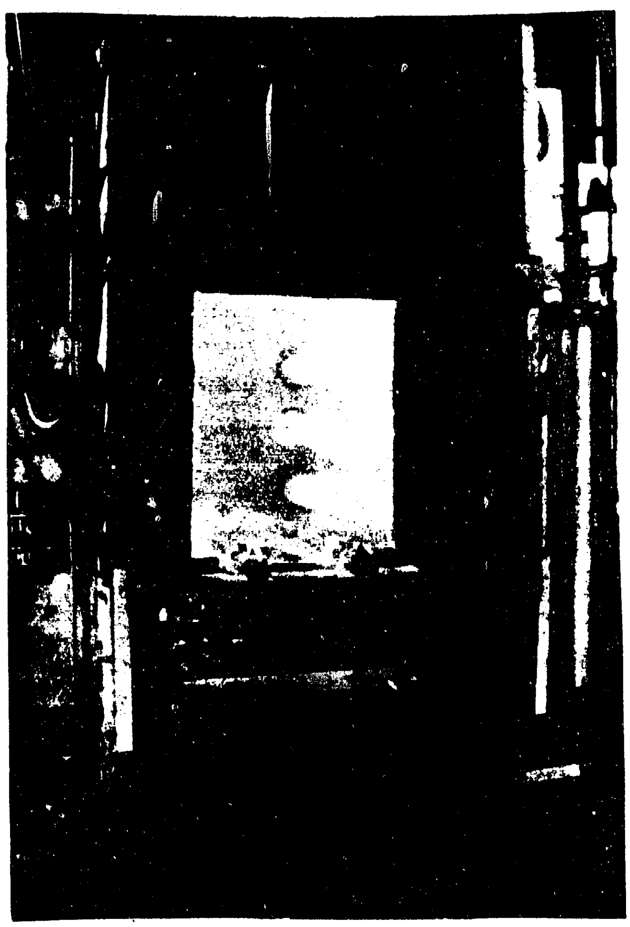
Market Potential:[3,5]
By 2010, an estimate of 96 new methanol plants worldwide will be needed, and a 25% market share for CFCCs would provide for 24 units, plus a retrofit market for older plants. An estimated near-term market of $10-20 million per year is expected, or the equivalent of 100-200 industrial sector jobs.

Relevant Markets:
Chemical, petroleum refining, and pulp & paper industries

RADIANT BURNERS (HIGH TEMPERATURE HEATING)

The use of burners for heating accounts for a large amount of industrial energy use. The high temperature heating segment consumes around 1.5 Quads annually. Conventional flame type industrial burner technologies rely heavily on convective (i.e., air or fluid movement) heat transfer from hot flue gases to meet process heating requirements. In contrast, radiant burners transfer as much as 50% of their energy input directly to the process load in the form of infrared radiation. The use of CFCC components in radiant burners will allow for greater market acceptance.

Description:
Radiant burners (see illustration) may be able to operate under high temperatures, for metals processing, glass melting, etc. If successful, efficiency gains of 40-50% are possible.



Energy Benefits:[18,21]
Annual energy savings of 0.075 Quads are projected based on projected market penetration; with universal market acceptance of this application, savings of 0.5 Quads could be possible.

Environmental Benefits:[18]
A minimum CO_2 emissions reduction of 4.2 million tons per year is expected; NO_x emissions reduction are unknown, but expected to be small.

Economic Benefits:[18]
Energy savings of $375 million per year are anticipated.

Market Potential:[3,18]
The best near-term markets are for radiant tubes and impingement burners, with an estimated near-term market of $40-80 million per year, or the equivalent of 400-800 industrial sector jobs.

Relevant Markets:
Metals, stone/clay/glass, chemical, and petroleum refining industries

LOW HEAT REJECTION DIESEL ENGINE (VALVE GUIDE)

The low heat rejection, or insulated, diesel engine is an attractive energy conversion concept for both stationary and mobile (transportation-related) power plants. The development of this technology will require new in-cylinder materials capable of withstanding the higher temperatures produced from insulating the combustion chamber components.

Description:[23]
CFCCs are being examined as materials for self-lubricating valve guides in diesel engines. This technology has the potential for use in high load factor industrial and agricultural applications.

Energy Benefits:[23]
Insulation of the in-cylinder components combined with a turbocompound device has the potential to improve the specific fuel consumption and eliminate the need of the cooling system for accessory power.

Environmental Benefits:[5]
A 25% reduction in particulate emissions is expected.

Economic Benefits:[5,23]
Expected benefits include fuel savings, increased engine reliability, and lower engine production costs. Improved valve guide wear is expected. This will benefit consumers due to lower transportation and production costs for industrial and agricultural products.

Market Potential:
Unknown at this time.

Relevant Markets:
Industrial, agricultural, transportation and construction sectors

DIESEL PARTICULATE TRAPS

Diesel engines currently generate a large amount of particulate matter when used. This particulate matter is a large source of air pollution. Particulate traps are fitted to the exhaust line, and are used to keep the particulates close to the combustion area, where the particulates are burned with the heat of the exhaust. These devices must be able to withstand high temperatures, thermal cycling, and corrosive environments.

Description:[5]
CFCCs applied to the particulate traps placed on diesel exhaust systems will help meet the Clean Air Act Amendments requirements on exhaust particulates. These requirements will become more stringent for diesel engines in 1994, and likely again later in the decade. CFCCs can be applied to improved combustion chamber designs to reduce particulate emissions, and to after-treatment technologies that catch particulates that do get through the system.

Energy Benefits:[5]
The impact on fuel economy of diesel engines is unknown at this time.

Environmental Benefits:[5]
Tests of particulate collection showed an 80% efficiency. A ceramic wall flow trap system on a developmental engine had the potential to reduce soot emissions by 85%.

Economic Benefits:
This technology will help vehicle manufacturers and state and local governments meet emission regulations in a cost-effective manner.

Market Potential:[5,24]
A large potential market is available, with 42 million buses and trucks currently registered in the United States. In 1990, over $500 million was spent in the United States alone on air pollution control equipment for particulates.

Relevant Markets:
Transportation sector

OTHER - INDUSTRIAL

Other opportunities exist for CFCCs in industry, including hot gas transfer pipes, opportunities in refractories, such as crucibles, and structural applications, such as containers and infrastructure repair.[1,11] However, even though these markets are substantial in size, the widespread use of CFCCs in these areas is not expected due to numerous competing materials and technologies that currently provide better value to the consumer. Several niche markets will likely emerge where CFCCs will be able to compete with current materials and technologies.

Description:
CFCCs will be evaluated for use in applications where appropriate as the CFCC production technology matures, thereby becoming more cost competitive.

Energy Benefits:
Unknown at this time, but likely to be small in comparison to previously mentioned applications.

Environmental Benefits:
Unknown at this time, but likely to be small in comparison to previously mentioned applications.

Economic Benefits:
Benefits will depend on the application; however the increased durability and other material properties that CFCCs exhibit will benefit the end user of the application, and ultimately, consumers.

Market Potential:
Applications are likely to be primarily niche markets in the near-term.

Relevant Markets:
Metals, pulp & paper, and chemical industries

RADIANT BURNERS (COMMERCIAL/RESIDENTIAL)

The use of burners for heating accounts for a large amount of commercial/residential energy use, such as water heaters and gas stoves. Around 15 Quads are consumed annually by the commercial/residential sectors for heating. Conventional flame type industrial burner technologies rely heavily on convective (i.e., air or fluid movement) heat transfer from hot flue gases to meet process heating requirements. In contrast, radiant burners transfer as much as 50% of their energy input directly to the process load in the form of infrared radiation. The use of CFCC components in radiant burners will allow for greater market acceptance.

Description:
Radiant burners may be used in several applications, including warm air furnaces, space heaters, cooking equipment, hot water heaters, and chillers. For the most part, unless the commercial and residential sectors becomes fully regulated for NO_x emissions, higher prices for CFCCs will limit entry.

Energy Benefits:[18,21]
With an efficiency gain of 2%, annual energy savings of 0.06 Quads could be expected; with universal market acceptance, annual savings of 0.4 Quads could be possible.[9]

Environmental Benefits:[18]
NO_x emission reductions of 113,000 tons per year, along with a minimum CO_2 reduction of 3.4 million tons per year. Emissions of carbon monoxide will also be reduced.

Economic Benefits:[18]
Energy savings of $300 million per year, and possible environmental savings as well.

Market Potential:[18]
The best near-term market is for burners for absorption chillers. CFCCs would be cost-prohibitive for other applications currently. The acceptance of radiant burners depends heavily on government regulations of NO_x in these sectors. The market for new warm air furnaces is roughly 2 million units per year.

Relevant Markets:
Residential and commercial sectors

OTHER - NON-INDUSTRIAL

CFCCs will have opportunities in other non-industrial applications also. The material properties that make CFCCs so valuable to industry also make them valuable to other sectors of the U.S. economy. Possible markets include the military/aerospace sector, with possible applications for engine/nozzle components for tailcones of jet engines, engines, combustors, engine exhausts, and aerospace structures. The biomedical sector is also a possible market, with applications in reconstructive surgery and implants, and medical equipment and surgical aids.

Description:[5,17]
CFCCs will be evaluated for use in applications where appropriate as the CFCC production technology matures, thereby becoming more cost competitive. The military/aerospace sector will more than likely be involved early in the adoption process for CFCCs.

Energy Benefits:[17]
For aerospace applications, improved fuel economy and engine efficiency is expected.

Environmental Benefits:
Emissions should be reduced from improved fuel economy and engine efficiency in the aerospace sector.

Economic Benefits:
Operating costs should be reduced in the aerospace sector.

Market Potential:[17]
Estimated sales of $8.7 million per year and 90 industrial sector jobs affected for one specific aerospace application alone (engine/nozzle components). The aerospace/military sector is thousands of times larger.

Relevant Markets:
Military, biomedical, and transportation sectors

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TABLE 1
BENEFITS OF CFCCS IN INDUSTRIAL APPLICATIONS

Application	Energy Savings (Quads)	Energy Cost Savings ($billions)	NO_x Reduction (tons)	CO_2 Reduction (million tons)
Gas Turbines - Large Industrial	0.400	1.30	300,000	22.6
Gas Turbines - Small Industrial	0.120	0.60	137,000	44.5
HIPHES	0.500	1.80	100,000	28.3
Waste Incineration	0.500	2.50	?	?
Radiant Burners - Steam Generation	0.066	0.33	240,000	3.7
Hot Gas Filters	0.100	0.50	23,000	5.7
Radiant Burners - Drying and Low-Temperature Heating	0.150	0.75	117,000	8.5
Reformers	0.250	?	?	1.4
Radiant Burners - High Temperature Heating	0.075	0.38	?	4.2
Low Heat Rejection Diesel Engine	?	?	?	?
Diesel Particulate Traps	?	?	?	?
Other - Industrial	?	?	?	?
Total	2.160	8.16	917,000	118.9

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