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ADVANCED TECHNOLOGY OPTIONS FOR INDUSTRIAL HEATING EQUIPMENT RESEARCH

By
Ramesh C. Jain

October 1992

For
U.S. Department of Energy
Office of Industrial Technologies
Conservation and Renewable Energy
Washington, D.C.

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FOREWORD

This report was prepared as a part of the ongoing strategy of the DOE Office of Industrial Technologies for developing program plans that are consistent with the private sector needs. These plans establish adequacy of the OIT's role in developing advanced technologies which is to contribute large improvements in energy-use efficiency and/or productivity in the U.S. process industries and, in turn, help advance U.S. competitiveness and technological leadership internationally. Technologies discussed in the report were identified as candidates for integration into the OIT-supported program for developing improved combustion and process heating technologies.

Beginning under the direction of John N. Eustis, Director, Industrial Energy Efficiency Division, and Thomas J. Gross, Associate Deputy Assistant Secretary, Office of Industrial Technologies (OIT), the technical information presented in the report was prepared by Ramesh C. Jain, Program Manager, DOE-OIT. Supporting information on the heating equipment energy use, and calculations to verify the potential improvements presented in the report, were provided by Dr. W. Bradford Ashton, Gregory P. Sullivan, and Dale A. King of the Pacific Northwest Laboratory.

Sections 1, 2, and 3 provide an overview of potential improvement areas and a number of technology options for more efficient industrial heating equipment. The heat transfer improvement technologies presented could be employed to increase the production rate of an industrial heating system and, simultaneously, reduce its overall energy consumption by lowering the energy required per unit of production.

Due to limitation of scope, only the energy savings based on constant production rate were estimated for each technology presented. The report, however, does recognize the importance of a new technology's ability to increase production rate and, in turn, reduce product cost. In this respect, the report calls for the preparation of more detailed technology information packages if required as the next development step. These packages will include economic benefit assessments of selected technologies based on more in-depth productivity and energy calculations.

Section 4 provides a brief discussion of the barriers to development of new heating equipment technologies. Sections 5 through 8 provide an overview of program planning, execution and technological contribution.

Subject program must be responsive to the needs and concerns of the U.S. heating equipment industry; therefore industry views or comments on the technologies discussed in the report are extremely important, without which integration of any of these technologies into the program would be neither meaningful nor valid.

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EXECUTIVE SUMMARY

This document presents a strategy for a comprehensive program plan that is applicable to the Combustion Equipment Program of the DOE Office of Industrial Technologies (the program). The program seeks to develop improved heating equipment and advanced control techniques which, by improvements in combustion and heat transfer, will increase energy-use efficiency and productivity in industrial processes and allow the preferred use of abundant, low grade and waste domestic fuels. While the plan development strategy endeavors to be consistent with the programmatic goals and policies of the office, it is primarily governed by the needs and concerns of the U.S. heating equipment industry.

The program, by nature, focuses on energy intensive industrial processes. According to the DOE Manufacturing Energy Consumption Survey (MECS), the industrial sector in the U.S. consumed about 21 quads of energy in 1988 in the form of coal, petroleum, natural gas and electricity. This energy was used as fuels for industrial boilers and furnaces, for agricultural uses, for construction, as feedstocks for chemicals and plastics, and for steel, mining, motors, engines and other industrial uses. Over 75 percent of this energy was consumed to provide heat and power for manufacturing industries. The largest consumers of fuel energy were the primary metals, chemical and allied products, paper and allied products, and stone, clay and glass industry groups which accounted for about 60% of the total fuel energy consumed by the U.S. manufacturing sector.

Industrial process thermal efficiencies are generally low (ranging from 10 to 20 percent in high temperature processes to 40 to 60 percent in low temperature processes). Fired heaters, which are employed on more than 80 percent of the process heating installations, show little evolution, although their fuel efficiency could be improved by as much as 40 percent. Boilers operate with approximately 78 percent overall efficiency, although their fuel efficiency could be improved by 5 percent to 10 percent. It follows that potentially large production increases and energy savings could be achieved through the introduction of advanced technologies that can offer more efficient fuel-to-energy conversion, improved furnace heat transfer, and improved process and combustion controls.

In an industrial heating system, improvements in combustion and heat transfer could be utilized either to increase the production rate maintaining a constant fuel input, or to reduce the fuel input while maintaining a constant production rate. Both options will result in energy conservation, however, the limited scope of this report did not allow calculations based on the "constant fuel" option. By examining five of the most energy-intensive industries, it is estimated that 0.71 quads of energy per year could be saved in the U.S. while maintaining the same production rate. This savings is made possible by the application of the advanced heating equipment technologies described in this document. The 0.71 quads, being a technical energy savings (assumes 100% penetration), only represents a subset of the total potential applications for these technologies. The total potential of energy savings based on constant production for

these technologies, as applied across all industries and processes, is estimated to be between 1.0 and 1.5 quads per year.

From an environmental perspective, the development of energy-efficient heating equipment will reduce the rate of fossil fuel use, and will reduce emissions of carbon dioxide and other compounds which contribute to global warming and urban pollution.

Introducing improved combustion and furnace heat transfer technologies will also have economic ramifications. More economical furnaces will be designed through reductions in furnace size and/or requirements of the heat recovery equipment and, in many cases, of emission control equipment. Thus, first costs as well as the operating costs of new industrial furnaces could be reduced substantially through innovative energy-efficient designs. Retrofits could also be designed to offer large reductions in overall operating costs, leading to attractive payoffs for furnace users.

Potential methods to improve overall efficiency in the combustion of fuels and the transfer of heat generated to industrial processes can come about through research and development in three general areas of optimization:

- Improved Combustion of Fuel;
- Increased and Uniform Heat Transfer to Furnace Load; and
- Reduced Heat Loss from Combustion System.

Retrofit technologies and new equipment are needed to: (a) minimize the temperature difference between exhaust gases and load; (b) minimize excess oxygen in combustion exhaust gases; (c) control fuel supply according to load temperature; (d) maximize heat transferred to load; (e) reduce heat loss from furnace walls; and (f) reduce gaseous emissions within the combustion zone as far as possible.

Section 3.0 provides brief descriptions of several research and development (R&D) opportunities in the areas of combustion of primary and waste-derived fuels, combustion process control and furnace heat transfer, applicable to a wide range of industrial processes. These opportunities are based on the recommendations given in various technology assessment reports previously funded by the Office of Industrial Technologies (OIT) and the analyses of information obtained from an extensive literature search, other similar programs and researchers in industry. Section 4.0 provides a brief description of the barriers that currently impede the development of these new technologies.

Sections 5.0, 6.0 and 7.0 provide an overview of the program planning and execution approach, including an understanding of the program objectives and the OIT's approach for procurement action, development of technologies, and technology transfer. OIT's approach for developing a program plan is to structure the program in conjunction with the private sector; therefore, as a rule, the plan must reflect relevant inputs from private companies, researchers, universities and government laboratories.

The plan, as a minimum, must contain descriptions of: program applications; energy, economic and environmental payoffs; technical needs; foreign competition; technical plan; execution plan; and resource plan. In this respect, the following elements are considered integral to the development and implementation of the program plan:

- Prioritize promising technologies based on energy savings, market size, competitiveness and generic quality.

- Summary of selected technologies that include potential market and preliminary estimates of the economic, productivity, energy and environmental benefits from industrial use of the technology.

- Meeting with manufacturers and end users of industrial heating equipment to discuss candidate technologies and their priorities, and to identify potential industrial applications of these technologies and other major technical issues.

- Interviewing equipment suppliers and researchers in industry, universities and government laboratories to identify their version of promising technologies, and the potential applications, hurdles and R&D needs.

- Identifying project areas of research for integration to the program.

- Developing work breakdown structure(s) consistent with the R&D needs.

- Developing a multi-year research plan to address R&D needs and indicate scope, objectives, schedules and resource requirements for each selected project area.

- Developing an execution plan to define implementation and management of the program.

- Reviewing results with industry and other federal agencies to avoid duplication.

The program has also resulted in a number of conservation technologies that are penetrating the market place. Section 8.0 provides an overview of program accomplishments and on-going research activities.

1.0 INTRODUCTION

The U.S. industrial sector consumes about 21 quads of energy annually in the form of coal, petroleum, natural gas, and electricity. This energy is used as fuel for industrial boilers and furnaces, for agricultural uses, for construction, as feedstocks for chemicals and plastics, and for steel, mining, motors, engines, and other industrial uses. A large percentage (on the order of 65%) is consumed as burnt fuels in various manufacturing processes. The largest consumers of fuel energy are the primary metals, chemical and allied products, pulp and paper, and stone, clay and glass industries, which account for about 60 percent of the total fuel consumed by the U.S. manufacturing sector. During 1988, manufacturing industries consumed over 15 quads of primary energy to produce heat and power; this accounts for more than 75 percent of the total (see Table 1). During 1988, natural gas was used most intensively, and primarily as a fuel. Petroleum products, e.g., liquid petroleum gas (LPG), residual and distillate fuel oils were less important, accounting for a very small portion of total primary energy used in the manufacturing sector.

Motivated by the oil crises of the 1970s, U.S. industry has made impressive gains in energy efficiency over the last twenty years; while industrial output increased by 25 percent, energy use decreased by 8 percent. In spite of these gains, effective use of all energy resources remains a critical issue for many industries, particularly the energy-intensive process industries. In these industries, energy costs account for a substantial share of production costs and can limit the ability of the industry to compete in domestic and global markets. Improving energy efficiency can thus be an effective way for many industries to reduce costs and improve productivity while conserving energy resources.

The Combustion Equipment Program of the DOE Office of Industrial Technologies (OIT), under the Deputy Assistant Secretary for Conservation, has been in progress since the office was organized in 1977. The Combustion Equipment Program is essentially an applied research program that supports research and development of improved heating equipment and advanced control techniques applicable to energy-intensive industrial processes. The program seeks to develop improved combustion, heat transfer and control technologies and to enhance fuel-use flexibility that will allow industry and public utilities the option to select from a variety of fuels according to a changing economy.

2.0 INDUSTRY TARGETS OF OPPORTUNITY

2.1 Energy Efficiency

Because it accounts for such a large proportion of the energy consumed by the manufacturing industries, the generation of heat and power represents considerable opportunities to improve energy efficiency. For example, industry consumes about 5 quads of primary energy every year in furnaces, ovens and kilns. Developing new equipment with improved efficiency could reap substantial benefits because over half of the furnaces, ovens and kilns operating today

TABLE 1

Manufacturing Sector Primary Energy[a] Consumption for Heat and Power by Industry Group, 1988 (Estimates in Trillion Btu)

SIC CODE/INDUSTRY GROUP	ALL ENERGY SOURCES[b]	NET ELEC-TRICITY[c]	FUEL OIL	NATURAL GAS	COAL	OTHER
20 - Food	996	171.3	NA	488.1	149.6	90
21 - Tobacco	24	2.95	1.9	2.1	16.9	NA
22 - Textiles	275	101.5	25.7	92.9	38.7	12
23 - Apparel	54	22.7	4.3	21.7	2.9	1.0
24 - Lumber	404	56.1	25.2	35.1	2.3	282
25 - Furniture	63	19.3	4.6	22.7	2.9	12
26 - Paper	2,347	189.0	190.2	428.3	309	1221
27 - Printing & Publishing	115	58.2	3.0	48.5	NA	4
28 - Chemicals	2,862	415.8	119.8	1,511.9	289.4	519
29 - Petroleum	3,122	106.2	124.1	724.5	6.4	2,109
30 - Rubber & Plastic	252	106.8	4.6	110.4	8.2	4.0
31 - Leather	16	4.7	4.4	5.2	1.3	NA
32 - Stone, Clay, & Glass	1,000	115.3	49.5	465.4	286.3	67
33 - Primary Metals	2,622	509.1	54.1	743	58.3	470
34 - Metals Products	343	105.6	11.6	203.3	9.2	9.0
35 - Nonelectric Machinery	276	114.2	12.0	126.9	17.7	2.0
36 - Electrical Equipment	215	108.7	9.9	84.6	7.1	2.0
37 - Transportation Equip.	349	127.2	18.7	138.3	36.2	9.0
38 - Instruments	113	48.9	7.9	32.0	21.5	2.0
39 - Miscellaneous	41	14.3	2.8	19.6	1.8	1.0
TOTAL	15,498	2,393.6	674.3	5,304.5	1,265.7	4,816

NA - Data not available.

Source: "Manufacturing Energy Consumption Survey - Consumption of Energy, 1988", Energy Information Administration, May 1991. DOE/EIA-0512(88).

[a]Refers to energy consumed to produce non-energy goods.

[b]Also includes liquified petroleum gas and coke and breeze.

[c]Excludes electricity that was generated or cogenerated on-site.

were installed when energy costs were much lower and energy efficiency was not a major concern.

In general, the thermal efficiency of industrial processes is low (ranging from 10-20 percent in high temperature processes to 40-60 percent in lower temperature processes) and conservative improvements could yield significant energy savings. Conventional high temperature processes, e.g., metals heating, melting and conversion (forging, brazing, sintering), are the least efficient and are very energy-intensive. While boilers currently operate with approximately 78 percent overall efficiency, their fuel efficiency could be improved by as much as 10 percent. Fired heaters, which are employed on more than 80 percent of process heating installations, show little evolution, although their fuel efficiency could be improved by as much as 40 percent. Substantial fuel savings can be achieved in multi-burner industrial and utility boilers through improved combustion control. The same can be said for the multi-fuel boiler systems which have enjoyed high market penetration in recent years.

In industrial heating systems, improvements in combustion and heat transfer could be utilized either to increase production rate while maintaining a constant fuel input, or to reduce fuel input for a constant production rate. Both options will result in energy conservation due to reduced energy requirement per unit of product, although the magnitude may be different in each case.

The magnitude of potential energy savings and/or productivity increases in industrial heating equipment can be substantial even with a modest claim of 5 to 10 percent improvement in thermal efficiency. For instance, in high temperature processes, based on a constant rate of production, an improvement in thermal efficiency from 20 to 25 percent will result in a 20 percent fuel savings; 20 to 30 percent in 33 percent fuel savings, and so on. Alternatively, by maintaining the same fuel consumption, proportional increases in production rate could be accomplished by introducing more energy efficient heat transfer technologies. Overall, potentially large energy savings could be achieved through the introduction of advanced technologies that will improve the efficiency of equipment used for process heating. These technologies will provide more efficient fuel-to-energy conversion, improved furnace heat transfer, and improved process and combustion controls.

2.2 Industrial Competitiveness

To remain competitive, U.S. manufacturing industries must place high priority on reducing production costs. Investments for energy conservation alone are not likely to attract industry dollars because of the relatively low cost of fuel compared with the overall cost of product. Thus, while energy conservation is an important objective, DOE industrial technology development is also directed to provide improved productivity and/or product quality. In addition to lowering costs, improvements in productivity and product quality typically translate into substantial energy savings because of the reduced consumption of energy per unit product.

Maintaining high product quality, although an essential prerequisite in all operating furnaces, is especially desirable for furnaces that have a high product rejection rate due to age or obsolescence. Advanced technologies that offer improved control and distribution of heat transfer to furnace load are thus likely to be attractive for many industrial applications. Energy savings from product quality improvement will be achieved through reduced fuel input to the furnace, as well as from a reduction in the electric energy required to run auxiliary equipment.

The introduction of advanced combustion and furnace heat transfer technologies will also enhance the ability of manufacturers to design more economical furnaces through furnace size reductions, minimized requirements for heat recovery equipment, and reduced emissions control systems. Potentially, first costs as well as operating costs for new industrial furnaces could be substantially reduced through innovative, energy-efficient design. Where the improved technology is suitable as a retrofit, it could also be designed to offer large reductions in overall operating costs, providing an attractive payoff for the end-user.

2.3 Environmental Protection/Regulatory Considerations

Despite the current poor business climate, manufacturing plants will continue to invest in advanced technology, both to remain competitive and to meet new environmental emission standards. As more stringent regulations are enacted, design concepts which can use increased efficiency to offset some of the extra costs of meeting environmental standards are expected to gain acceptance. In general, the development of fuel-efficient heating equipment will benefit the environment through reductions in emissions of urban pollutants (CO, NO_x, VOCs, and particulates) as well as greenhouse gases such as carbon dioxide that are associated with the combustion of fossil fuels.

The program, through the development of fuel-efficient heating equipment, and a concomitant reduction in the rate of fossil fuel use, helps to: (1) reduce the emissions of carbon dioxide, nitrous oxides, and other pollutants, and (2) mitigate regional climate problems like acid rain by promoting use of alternative fuels. The program not only seeks to promote energy-efficiency, but also the environmental acceptability of the technologies it supports. The technologies developed under the program are required to satisfy national environmental regulations and acts, wherever applicable.

3.0 TECHNOLOGY OPTIONS

Rising costs of production and energy could force industry users to replace or improve inefficient heating and heat transfer equipment, especially where conditions dictate that the use of recuperators (heat exchangers that recover waste heat from process streams) is not feasible or is uneconomical. Potential methods to improve overall efficiency in fuel utilization and heat transfer processes can come about through research and development in three general areas of optimization:

- Improved Combustion of Fuel;
- Increased and Uniform Heat Transfer to Furnace Load; and
- Reduced Heat Loss from Combustion Systems.

Based on recent technology assessments and information from various industry contacts, several opportunities for research and technology development have been identified in the areas of combustion and furnace heat transfer improvement. These opportunities are identified in Table 2. These technologies were researched to estimate potential energy savings (see Appendices A and B). Table 3 summarizes the estimated technical energy savings resulting from the 16 energy conservation opportunities. The "industry total" savings is estimated to be 713 trillion Btu/year. The "other industry total" (utility boiler, waste-derived fuel) is estimated to be 2,540 trillion Btu/year. As stated before, the energy savings reported were calculated assuming a constant production rate.

Descriptions of these technology options based on technical assessments, extensive literature surveys, and contacts with researchers in industry are provided in the following discussion. Detailed analyses of these technology options, as well as the appropriate assumptions and references, are provided in Appendices A and B. References for Sections 1.0 through 3.0 are provided in Appendix A.

(1) Optimal Heat Transfer to Furnace Load (General Area)

Metal Heat Treating (SIC 3398), Fabricated Metal Products (SIC 34), and Machinery, except Electrical and Transportation Equipment ((SIC 37), all involve various types of furnaces for forging and heat treating metal parts that operate between 1350 to 2400°F. Based on EPA, NEDS and other published information it is estimated that there is a total furnace population of 192,000 units consuming about 3.1 quads of energy. While the furnace population today could be less because of lower production and the poor economic climate in the metals industries, the resulting savings from maximized heat rate to furnace load could be considerable.

In the case of large industrial furnaces, the convection heating of the furnace walls is a major factor for limiting the furnace heat transfer; increasing the contact time of flue gases with the furnace walls will increase the heat transfer to furnace walls and, in turn, to load. Increasing heat flux and heat transfer rate to load will increase the thermal efficiency and therefore reduce the furnace size and the capital cost of a new furnace. A higher production rate will reduce energy as well as labor costs. Furthermore, the reduced heating time resulting from the increased heat flux will shorten the time for the product to oxidize or to undergo a distortion, therefore product quality will improve simultaneously. The use of high heat flux radiation system could increase the flue gas temperature, but when supplemented with the use of heat recovery devices, it could reduce the process energy consumption by 5 to 25% depending upon the temperature of the process. A research program that will advance the control of the combustion system, so that the load is heated under optimal heat flux condition, would thus be very attractive to industry.

TABLE 3

POTENTIAL ENERGY SAVINGS FROM ADVANCED HEATING AND POWER TECHNOLOGIES

SIC INDUSTRY	NEW TECHNOLOGY	TECHNICAL ENERGY SAVINGS (trillion Btu/year)
Integrated Paper (2621)	4, 5, 7, 10	56.2
Paperboard (2631)	4, 5, 7, 10	47.2
Chemical-Alumina (2819-1)	4, 7	5.3
Chemical-Ethylene	2	42.1
Chemical-Methanol	2, 5, 7	4.1
Chemical-Ammonia	2, 5, 7	26.4
Petroleum Refining (2911)	2, 7	86.9
Container Glass (3221)	1, 3, 4, 11, 14, 16	44.5
Portland Cement (3241)	4, 15	152.1
Blast Furnace/Steel Mills (3312)	1, 3, 6, 7, 9, 14	242.8
Primary Aluminum	1, 3, 14	1.8
Secondary Aluminum	1, 3, 8, 14	3.9
INDUSTRY TOTAL:		713
Utility Boilers	13	190.3
Waste Derived Fuel	12	2,350
OTHER INDUSTRY TOTAL:		2,540.3

(2) Re-radiation Plate Enhancement

The use of radiation re-emitting plates in the high temperature gas stream between heat absorbing surfaces is one technique that is suitable for retrofit into existing furnaces and heat exchangers but has not been developed and used commercially. The radiative heat flux is increased by installing a solid plate in a high temperature radiative gas surrounded by heat absorbing surfaces. Radiation plates could be profitably applied such that, besides direct

radiation, combustion gases would transfer energy by convection to the radiation plate which in turn would transfer energy by radiation to the heat absorbing surface. Energy transferred to the load per unit area per unit time (heat flux) is thus increased.

Radiation plate technology applied to reactors and fired heaters in the petrochemical industries could result in large improvements in heat transfer (on the order of 120%). This is because the liquid side heat transfer coefficients are about 15 times those of gas side heat transfer process and improvements in the outside coefficient by the reradiating plates will very effectively increase the overall heat transfer.

Major users of fuel in tubular heaters in reactors and refineries are catalytic reforming (300 Btu/bbl of crude), atmospheric distillation (using about 230 BTU per pound of crude), catalytic cracking (142 BTU/Lb), alkylation (102 BTU/Lb), vacuum distillation (61 BTU/Lb), and other processes such as delayed coking, lube oil processing and hydrotreating. All of these processes use fired heaters where the used of re-radiation plate enhancement could provide large energy savings. Other applications include steam reforming; reradiation plates on the outside tubes of the reformer can be used to increase the outside heat transfer coefficient. In the methanol synthesis process, reradiating plates in the reformer would allow higher pressures by increasing the heat transfer to the tube surface and thus decreasing the tube wall temperature.

(3) Refractory Emissivity Enhancement

Heat transfer analysis has indicated that energy consumption in furnaces is a strong function of the emissivity of the load. Recently there has been growing interest in exploring the use of high-emissivity coatings on furnace refractories and metallic surfaces to increase the heat transfer to the furnace load, thus increasing productivity or saving energy or both. High emissivity coatings on the refractory walls of industrial furnaces also provide: (a) rapid heat-up to the desired temperature; (b) increased heat transfer under steady-state conditions; (c) more uniform temperature distribution in the furnace; and (d) less refractory erosion and longer refractory life.

Developments in England using a zirconia based coating on refractory surfaces in several furnace applications have resulted in claims of energy savings varying from 14 to 25%. In the U.S. it has been reported that reheat furnace energy consumption was reduced 15 to 30% and refractory service life increased by 100 to 400% with the application of zirconia coatings. Ceramic silica-alumina coatings are also available for metal surfaces, such as radiant tubes or electric heating elements and improved performance has been reported in these applications as well.

Applications include steel forming, glass melting, brick/clay kilns, copper smelting and refining, aluminum remelting, and non-ferrous metals production. Steelforming involves heating, reheating, and annealing processes which are conducted in various types of high temperature furnaces operating at temperatures from 1400 to 2400°F. Enhancing wall emissivity could account for considerable energy savings in these furnaces. In existing glass furnaces, enhanced

emissivity of furnace refractories would provide improved heat transfer to the molten glass. These coatings could also improve operations in tempering and annealing furnaces operating at lower temperatures up to 1600°F. Emissivity enhancement of the refractory walls could further increase the efficiency of the tunnel kiln used to fire bricks. There are also copper refining and remelting operations where emissivity enhancement of the refractory or molten metal surface could result in additional fuel savings and higher productivity.

(4) Entrained Flow Processes for Calcination/Clinkering in Cement Manufacture and Other Industries

A proven way to improve heat transfer between gas and solids is to entrain the solids in the gas stream instead of contacting them in a rotary kiln. This can be accomplished in cyclone type vessels or flash reactors, in what is referred to as suspension preheaters and flash calciners. In both of these cases, the particles are entrained in the gas stream, the heat transfer coefficients are higher and the smaller particles have a larger surface area exposed to the gas resulting in an increase in heat transfer.

Although these more efficient flash calciners and suspension preheaters are now available, the U.S., Japan and Europe still use inefficient rotary kilns for the cement clinker forming step. By using the flash processes, specific energy consumption could be lowered to 2.3 MMBTU/ton from 4.3 MMBTU/ton for the best state-of-the art cement manufacturing process. Another example is the lime industry (SIC 3274), which uses rotary kilns operating at 1800°F to calcine limestone feed to produce calcium oxide. A change to flash type preheaters and calciners could save energy and increase productivity. In the production of alumina, aluminum hydroxide is calcined in a rotary kiln at 1800°F consuming about 4.9 MMBTU/ton of product. While the flash calciner would be a more efficient process, most alumina operations still use the rotary kiln. Primary lead smelting is currently conducted in blast or reverberatory furnaces, where a flash type of system would be a significant improvement. Conducting melting processes as an expanded process could also improve the efficiency, productivity and flexibility of conventional glass tanks.

(5) Submerged Combustion/Injection

Submerged combustion/injection (e.g., direct contact heat transfer) processes are characterized by highly effective heat transfer, and yield high productivity and low capital investment per unit of capacity. The most important advantage of direct contact devices is that no surface is required to separate the hot and cold fluids. Therefore, corrosive fluids and those that contain dissolved and suspended solids can be used in these devices without the problems of heat transfer surfaces corroding and fouling and thus causing a deterioration in the heat transfer.

There are several processes in industry where these direct contact devices have been used for many years, e.g., concentrators, evaporators, absorbers, wet cooling towers, grain dryers, distillation columns, etc. They are not more widely used primarily because of economics, but

also because of a lack of an adequate design data base. As the cost of energy and the capital cost of industrial equipment increases, direct contact devices will be considered because they offer the potential for improved performance and reduced first cost. Applications for submerged combustion/injection are diverse. For example, the production of chloride and sodium hydroxide is performed in electrolytic cells such as diaphragm or mercury cells or more recently membrane cells. Direct contact or submerged combustion evaporators appear to be more energy efficient and economical alternatives. Phosphoric acid production by wet process involves an evaporation step where vertical tubular evaporators could be replaced by more efficient direct contact evaporators. Other applications exist in chemical pulping processes, glass melting, and primary metals melting processes.

The non-ferrous metals industry offers considerable scope for submerged injection processes. Secondary metal production from scrap and other waste materials will increase in the future not only because it requires a fraction of the energy used for primary metal production, but because it saves scarce mineral resources. One of the limiting factors in the recycling of scrap, such as aluminum, is that impurities such as copper, iron silicon and other elements exist and must be removed in the secondary processing. Submerged injection processes could offer the potential for not only melting the scrap with savings in energy but also effectively removing the impurity metals in the molten metal. This technology also appears to offer tremendous potential in steam generation and environmental treatment of waste gases and could be applied in various industries ranging from food (SIC 20) to non-ferrous metals (SIC 33).

(6) Scale Free Metal Reheating

The problem of material waste is common to the manufacture of metals and metal alloys including steel, aluminum and copper. Avoiding loss of material during the heating process would contribute significantly to increase productivity. Technologies (e.g., scale-free heating) are needed for heating metals to high (1500 to 2300°F) temperature without affecting surface quality or metal loss through oxidation. For example, all oxidation and many material defects can be avoided by maintaining a chemically inert gas (e.g., nitrogen) blanket in direct contact with the process material.

Reduction in process material waste is also expected to reduce production cost, which provides numerous economic advantages. For instance, 1.5% to 4% of steel is lost due to oxidation by combustion gases, during the steel reheating process. In the case of scrap aluminum melting, 2% to 5% of metal is lost due to oxidation. For example, all oxidation and many material defects can be avoided by maintaining a chemically inert gas (e.g., nitrogen) blanket in direct contact with the process material to yield scale-free heating.

(7) Fluidized Bed Industrial Thermal Processing

An advanced fluidized bed technology for heat transfer to the process material by means of entrained hot solid particles can increase the rate of heat transfer and, as necessary, provide a non-oxidizing environment for the process material. Such technology offers local control of

heat transfer to the process material and provide an attractive means of increasing heat transfer to the load, reducing heat-transfer surface temperature, reducing air pollution and emissions control costs, and accommodating alternative fuels ranging from natural gas to low grade by-product fuels. Fluidized bed processing can increase thermal efficiency by 1% to 2% and thus reduce the energy cost substantially. Furthermore, if a by-product gas is used as the fuel, the cost of the process energy can further be reduced by 25 to 33% of the present energy cost.

The fluidized bed process can be used to improve performance, reduce size and increase the life of various process heaters, furnaces and reactors used in many industries including petroleum (SIC 29), chemical (SIC 28) electrometallurgical (SIC 3313) and food (SIC 20). Fluidized bed processing will be particularly beneficial for tube still heaters used in the petroleum industry because it offers uniform and controlled heat, greatly increased heat absorption rates leading to improved productivity, reduced pollutants (NO_x and SO_x) emissions, higher thermal efficiency, and prolonged tube life. Fluidized bed-based reformers and furnaces could also be designed as more cost effective options to many of the presently used tubular type reformers (steam reforming, methanol synthesis) rotary kilns, and drying processes. Major development concerns are: performance, reliability, life of equipment, maintenance, frequency and required flexibility of changing operating parameters.

(8) Immersion Tube Melters for Non-Ferrous Metals

Advanced, high-efficiency, indirect-fired immersion tube melters can provide significant improvement in the heat flux to melt and the melt rate, and decrease the melter size, when compared with the conventional reverberatory type melt furnaces. Since the exhaust gases do not get contaminated by the process, and since the furnace atmosphere can be kept inert, these melters have minimal environmental problems and could eliminate metal oxidation losses as well as contaminants in the melt.

In the case of the non-ferrous metals with lower melting temperatures, e.g., aluminum, lead, zinc, etc., immersion tube melters may find more application because these types of furnaces offer fewer environmental problems, provided that tube materials are found that could give adequate tube life in corrosive furnace environments. This technology could also be applied to Aluminum Sheet, Plate, Foil (SIC 3353) and to Aluminum Foundries (SIC 3361). Primary lead is refined in a series of kettles where immersion tube heaters could be used with associated energy savings as well as reduction in emission problems and hence costs. However, the long life of immersion tube material is essential to commercialization of this technology for corrosive applications such as aluminum; and applications/materials compatibility could be explored for use in other nonferrous metal industries, - e.g., steel immersion tubes in secondary lead and lead pots.

(9) Cleanup Hot Furnace and Combustor Exhaust Gases

Energy recovery techniques are often not cost effective or thermally efficient when the waste gas stream has a high particulate level. For example, flue gases from most electric arc melting furnaces and, to a lessor degree, reheating furnaces contain particulates which prevent

heat recovery from these high temperature heat sources. For temperatures over 700°F, hot gases must also be cooled by mixing with cool air, water injection, or by indirect cooling. The development of a high temperature (1400-2000°F) particulate removal system that has a relatively low pressure drop could thus be very beneficial economically for electric arc melting furnaces used in the steel industry, aluminum melting, glass melting and blast furnaces, fluidized bed heating devices, waste incineration equipment, pulp and paper industries and steam generation. Development and use of the hot gas cleaning system will permit better utilization of the conventional heat recovery systems such as recuperators, cogeneration and work preheating systems.

In addition, such gas cleanup technology would allow fuel switching by reducing particulate problems from high-ash fuels, and reducing deposits in industrial boilers and wear in industrial gas turbines. In the case of waste-to-energy conversion systems, an ash separator, designed for high temperature operation (order of 2200°F), could be introduced between an external combustor/combustion chamber and a boiler or a gas turbine, for reducing the problems of deposit and wear inherent with these systems and thus improving their ability to use high-ash wastes and waste-derived fuels.

(10) Low Temperature Combustion

About 7% of the energy used by industrial sector is used for heating applications in the range of 600 to 1000°F. Most of the low temperature direct heating applications use either heated air, or dilution air mixed with the combustion gases, controlled to operate within the required temperature limits. In such cases, methods of combustion which eliminate the need of excess dilution air to supply low temperature flue gases (e.g. gas recirculation) can offer significant fuel savings. These methods could also reduce NO_x emissions to a large extent, not only because of lower achievable flue gas temperatures, but also because of possible reductions in the large quantities of hot air traditionally used in various drying and other low temperature processes.

By offering the ability to apply heat uniformly, the technology will also help to improve product quality, reduce product rejections and, in turn, save energy that would have otherwise been wasted in producing rejected items. Through these improvements in product quality and reductions in energy costs, significant reductions in product costs could also be achieved.

(11) Oxygen Enrichment of Combustion Air: Waste Heat Driven

Significant energy savings can be achieved if technologies can be developed for producing oxygen enriched air through the use of energy contained in the gaseous exhaust stream from an industrial furnace. Energy to produce oxygen enriched air could be reduced appreciably through the development of an exhaust-heat driven oxygen production process which uses different materials for the absorption-desorption cycle, or thermal swing. This reduction will be additional to the energy savings that oxygen enriched air will provide through the improvement of heat transfer in various high temperature industrial furnaces that are driven primarily by radiant heat.

The capital cost of an oxygen enriched combustion system (35-100% oxygen) is roughly one-third to one-quarter that of an equivalent recuperator-hot air burner system for retrofit applications. In addition, fuel savings with oxygen enriched combustion systems are often much greater than those with the recuperator systems. Furthermore, with the oxygen generation done on-site, the costs of transportation, storage and handling, associated with purchased oxygen will be eliminated.

(12) Adjustable Cofired Combustors/Combustion Chambers for Burning Wastes and Waste-Derived Fuels

The cost of landfill disposal is rising steeply as sites are being exhausted; costs of $8 to $10 per ton are not uncommon in metropolitan and suburban areas. Further, regulations that mandate satisfactory emission controls make the upgrading of conventional incinerators a very uneconomic alternative. Therefore, sophisticated utilization of industrial wastes will continue to gain support, and will become competitive with landfill disposal as credits for energy and reclaimed materials continue to mount. Alternatives to landfill disposal include direct combustion of industrial plant wastes (ie industrial waste paper, petroleum, plastic, rubber, corrugated card board) and textile and allied products (clothing strips, food processing wastes -- particularly corn cobs, peanut hulls and olive pits, and, to some degree, combusted wastes), and the combustion of solid fuels and oils derived from pyrolytic convertors and anaerobic digestors.

While utility applications of waste burning technologies are supported by DOE's Clean Coal Technology Program, and the knowledge base to commercialize municipal solid waste (MSW) combustion technologies is being developed by the OIT-MSW program, waste cofiring technology applications to industrial processes and site specific waste-to-energy conversion plants require additional development efforts. Research is needed for the development of adjustable, high intensity combustors/combusting chambers suitable for: (1) direct combustion or cofiring of plant wastes and the textile and allied products wastes collected and refined onsite; and (2) combustion of waste-derived liquid and solid fuels obtained from central waste-to-fuel preparation plants. Asphalt may also be included as a fuel. These combustors may be cofired with natural gas and will be installed external to the driven equipment (ie, boiler, dryer, or turbine) such that the combustion is completed within the combustion chamber. From an environmental standpoint, particulate emissions and corrosion are major concerns. To reduce particulate loading, a high-temperature ash separator or other means of separation will be required between the combustor and the driven equipment.

(13) Excess Oxygen Control for Multi-burner Boilers and Furnaces

In industrial furnaces and boilers, unusual excursions in excess air can cause substantial increases in fuel consumption or formation of pollutants due to incomplete combustion. The propensity of such excursions is greater in centrally-controlled multi-burner systems where maldistribution of fuel or air, and any unequal wear in industrial burners, could go unnoticed. It is therefore very desirable to accomplish individual burner control in multi-burner combustion systems which would allow each burner to operate close to the optimum air/fuel (A/F) ratio.

Conventional stack gas monitoring techniques, e.g., individual or central burner control, spectral flame sensing, are inadequate when applied to multi-burner systems. A new multi-burner A/F control approach, that can overcome the limitations of conventional stack gas monitoring and spectral flame sensing techniques, could offer a very high return on investment to high-temperature furnace or boiler operators, as well as provide a significant potential for large energy savings, both in the industrial and the utility sectors.

(14) Regenerative - High Luminosity Natural Gas Burners

By maintaining a sufficiently high furnace temperature (and corresponding flame temperature) a high radiation heat transfer to load can be maintained. Further, by increasing the temperature difference between flame and load and the flame emissivity, the heat transfer to furnace fabric and load can be increased, leading to substantial improvements in thermal efficiency. Radiant heat transfer in furnaces is either temperature-governed (large furnace), or emissivity-governed (small furnace). A burner with the flexibility of changing the flame temperature and/or the flame emissivity could thus substantially increase the heat transfer to furnace load, regardless of the furnace size or whether the furnace is recuperated or not. Preheating or oxygen enrichment of combustion air could be used as methods to increase the flame temperature, whereas cracking of natural gas into carbon particles (greater than 1000°C required for cracking) could be used to increase the flame luminosity (emissivity).

High radiation burners could be designed for retrofitting recuperated industrial furnaces by including the air preheat and natural gas cracking features. In the case of industrial boilers and non-recuperated furnaces, these burners could be designed to operate with oxygen-enriched combustion air and natural gas cracking. Where industrial furnaces are not recuperated, and economic or other reasons do not allow the use of the recuperators or oxygen enrichment equipment, natural gas cracking burners could be designed to operate with the outside air for combustion. When used as retrofits gas cracking burners will improve the thermal efficiency of existing recuperated or non-recuperated industrial furnaces and boilers. When used to develop new industrial heating equipment, these burners will allow reduction in equipment sizes corresponding to the same thermal capacities and thus help to reduce the costs and improve the competitiveness of new equipment outside of the United States.

(15) Variable Flame Length and Shape/Advanced Control System

Typical cement kilns currently utilize a coal burner to provide the necessary heat for clinker production. These burners are usually designed to produce a flame of fixed length and shape, and, thus, a fixed temperature. Over time, feed material composition can vary, and the feed rate itself may be changed to account for fluctuations elsewhere in the process. The combined effect of the constant flame temperature, varying feed rate and composition, and changing thermal loss rates can result in increased energy consumption and inconsistent product quality. Also, overheating of the load can result in more maintenance and downtime as well as decreased thermal efficiency. Therefore, it would be beneficial to develop a burner which could operate efficiently at varying loads. This would require that the flame length and shape could be

set according to the process parameters at a particular time. A control system would also be required to characterize the operating condition (temperature, material flow rate, etc.) and adjust the flame setting accordingly.

(16) Melt Temperature Measurement and Prediction System

Methods currently used to melt glass result in large variations in temperature throughout the melt volume. Particularly in large melters, the relatively low thermal conductivity of glass results in high temperatures near the heat source and lower temperatures elsewhere. Energy efficiency could be improved if heat could be directed toward the cooler areas of the melt. Such a system would first require hardware and software which could measure temperatures at representative sites within the melt and predict the temperature at remaining locations.

Economic benefits of this technology increase with furnace size, but an average savings of 15% is estimated for a representative plant. Additional benefits of a temperature measurement and prediction system are improved glass quality, increased throughput, lower pollution, a lower degree of technical competence required of personnel, and reduced manpower requirements.

4.0 BARRIERS TO TECHNOLOGY DEVELOPMENT

A number of barriers to the development and implementation of new heating technologies are perceived by industry groups and equipment manufacturers and end-users. Most consistently apparent is the relative low cost of fuel, particularly natural gas. With lower fuel prices, energy projects do not receive as high a priority as projects that increase productivity and/or product quality. In addition, the poor business climate over the past several years and current recessionary trends have contributed to a lack of capital for investment, and some industries will be cautious when considering the implementation of a new technology. Major concerns often center around whether the technology will have high maintenance costs, or whether qualified personnel are available to operate and maintain the technology. A general resistance to new technology can also create impediments to investment in conservation technology, particularly when that technology has not been proven on the commercial scale.

Compliance with environmental regulations can also hinder or promote the adoption of new technology. A conservation technology that will increase the cost of environmental compliance will necessarily be restricted in its market potential; equipment designed for low emissions will have a much greater chance of being adopted by industry. On the other hand, a technology that is conducive to emissions may also de-rate the heating equipment. Thus, a technology that improves thermal efficiency while keeping emissions low will receive high priority. For example, in some cases NO_x emission standards may curtail the use of preheated combustion air, which can increase thermal efficiency and save energy. Conversely, with oxygen-enriched air, certain combustion processes can be operated with not only significant energy savings but a potentially large reduction in regulated emissions. While low energy prices

may reduce the attractiveness of a conservation technology, eliminating the cost of emission controls could provide a strong incentive for investment.

5.0 PROGRAM MISSION AND OBJECTIVES

The objective of the Combustion Equipment Program is to help increase industry's output per unit of energy requirement by improving the energy efficiency of industrial combustion and process heat technologies. The program seeks to work closely with industry to broaden the technology base that will contribute to increase productivity, reduce energy cost, and improve the technical performance of industrial heating equipment, while, at the same time, promote the use of abundant, low-grade and waste domestic fuels.

Program boundaries are set to include all activities involved in the conversion of chemical energy in the fuel to heat, and the transfer of this heat to load prior to exhausting the excess heat. Energy recovery is not included. Technology developments are targeted to reduce the cost and improve the performance of existing systems and also to enlarge the data base for advanced technology development. Technological development is carried out to enhance the use of alternative fuels, and capitalize on reductions in the costs of delivered fuel, system operation, system maintenance and emissions control.

The overall efficiency in the combustion of fuels and the transfer of heat generated to industrial processes can be improved either by modifications to the existing combustion process or through the introduction of a new revolutionary process. In the first case modifications will result in incremental energy saving improvements; in the second case the energy savings potential is more dramatic but the technical or economic risks may be higher. Potential methods to improve energy efficiencies in industrial heating processes can come about through selective research and development in the following general areas of optimization:

- <u>Improved combustion of fuel</u>

  - Reduce inert and emission causing matter, hydrogen and moisture in fuel
  - Reduce nitrogen in combustion air
  - Optimize fuel particle sizes (fuel atomization/pulverization)
  - Improve mixing/turbulence
  - Maintain flame stability
  - Optimize combustion residence time
  - Improve diffusion to increase reaction rate
  - Stage combustion for uniform temperature
  - Reduce particulates and gaseous emissions
  - Control thermal output closely

- Increased and uniform heat transfer to furnace load:

  - Increase gas & furnace wall emissivity
  - Increase convective heat exchange
  - Improve flame properties for increased heat transfer
  - Improve flame shape for even loading
  - Increase thermal absorption of furnace load
  - Minimize fouling
  - Improve controls for heat transfer uniformity
  - Control process based on furnace load
  - Meet furnace load thermal requirement closely

- Reduced heat loss from combustion systems:

  - Reduce exhaust gas quantity and temperature
  - Reduce excess oxygen in exhaust gas
  - Recover exhaust energy for preheating air, preheating fuel, and other uses
  - Improve controls for reducing temperature spread
  - Minimize acid dew point in exhaust gas
  - Increase thermal insulation
  - Decrease containment surface

In summary, the key to developing energy-efficient heating equipment is to design retrofit technologies and new heating equipment concepts such that the: (1) temperature difference between the equipment exhaust gases and the load is minimized; (2) excess oxygen in the combustor exhaust gases is minimized; (3) fuel supply is controlled according to the load temperature requirement; (4) heat transferred to the load is maximized; (5) heat losses from the furnace walls is reduced; and (6) gases emissions are reduced within the combustion zone as far as possible. Such retrofit technologies and new equipment concepts, when developed, could provide large potential for reducing the costs of heat recovery and emissions control equipment and introducing highly cost effective industrial heating equipment in both the domestic and the foreign markets.

Presently, reducing energy which is exhausted to the stack is a major element behind the program. This can be accomplished either by transferring more energy to the load (increased heat transfer methods) or by retarding the processes which rob energy from the combustion gases (heat transferred through the walls, operating off-stoichiometric, overheating the load etc.) Advanced diagnostics, for example, are an integral program element since sensors can convey information and better control the combustion process, thus reducing heat losses. In addition these methods could provide improved product quality, resulting in reduced product rejection rate, and, in many cases, reduced gaseous emissions contributing to lowering the first cost.

6.0 PROGRAM PLAN DEVELOPMENT STRATEGY

New project areas which may be identified for integration within the program are restricted to those which meet the policy and programmatic goals of the office and have potential for wide industrial application as indicated by the private sector. Extensive contacts and discussions with executives from the private sector and the national laboratories are carried out and R&D planning is developed in conjunction with the private sector.

The following elements are considered to be integral to development and implementation of the program plan:

- Prioritize promising technologies starting with those described in section 3.0. Rating will be based on the potential for energy savings, market size to be impacted, competitiveness and generic quality.

- Prepare summary packages of selected technologies including, as a minimum, the objectives, potential market, and preliminary estimates of the economic, energy and environmental benefits of the industrial use of the technology.

- Meet with manufacturers and end users of industrial heating equipment. Discuss candidate technologies and determine which candidate technologies they will use if made available. Identify potential industrial applications of the technologies of interest and other major technical issues to be resolved.

- Interview equipment suppliers and researchers in industry, universities and government laboratories to identify their version of promising technologies, and the potential applications, hurdles and R&D needs associated with those technologies.

- Identify project areas of research for integration to the program, based on input from the meetings and the interviews. Form work groups if necessary.

- Develop work breakdown structure(s) consistent with the R&D needs, and the required framework for coordinating inter-related activities.

- Develop a multi-year research plan to address the R&D needs and indicate scope, objectives, schedules and resource requirements for each selected project area.

- Develop an execution plan to define implementation and management of the program. Leverage program funds by cofunding the projects of common interest and/or joint solicitations for new technologies.

- Review results with industry and other federal agencies to avoid duplication.

7.0 PROGRAM EXECUTION STRATEGY

7.1 General

The basic program strategy involves expanding relevant technology bases and supporting the development of innovative and partially investigated concepts, carried through the techno-economic and environmental acceptability stages to the point where the new technologies are proven. *Innovative concepts* are a relatively long-range effort to develop new ideas that may not be supported experimentally other than in the literature. Innovative concepts are funded at low levels to do a theoretical feasibility study as the first phase of what could become a multi-phase research project. Each phase includes a decision point regarding the advisability of continuation. *Partially developed concepts* are a relatively short-term effort, intended to further develop a system that has previously been tested at the bench or pilot scale. The available data is utilized to advance the technology and its application data base, prototype design and industrial testing.

Project activities utilize all available research and development (R&D) resources, including private industrial research laboratories, university facilities, DOE laboratories and private institutional research facilities such as Battelle and the Institute of Gas Technology. Current industrial processes and heating equipment technologies and proposals for new technologies relevant to program activities are reviewed and assessed, and contacts with industry, academia and national laboratories are made regularly. This is done to identify equipment improvement opportunities among concepts which offer large attributes for federally sponsored R&D. From these, the crucial R&D activities for the program are determined.

Proposals are evaluated by a team of qualified technical experts within the DOE, its national laboratories and, if necessary, by experts outside of the government, provided that the team members are not associated in any way with the proposers and that the non-government evaluators sign non-disclosure and no-conflict-of-interest statements before conducting the evaluations.

Market assessments are made to determine responsiveness of the proposed concepts to the U.S. process industry needs, market size impacted, environmental acceptance, process parameters, customer acceptance and developmental risks involved. Technical assessments for each concept are made regularly to establish technical and economic feasibility with respect to the performance and use of various types and grades of fuels. The technical barriers to implementing the technology on industrial processes are recognized, resolved and the resolutions are reflected in the development planning.

The federal role in applied R&D is focused on high payoff areas with multiple applications. Fundamental types of risk associated with the R&D activities for product development are related to the necessary level of technical performance and economic attractiveness of the developed product. A risk analysis is therefore performed for each concept to determine if improvements in technical risk and economic acceptability would occur as the technology moves through R&D stages.

Technology development under federal support is carried to a stage at which the technical risks are reduced to a level where the private sector can be motivated to independently pursue further development. The technology development schedules are based on the following general stages of R&D:

- Basic and Applied Research -- create knowledge to establish technology base with or without known application

- Exploratory Development -- of product/process innovation and concepts including laboratory design, fabrication, test and evaluation of system elements

- Technology Development -- system engineering and design, and establish technical feasibility

- Engineering Development -- design, fabricate, evaluate pilot-scale and full-scale proof-of-concept unit

- Proof of Concept -- large scale or multiple testing and performance monitoring to verify commercial application

The program is coordinated with those of the other offices within the DOE, other federal agencies, industry-funded institutions such as the Gas Research Institute and the Electric Power Research Institute, and the private sector. The purpose of these coordinations is to avoid duplications, avoid redundancies, identify complementing activities for DOE support, and seek out opportunities for leveraging the program funds through joint solicitations and/or cofunding of the projects of common interest.

Efforts are made to maintain interface between technology developer, suppliers, manufactures and end users with the intention of accelerated development of an improved technology base, and effective technology transfer in close cooperation with the end users. The government laboratories also play a crucial role in the R&D efforts by providing advanced technical expertise in specific technology areas. The contract, procurement and administration procedures are executed in accordance with the rules derived from DOE's interpretation of laws passed by the Congress. Many projects take one year from completion of the statement of work by DOE staff to start of the contracted activity. Competitive procurement is generally sought. Contractors are required to agree to reasonable accounting procedures and an increasing number of "social architecture" requirements. Environmental impact is addressed via evolving administrative procedures whereby at the very least a "memo to file" is prepared and held ready for each obligated phase of each project.

7.2 Private Sector Participation

Close involvement of private industry in the planning and the execution of conservation efforts is an essential element of the program. This involvement is instrumental to defining the

federal role, ensuring that the program actions are not redundant with the private sector actions, and to enhance acceptance of new technologies by the private sectors once they are developed. Research and development supported must include cost-sharing participation by companies that are potential users of the resulting technologies.

Private-sector involvement in program planning takes a variety of forms. Industry's activities, views, and needs are identified through the use of analytic studies, workshops and seminars, interactions with trade associations and professional societies, unsolicited proposals, meetings with individual companies and interested organizations and, when necessary, project-level reviews by independent experts. Contacts are made with representatives of private industry to keep abreast of the R&D needs of industry, and to obtain recommendations on the direction of research. The technical needs expressed in these meetings on appropriate areas for involvement are major factors in developing the program's research agenda and in prioritizing of the candidate projects.

Private industry is expected to take a leadership position in the development of research proposals. Industry leadership may be manifested either by organizing and conducting specific projects within industrial facilities, or by participating in research and development projects led by other organizations. In the former case, after a decision is made to fund a specific project, the lead corporation (prime contractor) will be responsible for:

- Conducting the project research in a timely and efficient manner.
- Awarding subcontracts as appropriate and in accordance with federal acquisition and assistance regulations.
- Ensuring that it takes all steps necessary so that all necessary rights in intellectual property, including rights in patents and technical data, can be appropriately secured.
- Management of efforts necessary to achieve project objectives identified in the proposed Statement of Work or otherwise as agreed upon between DOE and the proposer.
- Periodic research and progress reports.

7.3 Cost Sharing

Cost-sharing provides a leverage of available federal funds and demonstrates a real interest on the part of the contractor in the development effort. Cost-sharing is required when the ultimate purpose of a project is commercial utilization of a technology and when the contractor is expected to receive economic benefits beyond the performance of the contract. Further, cost sharing must be offered in a manner whereby the established product quality will not be compromised.

Determination of the manner and amount of cost-sharing for each project is negotiated on a case-by-case basis, depending upon the degree of benefit to the contractor, as opposed to the technical and economic risk assumed by the contractor. The amount of private sector cost-sharing has ranged from about 5 percent to 50 percent of total project costs. As technical uncertainty diminishes and as the prospects for successful commercialization increase, participants are required to pay larger shares of DOE-assisted project costs. In addition to the maturity of the technology (including the availability of prior art and patents), the participant's(s') financial capability is considered in determining the amount of cost sharing that will be required.

The DOE Financial Assistance Rules, 10 CRF Part 600 (see, articles 600.103, 600.107, 600.422, and 600.424) and the various applicable OMB circulars establish strict guidelines for determining the allocability and value of in-kind (non-cash) cost sharing. For existing equipment and facilities, these rules provide that their "value for cost-sharing purposes" shall be limited by the amount of annual depreciation being claimed. If the item is fully depreciated or is not being depreciated, a "fair use" or market rental value is used for the in-kind contribution. To be allowable as a cost of the project, the equipment or facility must be essential to the performance of the project. The allocability and value of all proposed non-cash cost sharing is determined by DOE before project funding is approved.

Research projects funded may consist of a single phase or contain several proposed phases. The general concept for all phases beyond Phase I, including anticipated cost, are defined prior to initiation of any project. Cost sharing is defined for each phase, although commitment may be on a phase- by-phase basis. Additional participants may be added to a project at any time with the approval of the current participants.

7.4 Project Evaluation Criteria

The project evaluation specifically takes into account the following economic issues:

- Industry's concerns of high return on investment (ROI) and improved performance in terms of productivity gains without having to introduce unfavorable complexities in the plant operation.

- Government's concerns of energy savings and reduction in the use of foreign and less abundant domestic fuels.

Projects are thus generally evaluated with respect to their responsiveness to the needs of the U.S. process industries, market size to be impacted, generic quality of the concept, technical feasibility, technical risk involved, and whether the private sector would be willing to pursue the project alone.

The OIT Program Review Board (PRB) selects program activities worthy of adoption by following several distinct steps in its evaluation procedure:

(1) **Determine benefits/cost ratio.** Benefits are computed as the annual energy savings in quadrillion BTUs estimated in terms of the expected market in the year 2010 for new technology resulting from the program activity and of the expected maximum market penetration achievable by this new technology in all years up to that time. The estimated market penetration percentage and the unit energy savings for the year 2010 are used as a measure of the energy benefit of the program activity. Costs of the program activity are computed as the balance of federal funds required to advance its technology to the point at which private sector commercialization is likely.

(2) **Apply risk assessment.** Risk assessment of the proposed program activity is based on the level of risk at its present stage of development and the risk remaining at the proposed stage of completion. A subjective judgement by the program manager, this assessment relates to risk values developed from prior industry research and development outcomes.

(3) **Consider ancillary benefits.** Expected ancillary benefits of the proposed program activity are considered in terms of its probable contributions to environmental quality, U.S. competitiveness, national security, public health, employment, reduction of consumer cost, systems reliability, and technical leadership.

(4) **Determine appropriateness of the federal role.** Appropriateness of the federal role in the proposed program activity is determined by considering the range of industries which could benefit from the program activity, the current industry interest in the program activity, the likelihood that industry will pursue the program activity in the absence of federal assistance, and the constraints, if any, preventing the private sector from conducting the necessary research.

(5) **Determine relative merit.** The Program Review Board assigns a relative ranking to the proposed program activity based on the above assessments.

The availability and accuracy of information on a proposed program activity depends on its stage of development. Frequently, new program activities have only limited hard data available on their potential; therefore, these program activities must be ranked according to the best judgment of the PRB. As program activities mature, the accuracy of this information improves, and the program activities are again compared with newly proposed program activities for subsequent multi-year plans. PRB reviews also consider changes in industry, such as new technology developments or the relocation overseas of potential users. New opportunities for energy conservation are considered during the entire fiscal year at PRB meetings, and new program activities with higher potential may replace on-going program activities.

7.5 Technology Transfer

An important elements of the program is the rapid dissemination of results to appropriate industries. The transfer of new knowledge is accomplished through several communication activities including publications, meeting, and workshops.

Final reports are prepared and distributed for every technical project undertaken. Where the subject matter warrants further written elaboration, appropriate additional information and transfer publications are developed. These are condensed as comprehensive reports that address the technical and economic considerations associated with the adoption of new technology. Where the results of the funded R&D are to be retained for the benefit of the domestic industry only, and the time-value of the research is to be retained by the participants, the distribution of the R&D-results documentation will be accomplished in a two-tier approach for reporting. In the first tier of reporting, the results distribution will be limited to DOE, the participants, and the appropriate technical outside panels for a predetermined period after original publication. The participants will be responsible for publishing the comprehensive documentation, including technical details subject to industry competitiveness concerns. In the second tier of reporting, administrative and generic technology information will be published by DOE and immediately made available to the public.

Other information transfer activities include 1) sponsorship and participation in workshops and seminars as forums for researchers to discuss technical achievements in detail and exchange state-of-the-art information; 2) submission of articles to trade journals to convey new knowledge on energy conservation equipment; and 3) participation in conferences held by the technical and trade associations to present and discuss R&D project results.

8.0 PROGRAM CONTRIBUTIONS

The program has resulted in a number of conservation technologies that are penetrating the market place. These have included: slagging and dry-ash removing coal combustors; retrofit pulsed coal combustor for industrial and utility applications; impact coal-ash separator; and hollow fiber membranes for oxygen enrichment of air. In addition, the program has provided: (1) a pilot scale performance study of an oxygen enriched combustion (OEC) system integrated to a test furnace, by Union Carbide Corporation; (2) a laboratory evaluation of two polymeric membrane systems for producing oxygen enriched air for combustion applications, by University of Wisconsin; (3) laboratory evaluation-scale development and performance study of a wet air oxidation system for burning coal and producing high pressure steam, by SAIC Corporation. Other recent accomplishments of the program are described below:

Coal-Fired Glass-Melting Process Heater Development - Vortex Corporation Collegeville, PA 19426.

The objective of this research is to use coal instead of natural gas or oil in a cyclone gasifier/combustor, and to use the heat in an advanced glass- melting furnace. This work is generating the technical, economic, and environmental data needed for private-sector decisions on the feasibility of choosing coal as a fuel. The work will be performed in three phases: (1) technical and economic analysis and pilot facility design; (2) procurement and construction of the pilot facility, and testing of system components; and (3) addition of equipment to obtain an integrated system, and testing of the system. The potential benefits of this technology over present methods are reduced size and capital costs, multifuel capability, integral emission control, rapid start-up and shutdown, rapid product changeover, high thermal efficiency, and fast payback time.

Development and Evaluation of a Workpiece Temperature Analyzer for Industrial Furnaces - Surface Combustion, Inc. Maumee, OH 43537-0428, Acurex Corp. Mountain View, CA 94042., and Babcock and Wilcox Company Alliance, OH 44601-2196.

The objective of this research is to increase the energy efficiency of industrial heating processes through the development of advanced measurement systems that measure the temperature of the workpiece itself, not the temperature of the gas cavity in which it is located. Workpiece is herein defined as a solid object, either metallic or ceramic. Examples of applications may include reheating, annealing, sintering, soaking, heat treating, thermal setting, and curing of refractories. This analyzer must be a remote (noncontact) system, capable for use in moderate (>1000°F) to high temperature processes in both new and retrofit applications. The temperature profile and surface temperature of the workpiece will be determined either by direct measurement or inferred by calculation from direct measurements.

Acurex Corporation is assessing two optical technologies to measure workpiece surface temperature. Industrial testing will be performed on an optical measurement device developed by Pyrometer Instrument Co., Inc. and called the "Pyrolaser". This system uses a laser beam directed at and reflected by the workpiece. The surface reflectivity can then be related to emissivity which is used to calculated the surface temperature. The second technology to be evaluated is Raman Spectroscopy in which a laser is used to excite the atoms on the surface of the workpiece and the temperature is determined from the resulting Stokes and anti-Stokes radiation.

At Surface Combustion, Inc., an ultrasonic methods of measuring the internal temperature of the workpiece are being investigated. The system uses a laser to induce an acoustic wave through the workpiece. The speed of the acoustic wave through the workpiece depends primarily upon the temperature and is calculated by determining both the distance and time of flight of the acoustic wave. The arrival of the acoustic wave at the opposite side of the workpiece is detected by using a laser interferometer. A potential triangulation technique to measure the dimensions of the workpiece (distance of flight) will be investigated.

At Babcock and Wilcox, ultrasonic methods of measuring the internal temperature of the workpiece are being investigated. The system uses a laser to induce an acoustic wave through the workpiece. The speed of the acoustic wave through the workpiece depends primarily upon the temperature and is calculated by determining both the distance and time of flight of the acoustic wave. The arrival of the acoustic wave at the opposite side of the workpiece is detected by using a laser interferometer. A potential triangulation technique to measure the dimensions of the workpiece (distance of flight) will be investigated.

Research Program for Advanced Combustion Systems Ferrous Scrap Preheating System - Surface Combustion, Inc. Maumee, OH 43537-0428.

The proposed scrap preheating system utilizes a unique combustion system called a rich fume reactor (RFR) which provides total independent control of the heating process. The scrap is heated in a charge bucket. Off gases from the bucket are ducked to the RFR where oils and moisture that are normally present on the scrap, are totally combusted providing energy to process via low oxygen exhaust gases. The hot gases from the RFR pass through the bucket and heat the scrap. The recycle gas loop has a very low oxygen fraction to allow higher preheat temperatures. All gases are incinerated prior to leaving the system. Natural gas supplies any energy not available from the oily scrap. The preheater is decoupled from the arc furnace making retrofit installation practical and process scheduling possible.

Research Program for Advanced Combustion Systems; Advanced Glass Melting System - Air Products and Chemicals, Inc. Allentown, PA 18195.

The objective of this research is to develop an oxygen-fuel fired, advanced, glass-melting system that will reduce the industry's energy consumption, capital cost, and impact on the environment. This system will substantially improve the overall thermal efficiency of the melting process, combining the most recent developments in oxygen-enriched combustion with heat recovery and integration techniques. Elimination of nitrogen from the combustion process will allow great reductions in equipment size, while reducing NO_x and particulate emissions. The Air Products advanced glass-- melting system will include four subsystems: (1) a batch preheater, (2) melter, (3) oxygen-fuel delivery system, and (4) combustion controls. High heat transfer rates will be achieved with oxygen-fuel combustion above and below the molten bath. The flue gases exiting the melter/refiner will be used to heat the batch (silica sand) or cullet (recycled glass) to temperatures in excess of 1000°F, and potentially up to its melting temperature. Overall thermal efficiencies as high as 60 to 70% are expected.

Research Program for Advanced Combustion Systems; Advanced Radiant Combustion System - Alzeta Corporation Santa Clara, CA 95054-1008.

The objective of this research by Alzeta Corporation is to develop, test, and demonstrate an advanced gas-fired radiant combustion system for use in industrial manufacturing processes that require very high, controlled heat fluxes at elevated process temperatures (greater than 1800°F). The project will undertake the primary objective of extending radiant burner use to

higher temperature processes. The system will use high-temperature, fast-response, porous-surface radiant burners combined with advanced combustion controls to allow profiling of radiant output to process load requirements. The proposed initial installation is in a hydrogen-steam-reforming process, whereby hydrogen is manufactured from methane. The combination of high heat flux at a lower uniform temperature means that loads can be heated efficiently in small volumes without being subjected to localized over-heating that might produce tube burnout, fluid choking, or material nonuniformities. An added advantage is that the low peak temperatures minimize or eliminate thermal NO_x formation (less than 30-40 ppm), resulting in a more environmentally acceptable combustion process.

Thermal Swing Absorption Process for Oxygen Separation form Air - University of New Hampshire Durham, NH 03824-3591.

The objective of this research is to define the potential to use the Thermal Swing Process (TSA) for oxygen separation from air for a low-cost, on-line generation of oxygen enriched air for combustion. This research is based on the premise that certain chemical compounds or substrates are capable of selectively absorbing oxygen at one temperature and desorbing this oxygen at a different temperature. The project includes (1) conducting a literature review to delineate chemical compounds or substrates which will selectively absorb oxygen; (2) experimentally measuring oxygen and nitrogen solubilities, oxygen absorption and desorption rates, and life of a few selected chemicals; and (3) designing, fabricating, and operating a bench scale experimental unit to validate the concept, understand engineering challenges, and to provide a basis for a later pilot-plant to solve those problems.

Assessment and Development of an Industrial Wet Oxidation System for Burning Waste and Low-Grade Fuels - Modell Development Corporation Framingham, MA 01701.

The objective of this research by Modell Development Corp. (Modec) is to develop a supercritical wet oxidation system for generating steam and/or power for industrial processes from industrial waste materials and/or low-grade fuels (excluding coal and municipal waste). The project is multiphased. Phase I was performed by Stone & Webster Engineering Corporation (SWEC) and is now complete. SWEC is proceeding to Phase II in concert with Modec. Phase II will prove or disprove that the concept of supercritical wet oxidation will meet the project objectives. Phase II is divided into a Phase IIA and IIB efforts. Phase IIA includes conceptual designs for a pilot unit and full- scale plants, research unit development plan and test plan, and a project review. Phase IIB will prove or disprove the concept by executing the test plan developed in Phase IIA. Phase III involves design and construction of a pilot unit. Phase IV involves testing the pilot scale unit at an industrial site under the host's operating conditions.

APPENDIX A

APPENDIX A - DETAILED ANALYSIS OF EQUIPMENT IMPROVEMENT

Potential methods to improve overall efficiency in the combustion of fuels and the transfer of heat generated to industrial processes can come about through research and development in three general areas of optimization:

(1) Improved Combustion of Fuel;

(2) Increased and Uniform Heat Transfer to Furnace Load; and

(3) Reduced Heat Loss from Combustion System.

The key appears to be to develop retrofit technologies and new equipment concepts such that: (a) temperature difference between exhaust gases and load is minimized; (b) excess oxygen in combustion exhaust gases is minimized; (c) fuel supply is controlled according to desired load temperature; (d) heat rate transfered to load is maximized; (e) heat loss from furnace walls is reduced; and (f) gaseous emissions are reduced within the combustion zone as far as possible.

Based on some recent technology assessment reports and analyses of information from various industry contacts, several opportunities for research and technology development were identified in the areas of combustion and furnace heat transfer improvement. These opportunities are identified with numbers and listed in Table A-1. Further discussions of these technologies with the equipment manufacturers, end users, trade associations and industry funded research organizations would be necessary to define the role that OIT could play in developing high-value technologies that are likely to be attractive to industry.

Table A-2 titled "Major Industrial Unit Processes & Heat Transfer Technologies" was prepared to show where the "new technologies" could be applied in various industrial sectors. This table presents four or five digit SIC industry annual production, purchased energy, and overall specific energy consumption, for the major industrial unit processes. For those unit processes where efficiency or heat transfer process improvements could be made, process temperature, specific energy consumption, and stack losses, were computed. New technologies that could provide improved efficiency and productivity are identified for each SIC/unit process with the numbers corresponding to the New Technologies List. Technology (9) is also applicable to steam generation and to wastes/waste-derived fuels-to-energy conversion processes. Major application of technology (10) is in the food and paper drying processes. The table does not reflect technology (12) because it concerns with wastes and waste derived fuels. The table also does not reflect technology (13) which is applicable to boilers and furnaces in all industrial sectors.

A.1 The following research and development opportunities are based on various technology assessment reports previously funded by OIT:

Included in the description of each opportunity is an estimated energy savings figure. These figures are based on information researched for five of the most energy-intensive industries and processes. The number cited is the sum of the estimated technical energy savings of an opportunity as it applies to relevant industries (the backup calculations are included in Appendix B). The energy savings reported here were calculated assuming a constant production rate. Although, through improvements in heat transfer, production rate could increase while energy savings also could increase by virtue of reduced energy input per unit of production, a constant production rate was assumed for simplicity. Again, the savings numbers reported here represent only a subset of all potential industry and process energy savings.

TABLE A-1: NEW TECHNOLOGIES LIST

(1) Optimal Heat Transfer to Furnace Load (General Area)

(2) Re-Radiation Plate Enhancement

(3) Refractory Emissivity Enhancement

(4) Entrained Flow Processes for Calcination/Clinkering in Cement Manufacture and Other Industries

(5) Submerged Combustion/Injection

(6) Scale Free Metal Reheating

(7) Fludized Bed Industrial Thermal Processing

(8) Immersion Tube Melters for Non-Ferrous Metals

(9) Cleanup-Up Hot Furnace and Combustor Exhaust Gases

(10) Low Temperature Combustion

(11) Oxygen Enrichment of Combustion Air: Waste Heat Driven

(12) Adjustable Cofired Combustors/Combustion Chambers for Burning Waste and Waste-Derived Fuels

(13) Excess Oxygen Control for Multi-burner Boilers and Furnaces

(14) High Luminosity - High Temperature Natural Gas Burners

(15) Variable Flame Length and Shape/Advanced Control System

(16) Melt Temperature Measurement and Prediction System

TABLE 2: MAJOR INDUSTRIAL UNIT PROCESSES & HEAT TRANSFER TECHNOLOGIES

SIC	NAME	ANNUAL PRODUCT. MM TONS	PURCHASED ENERGY TRILLION BTU		ENERGY PER UNIT MMBTU/TON	UNIT PROCESS					NEW TECHNOLOGIES
			FUEL+ ELECT.	FUEL ONLY		TYPE	EQUIP. USED	TEMP. F	ENERGY PER UNIT MMBTU/TON	STACK/CW LOSSES %	
2611 1	Pulp Mills Kraft Process	4.7	86	75	18.0	Multiple Evaporators	Multi-Effect Tubular	230	5.3	39.0	(5)
						Lime Re-burning	Rotary Kiln	1650	2.4	34.0	(4),(7)
2621 2	Paper Mills Integrated Plant	20	591	506	29.5	Multiple Evaporators	Multi Effect Tubular	230	4.7	40.0	(5)
						Lime Kiln (Calcination)	Rotary Kiln	1650	1.9	38.0	(4),(7), (10)
2631 2	Paperboard Mills Integrated Plant	27.4	445	397	16.2	Multiple Evaporators	Multi-Effect Tubular	230	5.1	39.0	(5)
						Lime Kiln (Calcination)	Rotary Kiln	1650	1.5	15.0	(4),(7), (10)
2812 1	Alkalies & Chlorine Diaphragm Cell	2.0	59	39	29.5	Multiple Evaporators	Tubular	250	9.0	30.0	(5)
2813 2	Hydrogen Steam Reforming	0.2	51	50	255.0	Steam Reformers	Tubular Reactors	1550	103	19.0	(2),(7)
2816 2	Inorganic Pigments	0.375	19	18	50.6	Calcination (TiO2)	Rotary Kiln	1650	10.8	85.0	(7)
2819 1	Alumina	6.0	138	135	23.0	Calcination	Rotary Kiln	1800	4.1	40.0	(4),(7)
2869-1	Ethylene	12.6	279	254	22.1	Pyrolosis Furnace	Tubular Furnace	1600	17.3	12.2	(2)
2869-2	Methanol	3.2	49	48	15.3	Steam Reformer	Tubular Reactor	1450	10.4	20.0	(2),(5),(7)
2873	Ammonia	19.4	265	251	13.6	Steam Reformer	Tubular Reactor	1500	15	20.0	(2),(5),(7)
2874-1	Phosphoric Acid	7.6	38	31	5.0	Evaporation	Tubular	200	3.0	65.0	(5)
2899-1	Salt	0.5	2	2	4.0	Evaporation	Tubular	250	1.4	54.0	(5)
2911	Petroleum Refining	790.0	1064	959	1.4	Reformer	Tubular Reactors	950	0.44	19.1	(2)
						Fired Heaters	Tubular Heaters	850	0.79	16.0	(2)

* For identification, see list.

TABLE 2: (Contd.)

SIC	NAME	ANNUAL PRODUCT. MM TONS	PURCHASED ENERGY TRILLION BTU		ENERGY PER UNIT MMBTU/ TON	UNIT PROCESS					NEW TECHNOLOGIES
			FUEL+ ELECT.	FUEL ONLY		TYPE	EQUIP. USED	TEMP. F	ENERGY PER UNIT MMBTU/ TON	STACK/ CW LOSSES %	
3211	Flat Glass	3.7	55	40	14.9	Melt Furnace	Glass Tank	2800	8.9	22.0	(1),(3),(4),(14)(9),(11
						Tempering	Furnace	1600	1.4	52.0	(1),(3),(14),(9), (11)
3221	Container Glass	11.1	173	101	15.6	Melt Furnace	Glass Tank	2800	8.9	22.0	(1),(3),(4),(14) (9), (11), (16)
3229	Pressed & Blown Glass	1.8	49	24	27.2	Melt Furnace	Glass Tank	2800	8.9	22.0	(1),(3),(4),(14) (9),(11)
3241	Portland Cement	76.0	304	270	4.0	Clinker Production	Rotary Kiln	2550	4.0	37.0	(4), (15)
3251	Brick & Structural Clay Tile	9.9	47	44	4.7	Firing	Tunnel Kiln	2100	4.6	48.0	(1),(3),(11)
3274	Lime	15.0	88	86	5.9	Calcining	Rotary Kiln	1800	5.6	40.0	(4)
3296	Mineral Wool	1.6	59	49	36.8	Melt Furnace	Glass Tank	2800	13.1	24.0	(1),(3),(4),(5),((14),(11)
3312	Blast Furnace & Steel Mills	84.6	1510	1283	17.8	Heating	Soaking Pit	2400	1.5	30.0	(1), (3),(6),(14) (9),(11)
						Reheating	Reheat Furnace	2400	1.5	55.0	(1),(3),(6),(14),(9),(11)
						Annealing	Furnace	1400	1.0		(1),(3),(6),(7),(9) (14),(11)
3313	Electro-metallurgical Products	2.2	55	30	25.0	Ore Preheat	Rotary Kiln	1500	2.7	54.0	(4),(7)
3331	Primary Copper	2.1	62	57	29.5	Smelting	Reverbertory Furnace	2200	23.5	54.0	(4)
						Refining	Anode Furnace	2200	3.5	24.0	(1),(3),(14),(11)
						Remelting	Reverbertory	2200	3.0	73.0	(1),(3),(6),(14),(11)
3332	Primary Lead	0.6	13	12	21.6	Smelting	Blast/ Reverbertory	2200	8.0		(4)
						Refining	Kettles		4.6		(8)

* For Identification, see list

TABLE 2: (Contd.)

SIC	NAME	ANNUAL PRODUCT. MM TONS	PURCHASED ENERGY TRILLION BTU		ENERGY PER UNIT MMBTU/TON	UNIT PROCESS					NEW TECHNOLOGIES
			FUEL+ ELECT.	FUEL ONLY		TYPE	EQUIP. USED	TEMP. F	ENERGY PER UNIT MMBTU/TON	STACK/CW LOSSES %	
3333	Primary Zinc	0.2	12	7	60.0	Smelting	Blast Furnace	2300	42.0		(4)
						Electrolysis	Electrolytic		47.0		(4)
3334	Primary Aluminum	4.6	313	71	68.0	Anode Production	Baking Furnace	2200	2.6	29.0	(1),(3),(14),(9),(11)
3341-1	Secondary Aluminum	1.2	5	3	4.5	Melting	Reverbertory	1460	1.7	42.0	(1),(3),(8),(14) (9),(11)
3341-2	Secondary Lead	0.8	1	1	0.7	Melting	Reverbertory	2100	0.3	41.0	(8)
3341-3	Secondary Zinc	0.2	1	1	4.3	Melting	Reverbertory	1000	1.0	56.0	(8)
						Distillation		2300	1.0	39.0	(1),(3),(11)
3341-4	Secondary Copper	0.5	2	2	4.0	Melting	Reverbertory	2400	1.0	34.0	(1),(3),(14),(11)
3353	Aluminum Sheet, Plate, Foil	4.1	68	54	16.6	Melting	Reverbertory	1250	4.8	60.0	(8)
						Ingot Preheat	Furnace	1000	2.6	50.0	(1),(3),(6),(14),(11)
						Annealing	Furnace	800	2.0	21.0	(1),(3),(6),(14),(11)
3361	Aluminum Foundries		28	22		Melting	Reverbertory	1400	4.8	60.0	(8)
3398	Metal Heat Treating		25	18		Heat Treating	Furnace	1400			(1),(3),(14),(11)
3462	Iron & Steel Forging	1.2	41	37		Heating	Furnace	2400	11.5	67.0	(1),(3),(6),(14),(11)
						Heat Treat.		1600	16.0	71.0	(1),(3),(6),(14),(11)
3523	Farm Machinery & Equipment		28	22		Heat Treat.	Furnace	1350	2.9	65.0	(1),(3),(14),(11)
3531	Construction Machinery		36	27		Heat Treat.	Furnace	1350	2.4	75.0	(1),(3),(14),(11)

* For Identification, see list

(1) Optimal Heat Transfer to Furnace Load (General Area)

Metal Heat Treating (SIC 3398), Fabricated Metal Products (SIC 34), and Machinery, except Electrical and Transportation Equipment ((SIC 37), all involve various types of furnaces for forging and heat treating metal parts that operate between 1350 to 2400°F. A study conducted in 1981[3] indicated that Iron and Steel Foundries (SIC 332) and Non-Ferrous Foundries (SIC 336) have numerous mold and die reheat furnaces and other melters. For example, in 1981, there were 115 open hearth furnaces, 1737 reverbertory, 190 rotary, 3700 diecast holding furnaces, 220 investment cast holding furnaces and 1400 radiant and direct heat treat furnaces that operate anywhere from 1200 to 2900°F. In non-ferrous metal rolling and drawing (SIC 335 using 153 trillion BTU in 1981) there are[2] about 4475 smelting, holding, heating, and annealing/ heat treating furnaces. Based on the EPA, NEDS and other data bases and published information it is estimated[2] that there is total furnace population of 192,000 consuming about 3.1 quads of energy. While the furnaces population today could be quite less because of lower production and poorer economic climate in the metals industries, their numbers and the resulting savings from maximized heat rate to furnace load could be very rewarding.

Increasing heat flux and heat transfer rate to load will increase the thermal efficiency and therefore reduce the furnace size and thus the capital cost of a new furnace, or increase the process throughput and thus the operating costs of an existing furnace. In the case of large industrial furnaces, the convection heating of the furnace walls is a major factor for limiting the furnace heat transfer, therefore by increasing the contact time of flue gases with the furnace walls will increase the heat transfer to furnace walls and, in turn, to load. In the case of steel furnaces, flux to load, which is in the range of 5,000 to 10,000 BTU/hr sq.ft at the steel processing temperatures, can be increased by a factor of two to four[4] through improvements in equipment design. Higher production rate thus achieved will reduce the energy as well as the labor costs. Furthermore, the reduced heating time resulting from the increased heat flux will shorten the time for the product to oxidize or to undergo a distortion, therefore the product quality will also improve simultaneously.

The use of high heat flux radiation system could increase the flue gas temperature, but when supplemented with the use of heat recovery devices, it could reduce the process energy consumption by 5 to 25%[4] depending upon the temperature of the process. Therefore, a research program that will advance the control of the combustion system, so that the load is heated under optimal heat flux condition, will be very attractive to industry. Advances sought include addressable burners that can produce flames with variable size and shape to optimize heat flux applied to the load in steel, secondary aluminum, glass, cement, chemical and petroleum industries. Additional advances sought include enhanced heat transfer by means of direct flame impingement of the load; high heat flux radiation systems; enhanced convective heat transfer within the combustion zone using principles such as increasing combustion gas recirculation and maintaining high gas circulation around the load; increasing combustion gas - load contact time; conductive heating; and optimized heating for well-defined load shapes.

Gas Research Institute (GRI) has funded an oxygen - natural gas-fired direct flame - impingement heating system, for reheating steel billet prior to forming and rolling operations. The burners are specially designed for uniform heating and fired intermittently to avoid damage to stock surface from overheating. A heating rate in excess of 200°F per minute was achieved but the thermal efficiency remained on the order of 30%.

By maintaining a constant fuel supply an increase in production rate of 10-15%, along with fuel savings based on reduced energy use per unit product, are possible through implementation of any one of these advanced heat transfer technologies. Technologies 2, 3, 4, 5, 7 and 14, in this report fall in this category. By maintaining a constant production rate the potential of national energy savings through successful commercialization of technologies in this area are up to 507 trillion Btu/year in reduced energy consumption.

(2) **Re-radiation Plate Enhancement**

The use of radiation re-emitting plates in the high temperature gas stream between the heat absorbing surfaces is one technique that appears to be simple and easy to retrofit into existing furnaces and heat exchangers but has not been used commercially. Therefore, this technique merits further evaluation.

The radiation plate can be constructed of any material, metallic or ceramic, as long as the material can withstand the operating temperatures. There are no critical strength requirements. The radiative heat flux is increased by installing a solid plate in a high temperature radiative gas surrounded by heat absorbing surfaces. In the products of combustion, species such as CO_2 and H_2O radiate only in discrete wave length bands. Radiation plates could be profitably applied such that, besides the direct radiation in discrete wavelengths, the combustion gases would transfer energy by convection to the radiation plate which in turn would transfer energy by radiation in a wide window of spectrum (including wavelengths in which the combustion gases are transparent) to the heat absorbing surface.

Energy transferred to the load per unit area per unit time (heat flux) is increased. Radiation plate technology applied to reactors and fired heaters in the petrochemical industries could result in large improvements[2] in heat transfer (order of 120%). This is because the liquid side heat transfer coefficients are about 15 times those of gas side heat transfer process and improvements in the outside coefficient by the reradiating plates will very effectively increase the overall heat transfer. There are, however, certain drawbacks to the technology. In high temperature applications conventional metals may not survive. In low temperature applications such as the chemical/petroleum industry, the stability of the working fluid may be affected because of the higher heat fluxes.

Petroleum refining (SIC 2911) is the largest industrial user of energy consuming about 3 quads of energy in 1980. The purchased fuels and electricity in 1980 amounted to about 1.1 quad indicating that nearly two thirds of the energy consumed came from byproduct fuels. Refineries differ widely in the processes employed depending upon the type of crude used and the desired product mix but they all partially separate the components of the crude and chemically transform the fractions into useful products. Catalytic reforming is an endothermic process and is used to increase the octane rating of gasoline. As is the case in many process vessels used in refining, it is conducted in a tubular reactor in the temperature range from 900 to 1000°F[2]. At these temperatures cracking produces undesirable compounds and this is reduced by reducing the residence times in the reactor. Radiation plates, if used in this reactor furnace, should provide higher heat fluxes and allow reduced residence times.

Most of the thermal energy requirements in a petroleum refinery above about 600°F are met with fired heaters, which are combustion chambers surrounded by tubes through which process fluids flow and absorb energy. Big users of fuel in tubular heaters are[2] atmospheric distillation (using about 230 BTU per pound of crude), catalytic cracking (142 BTU/Lb), alkylation (102 BTU/Lb), vacuum distillation (61 BTU/Lb), and other processes as delayed coking, lube oil processing and hydrotreating. All of these processes use fired heaters where the used of re-radiation plate enhancement could provide large energy savings.

The cheapest method of producing hydrogen is by steam reforming of natural gas. In a typical steam reformer, natural gas and steam are passed through alloy steel tubes containing a catalyst to form carbon monoxide and hydrogen. This endothermic reaction is driven by burning natural gas with air on the outside of the tubes. The yields of hydrogen can be increased by increasing the temperature or by lowering the pressure. The product from this reformer is mixed with additional steam passed through another catalytic reactor where the water-gas shift reaction, a slightly exothermic reaction, takes place and the carbon monoxide is shifted to carbon dioxide which in turn is scrubbed to remove carbon dioxide, leaving a hydrogen rich gas. The limiting step to the process is in the reformer where increases in temperature are limited by tube strength considerations. Improvements to the reformer can be obtained by providing reradiation plates on the outside tubes to increase the outside heat transfer coefficient. Another improvement is to replace the reformer furnace by a 2 stage fluidized bed process.

As in the case of hydrogen production, the synthesis gas used in methanol synthesis is produced by steam reforming of natural gas. However, the methanol synthesis reactions occur at between 3000 to 5000 psi[2] and considerable compression work has to be expanded on the reformer gas. It is therefore beneficial to conduct the reforming reaction at as high a pressure as possible to reduce the subsequent work of compression. However, reformer tube strength limitations would prevent increasing reformer temperatures to maintain the yield at the higher pressures. The considerations that apply to methanol production similarly apply to ammonia production. The reforming reaction usually occurs at 500 psi and 1500°F. As the ammonia synthesis reaction takes place at 130 to 600 atm, with 300 atm being common[2], compression work is large. With conventional reformers reradiating plates would allow higher pressures by increasing the heat transfer to the tube surface and thus decreasing the tube wall temperature. A direct contact fluidized bed reformer may also prove to be beneficial.

Practically all of the ethylene (SIC 2968-1) produced in the U.S. are derived from petroleum and natural gas feedstocks. The basic process is a pyrolysis process where the hydrocarbon feedstock and steam are introduced to a tabular furnace where cracking reactions occur at about 1500°F. The feedstocks usually used are ethane, (37% of the ethylene production), naphtha (24%), gas oil (21%), propane (15%), and butane (3%). Ethane is the preferred feedstocks and the ethane gives up hydrogen to form ethylene. To minimize further reactions, the pyrolysis products are cooled rapidly and heat is recovered as high pressure steam. Further energy recovery allows relatively high thermal efficiency of about 80%[2]. The exhaust gases are used to preheat the feed to cracking temperature or to heat the boiler feedwater. However, the radiation plate enhancement would increase the heat flux in the furnace and the furnace throughput.

Reradiation enhancement appears to offer high potential in energy savings due largely to the considerable amounts of energy used in numerous reactors/reformers and fired heaters in the petroleum industry. In keeping the fuel supply constant, a significant increase in production is expected, potentially as high as 10-15%. By maintaining a constant production rate, the potential of national energy savings in the petroleum industry alone could amount to 79 trillion BTU annually, followed by ethylene (42.1 trillion BTU), ammonia manufacture (21.8 trillion BTU), and methanol (3.1 trillion BTU). However, better understanding of re-radiation heat transfer is needed for specific applications such as fired heaters, chemical reactors and steam reformers where advanced materials are used for construction.

(3) Refractory Emissivity Enhancement

The most important mode of heat transfer in an industrial furnace, currently, is by radiation from the refractory walls to the load. The emissivity (capacity of a body to radiate energy) of refractory materials decreases considerably at higher furnace operating temperatures, thus adversely affecting the heat transferred to the load.

Recently, there has been a growing interest in exploring the use of high-emissivity coatings on furnace refractories and metallic surfaces to increase the heat transfer to the furnace load, thus increasing productivity or saving energy or both. Some benefits of using high emissivity coatings on the refractory walls of industrial furnaces are: (a) rapid heat-up to the desired temperature; (b) increased heat transfer under steady-state conditions; (c) more uniform temperature distribution in the furnace; and (d) less refractory erosion and longer refractory life.

Developments in England[5-9] using a zirconia based coating on refractory surfaces in several furnace applications have resulted in claims of energy savings varying from 14 to 25%. In the U.S. it has been reported[10,11] that reheat furnace energy consumption was reduced 15 to 30% and refractory service life increased by 100 to 400% with the application of zirconia coatings. Ceramic silica-alumina coatings are also available for metal surfaces, such as radiant tubes or electric heating elements and improved performance has been reported in these applications as well.

Heat transfer analysis indicated that the saving in energy is a strong function of the emissivity of the load. Therefore, application of this technology to glass and steel (iron oxide) furnaces, where the load emissivity is high, makes it more effective.

Blast Furnace and Steel Mills (SIC 3312) consume about 62% of the primary metals consumption of fuels and electricity. Excluding pelletizing and sintering of iron ore, which is performed in SIC 10, the major steps in SIC 3312 are[12] cokemaking, ironmaking, steelmaking, steelcasting and steelforming and each consumes 136, 675, 236, 180, 283 trillion BTU annually respectively. The steelforming step involves heating, reheating, and annealing processes which are conducted in various types of high temperature furnaces (Roller Hearth, Bell, Box, Hood, Carbottom, Pusher and Rotary Hearth) operating at temperatures from 1400 to 2400°F. Enhancing the wall emissivity could account for considerable energy savings in these furnaces.

The stone, clay and glass industry (SIC 32) is the fifth largest purchaser of fuels and electricity (1.0 Quads in 1988). The flat container and pressed & blown glass industry, SIC's 3211, 3321, and 3229 respectively use primarily natural gas to fire the glass melting furnaces at about 2800°F. In existing furnaces, the coatings to enhance emissivity of furnace refractory would provide improved heat transfer to the molten glass. These coatings could also improve operations in tempering and annealing furnaces operating at lower temperatures up to 1600°F. Brick and structural clay products are made either in a wet (15% water) or dry (7% water content) process and fired at about 2100°F. Old plants used periodic kilns while most of the production today is done in tunnel kilns where waste heat is used to dry the incoming brick. Emissivity enhancement of the refractory walls could further increase the efficiency of the tunnel kiln.

In the primary copper industry, modernization has allowed the replacement of the reverbertory operations with a flash or cyclone reactor using oxygen enriched air. This has resulted in a high furnace specific capacity[2], however, there still are reverbertory furnaces operating today. Besides smelting, there are refining and remelting operations where emissivity enhancement of the refractory or molten metal surface could result in additional fuel savings and higher productivity.

The secondary non-ferrous metals industry consumes about 39 trillion BTU of fuels and electricity and most of it (35 trillion BTU) is in the form of fossil fuels. Because primary non-ferrous metal production is highly energy intensive, the trend in recent years has been towards more recycling and secondary production. Most secondary production furnaces are of the reverbertory type and emissivity enhancement of the refractory and load can significantly reduce energy consumption because the emissivities of molten/ oxidized non-ferrous metals could be as low as 0.2 at the temperatures involved. The same technology could be applied to SIC 3353, Aluminum Sheet Plate, Foil and SIC 3361, Aluminum Foundries. In aluminum remelt applications, aluminum oxide formed on the melt surface has a low emissivity value, and the use of additives to the melt to increase the load emissivity must be explored first, before the high emissivity refractory coatings can have maximum benefit.

A data base and an industry guide on high emissivity coatings and additives is required for increasing the emissivity of refractories and the furnace load in heat treating and non-ferrous melting operations. For instance, a glass type cover on an aluminum melt surface that has high emissivity, can reduce energy consumption and aluminum oxidation losses. The work could be accomplished through analytical and experimental work by a national laboratory and cost shared efforts by the refractory industries.

An increase in production, potentially on the order of 15%, is possible through the implementation of this technology. In maintaining a constant fuel supply not only would there be increased production but, due to reduced energy use per unit product, there could be fuel savings as well. If, on the other hand, the production rate is maintained constant a potential national energy savings of 90.4 trillion BTU annually, primarily in steel and stone, clay and glass industries where high temperature furnaces are used is estimated. Also, there appears to be considerable potential for applying this technology to refractories used in process reactors and fired heaters used in the petrochemical industries.

(4) Entrained Flow Processes for Calcination/Clinkering in Cement Manufacture and Other Industries

The total heat transferred from the gas to the solids is a function of the heat transfer coefficient, the surface area and the temperature difference between the gas and solids. Increasing this heat transfer for a given temperature difference would require either an increase in the surface area or an increase in the heat transfer coefficient or both. A proven way to improve the heat transfer is to entrain the solids in the gas stream instead of contacting them in the rotary kiln. This is presently accomplished in cyclone type vessels or flash reactors in what is referred to a suspension preheaters and flash calciners. In both of these cases, the particles are entrained in the gas stream, the heat transfer coefficients are higher and the smaller particles have a larger surface area exposed to the gas resulting in an increase in heat transfer.

In 1985 the U.S. was the fourth largest producer of cement in the world (76 MM tons of Portland cement) and the cement industry (SIC 3241) purchased 304 trillion BTU of fuel and electricity[2]. The specific energy consumptions is about 5 MMBTU/ton of cement without considering the inefficiencies in producing the purchased electricity and this number has improved by 30%[12] from 1975 to 1985. Besides housekeeping type of conservation measures, this improvement is due to change over from wet to dry process and to use of preheaters and precalciners in more modern plants. Both wet and dry processes have been using long rotary kilns for clinker production. These kilns have been used first to dry the wet feed material, preheat the dried material, calcine the charge and finally produce the clinker at about 2550°F.

Although the efficient flash calciners and suspension preheaters are now available and used; yet the U.S., Japan and Europe still use the inefficient rotary kilns for the cement clinker forming step. These kilns are large pieces of equipment. They rotate at about 60 revolutions per hour and the residence time of the material in the kiln can be as high as 5 hours. By using the flash processes, the specific energy consumption could be lowered to 2.3 MMBTU/ton from 4.3 MMBTU/ton for the best state-of-the art cement manufacturing process. The lime industry (SIC 3274) uses rotary kilns operating at 1800°F to calcine limestone feed to produce calcium oxide. Just as in the cement industry, there is a need to change over to flash type preheaters and calciners to save energy and increase productivity. In the production of alumina, aluminum hydroxide is calcined in a rotary kiln at 1800°F consuming about 4.9 MMBTU/ton of product. A flash calciner would be a more efficient process but most plants still use the rotary kiln.

The most important white pigment used in surface coatings is titanium dioxide which is produced either by the chloride process using imported rutile or by the sulfate process using domestic ilmenite. The former accounts for 60%[16] of the U.S. production. Both processes have a calcination step. In the chloride process, titanium tetrachloride is reacted with air at 1500°F to form chlorine gas and titanium dioxide and consumes 0.4 MMBTU/ton product[2]. In the sulfate process, the hydrate from the hydrolysis step is fed to a rotary kiln operating at 1650°F and consumes about 10.8 MMBTU/ton of product[2]. It is here that a flash process could be used effectively if done in an environmentally safe manner. Primary lead smelting is currently conducted in blast or reverbertory furnaces, where a flash type of system would be significant improvement. Conducting melting processes as an expanded process could improve the efficiency, productivity and flexibility of conventional glass tanks.

Flash calcining technology needs to be transferred to lime, alumina and other industries, and the technology for flash clinker needs to be developed, starting with an analytical and experimental program for flash clinker production, preferably conducted through the cement associations.

A novel flash clinkering process must ensure that the chemical reactions proceed so that the clinker quality is maintained. This is critical in cement manufacture. Further, the flash process should not produce a clinker that requires excessive energy for grinding, and should have a provision such that clinkers do not stick to the reactor walls. Also, since the clinkering section of cement making process involves very high temperature, NO_x maybe produced and needs to be controlled.

Institute of Gas Technology (IGT) is currently developing a fluidized - bed based technology for cement clinkering. Since high temperatures are required for clinkering reactions it is debatable whether the fluid-bed characteristic would be effective to reduce NO_x emissions. Also it does not appear that the fluidized bed system would be competitive in overall heat transfer coefficient when compared with the flash type system.

If a constant fuel supply is maintained an increase in production rate of between 10-15% is estimated. This increase in production rate, given a constant fuel supply, may also be accompanied by a decrease in fuel consumption based on reduced energy use per unit product. Holding the production rate constant the entrained flow or flash type processes offer a potential national energy savings in the cement manufacture (132 trillion BTU/year) and in the paper, lime, alumina and other industries where rotary kilns are used (28.8 trillion BTU/year).

(5) Submerged Combustion/Injection

Direct contact heat transfer in process equipment is accomplished by bringing a high temperature stream into intimate contact with a low temperature process stream. The high effectiveness of heat transfer in submerged combustion/injection processes would result in a high productivity and low capital investment per unit of capacity[2], i.e. the process would result in a reactor of a high specific capacity. There are several processes in industry where direct contact devices have been used for many years, such as, concentrators, evaporators, absorbers, wet cooling towers, grain dryers, distillation columns, etc. However, there are numerous other applications where direct contact heat transfer processes could be used. Why they are not more widely used is primarily because of economics but also because of a lack of an adequate design data base. As cost of energy and the capital cost of industrial equipment increases, direct contact devices will be considered and evaluated for use because they offer the potential for improved performance and reduced first cost.

The most important advantage of direct contact devices is that no surface is required to separate the hot and cold fluids. Therefore, corrosive fluids and those that contain dissolved and suspended solids can be used in these devices without the problems of heat transfer surfaces corroding and fouling and thus causing a deterioration in the heat transfer.

Direct contact devices also have certain drawbacks. If two fluids are in direct contact, they will mix and, therefore, in these devices, the two fluids should be immiscible. If the two streams have to be separated, this could become expensive. In some applications, one stream may be contaminated by the other and subsequent purification of the contaminated stream could drive up the costs. In direct contact devices, the two streams should be at the same pressure because, if they are not, pumping one stream to the pressure of the other could be costly.

Since there is no heat transfer surface to corrode or foul, the submerged combustion has been used in evaporation and concentration of corrosive liquids. Some of the applications have been in the production of sodium sulphate, potassium chloride, calcium chloride, magnesium chloride, phosphoric acid, sulfuric acid and whey.

The kraft chemical pulping process used in the paper industry uses steam flowing in vertical tubes for concentrating the black liquor. Since black liquor is highly corrosive, the tubes have to be made of pure nickel or high cost nickel alloys. Direct contact heat transfer processes have been used in the past and dispense with the need for this high cost tubing[2]. Yet, vertical tube evaporators are still used whereas submerged combustion of oil/natural gas or direct contact with the products of combustion from a black liquor burner/furnace would offer the advantages of higher efficiency and lower cost.

The production of chloride and sodium hydroxide is performed in electrolytic cells such as the diaphragm or mercury cells or more recently the membrane cells. The sodium hydroxide produced by the diaphragm cell is relatively dilute (11% solution) and is normally concentrated in multiple-effect evaporators using steam at 250°F. Direct contact or submerged combustion evaporators appear to be more energy efficient and economical alternatives.

Phosphoric acid production by wet process involves an evaporation step where vertical tubular evaporators could be replaced by more efficient direct contact evaporators.

Mineral wool or fiber glass is formed directly from a molten state by a rotary fiberizer, steam or air blowing, drawing or flame blowing depending on the type of glass and use for the product. The melting may be done in gas fired units or electric furnaces depending on the product use. Technology such as submerged combustion or flash melters may be applied here with better chances for success than in the flat and container glass tanks[2] because bubble formation in the melt may not be a severe problem in fiber production. If traditional melters are used, emissivity enhancement techniques could help improve the efficiency of the melting process.

In industries, submerged injection has been used in smelting of copper, lead, tin and zinc as well as in treatment of slag for recovery of these metals. Despite the fact that submerged injection technology has been used in the past in these industries, submerged combustion, in oxidizing or reducing atmospheres as needed, has not been applied to purely melting operations and these opportunities need to be evaluated.

The non-ferrous metals industry offers considerable scope for submerged injection processes. Secondary metal production from scrap and other waste materials will increase in the future not only because it would require a fraction of the energy used for primary metal production but also because it would save scarce mineral resources. One of the limiting factors in the recycling of scrap, such as aluminum, is that impurities such as copper, iron silicon and other elements exist and must be removed in the secondary processing. Submerged injection processes could offer the potential for not only melting the scrap with savings in energy but also effectively removing the impurity metals in the molten metal.

GRI is currently funding a project to use oxy - natural gas submerged burners as the supplementary but primary energy source in a scrap-based electric-arc steel making furnace. The project also includes study of melt thermochemistry as an effort to avoid endothermic species. Laboratory tests showed problem of gas leakage through the refractory. IGT is developing a submerged combustion melter in which combusting oxygen/natural gas mixture is injected directly into a pool of molten mineral matter. Nox emissions in both the GRI and the IGT technologies are reduced because oxygen is used as the oxidant instead of air.

One application where submerged combustion has not been used in the past, but yet has potential, is in steam generation. Such a direct contact process requires both streams to be at the same pressure. Since steam at 212°F, mixed with large amounts of flue gas, does not have much use steam generation for industrial use will require a primary loop consisting of a fluid with a high saturation temperature at atmospheric pressure and the secondary water/steam loop. This arrangement is commonly used in double boiler systems in industry and nuclear power plants.

By maintaining a constant fuel supply a significant increase in production rate, 10-15%, is possible with this technology. As discussed above, there is potential for higher productivity at a lower capital investment per unit of capacity, and therefore a higher specific capacity. In holding the production rate constant, direct contact/submerged combustion was found to offer savings of about 96.14 trillion BTU in the paper and chemicals industries primarily in evaporation/concentration processes involving corrosive fluids. This technology also appears to offer tremendous potential in steam generation and environmental treatment of waste gases and could be applied in various industries ranging from food (SIC 20) to non-ferrous metals (SIC 33). As a start, conceptual design studies could be performed through industry/ university teams.

(6) Scale Free Metal Reheating

Reduction of material defects and oxidation losses will save the energy consumed in the manufacturing process equal to that associated with the loss of process material plus whatever energy is required to dispose of the defective and oxidized material.

Reduction in process material wastage is expected to reduce production cost, which provides numerous economic advantages. In the case of the steel industry alone, the number of applicable steel reheat furnaces in the U.S.A. is 800; and of forging furnaces is 10,000 where the material loss problem exists. For instance, 1.5% to 4% of steel is lost due to oxidation by combustion gases[4], during the steel (billets, blooms and ingots) reheating process which is carried out at 1600F to 2400°F temperature range. In the case of scrap aluminum melting, 2% to 5% of metal is lost due to oxidation[4].

The process material wastage problem is also common to the manufacture of most other metals and metal alloys including aluminum and copper. Avoiding loss of process material during a heating process will also contribute significantly to increase the production facility's productivity. Technologies need to be developed for heating metals to high (1500 to 2300°F) temperature without affecting surface quality or metal loss through oxidation.

All oxidation and many material defects can be avoided by maintaining a chemically inert gas blanket in *direct* contact with the process material. In many cases nitrogen is a satisfactory gas. Heating system design must carefully integrate atmospheric seals, material handling systems, burners controls and local chemistry so that heating occurs under controlled conditions.

As discussed above, this technology not only saves energy but, through reduced production wastage, increases productivity. By maintaining a constant fuel supply a significant increase in productivity is expected, also expected is an an energy savings through a reduction in energy use per unit product. If the production rate is held constant, a potential energy savings through the use of scale free metal reheating techniques in the steel reheating application alone are anticipated to be 56.8 trillion BTU/year[4] in reduced consumption of natural gas. The corresponding cost savings are anticipated to be $2.25/ton owing to energy reduction and $10/ton owing to increased throughput.

(7) Fluidized Bed Industrial Thermal Processing

An advanced fluidized bed technology for heat transfer to the process material by means of entrained hot solid particles can increase rate of heat transfer and, as necessary, provide a non-oxidizing environment for the process material. Such technology will offer the ability for a local control of heat transfer to the process material and provide an attractive means of increasing heat transfer to the load, reducing heat-transfer surface temperature, reducing air pollution and accommodating alternative fuels ranging from natural gas to low grade by-product fuels.

An important outcome of the use of fluidized bed processing is that it will allow a reduction of the flue gas temperature below the acid dew point by incorporating sulphur capturing materials within the bed, which, based on a possible decrement of 50 to 100°F, could increase the equipment's thermal efficiency by 1% to 2%[4] and thus reduce the energy cost substantially. This increase depends significantly upon the fuel's sulphur content, but will be additional[4] even to the maximum attainable efficiency (up to 95%) in a conventional equipment furnished with heat recovery devices. Furthermore, if a by-product gas is used as the fuel, the cost of the process energy can further be reduced by 25 to 33%[4] of the present energy cost.

The fluidized bed process can be used to improve performance, reduce size and increase life of various process heaters, furnaces and reactors used in many industries including petroleum (SIC 29), chemical (SIC 28) electrometallurgical (SIC 3313) and food (SIC 20). However, there are some major development concerns, which are: performance, reliability, life of equipment, maintenance, frequency and required flexibility of changing operating parameters.

In petroleum industry, tube-still process heaters and reactors are widely used in which burners fired with various fuels release and transfer heat to the process fluid. In these tubular heaters the process fluid in the tubes is preheated by convection heating, followed by convective and radiant heating by flame in a combustion chamber. The combustion zone temperature has to be controlled in a very narrow range in order to maintain the tube life.

For instance a 100°F temperature rise could shorten the tube life from 10 years to 2-3 years even with the best available materials used for these tubes. Consequently, the problem of unanticipated tube failures[4] due to uncontrolled temperature conditions has been a matter of grave concern in a petroleum refinery. In reactors, where catalysts are used on the inside of the reactor tube walls, low heat transfer rates[4] from flue gases to the reactor walls is the major limiting factor.

Fluidized bed processing will be particularly beneficial to the tube still heaters used in the petroleum industry because it will offer uniform and controlled heat, greatly increased heat absorption rates leading to improved productivity, reduced pollutants (NO_x and SO_x) emissions, higher thermal efficiency, and prolonged tube life. The heat flux rates through the tubes could be increased from the present range of 15,000-25,000 BTU/hr.sq.ft to 35,000-50,000 BTU/hr.sq.ft[4], and thus reduce the tube costs and maintenance costs substantially. The tube material however would need to have higher wear resistance even though a low temperature grade could be used.

Fluidized bed-based reformers and furnaces could be designed as more cost effective options to many of the presently used tubular type reformers and rotary kilns. Following are some examples[2]:

> The cheapest method of producing hydrogen is by steam reforming of natural gas. The yield of hydrogen can be increased by increasing the temperature or by lowering the pressure. The product from this reformer is mixed with additional steam passed through another catalytic reactor where the carbon monoxide is shifted to carbon dioxide which is scrubbed to leave a hydrogen rich gas. The limiting step to the process is in the reformer where increases in temperature are limited by tube strength considerations. Improvements to the reformer could be obtained by replacing the reformer furnace by a 2 stage fluidized bed process.
>
> The synthesis gas used in methanol synthesis is produced by steam reforming of natural gas. However, the methanol synthesis reaction occur at between 3000 to 5000 psi and considerable compression work has to be expended on the reforming reaction at as high a pressure as possible to reduce the subsequent work of compression. However, reformer tube strength limitations would prevent increasing reformer temperatures to maintain the yield at the higher pressures. With conventional reformers reradiating plates could be used to increase the heat transfer to the tube surface and thus reduce the tube wall temperature. However, direct contact fluidized bed reformer could also prove to be very beneficial.
>
> Electrometallurgical Products involve a step to preheat the ore which is usually done in a rotary kiln. This inefficient process could be replaced by a fluidized bed or an entrained bed process.

The production of hot drying air using heat exchangers is a major energy consuming process in the food industry (SIC 20)[4]. The use of fluidized bed will reduce the size of these air heaters.

By using the fluidized bed processing, energy will be saved through reduced heat losses per production unit and reduced losses of process material that already consumed energy to its point of rejection from the production process. In addition, since emissions to the atmosphere are reduced, the cost of the emission control to meet local requirements will be reduced. Together, these improvements will reduce the overall production cost for the process.

By maintaining a constant fuel supply a significant increase in production rate, along with fuel savings, are expected through the implementation of fluidized bed processing. On the other hand, by maintaining a constant production rate the anticipated national energy savings through successful commercialization of this technology is 18.6 trillion BTU/year in reduced consumption of natural gas.

(8) <u>Immersion Tube Melters for Non-Ferrous Metals</u>

Advanced, high-efficiency, indirect-fired immersion tube melters can provide significant improvement in the heat flux to melt and the melt rate, and decrease the melter size, when compared with the conventional reverberatory type melt furnaces. Since the exhaust gases do not get contaminated by the process, and since the furnace atmosphere can be kept inert, these melters will have minimal environmental problems and will eliminate the metal oxidation losses as well as the contaminants in the melt.

Radiant tube burners that can be used on the immersion tube melters, and are commercially available today, are fabricated from high temperature metals and can be used up to 2000°F, thus being limited to process temperatures of about 1900°F.

The thermal efficiencies of indirect fired furnaces are generally lower than those of direct fired furnaces, however the efficiency of the indirect-fired furnaces can be improved substantially and economically, by using regenerative radiant tube burners or waste heat recovery.

To counter the inroads made by electric furnaces, (electric arc, induction and vacuum furnaces), in process heating and melting applications, and to promote the use of natural gas, the Gas Research Institute (GRI)[13] funded the development of advanced high-efficiency regenerative indirect-fired burner systems that operate at temperatures in excess of 2000°F where electric technologies are widely used. These indirect-fired regenerate burner systems are available in sizes from 1-30 MMBTU/hr and are fabricated from advanced ceramics materials, such as silicon carbide, which extend their capabilities to applications up to 2700°F. These burners can compare with electric alternatives and can operate with combustion air preheat temperatures of up to 2400°F.

In the case of the non-ferrous metals with lower melting temperatures, as aluminum, lead, zinc, etc., immersion tube melters may find more application because these types of furnaces offer fewer environmental problems, provided that tube materials are found that could give adequate tube life in corrosive furnace environments. This technology could also be applied to Aluminum Sheet, Plate, Foil (SIC 3353) and to Aluminum Foundries (SIC 3361).

In the case of the aluminum industry, the growing aluminum castings market[14] and the fact that primary aluminum production is highly energy intensive (ignoring electricity generating efficiency, the primary aluminum production requires about 1600 kwh or 54.6 MMBTU/ton[13] as compared with approximately 3 MMBTU/ton for scrap refining in a modern reverbertory furnace) makes secondary aluminum production from scrap look increasingly favorable. GRI used the radiant tube burner technology to develop a high-efficiency, indirect-fired immersion tube melter and funded B&W Reynold's experimental program, but the project was terminated after 2 years because of material and dross removal problems. A British company is trying to market aluminum immersion tube melters from Canada.

Beside smelting, primary lead is refined in a series of kettles where immersion tube heaters could be used with associated energy savings as well as reduction in emission problems and hence costs.

The long life of immersion tube material is essential to commercialization of this technology for corrosive applications such as aluminum; and applications/materials compatibility could be explored for use in other nonferrous metal industries, - eg. steel immersion tubes in secondary lead and lead pots. Tokyo Gas Company had developed ceramic radiant tubes made of Si-impregnated SiC (Si-SiC) material which can sustain temperatures up to 2500°F and feature high chemical stability, oxidation suppressed at surface, and no creep deformation.

The immersion tube melter technology offers a potentially significant production rate increase through increased heat flux to melt and therefore melt rate. The potential energy savings of this technology, estimated while holding the production rate constant, is 17 trillion BTU per year[2] and 2.7 trillion BTU per year[2] in the non-ferrous and secondary aluminum industries respectively.

(9) <u>Cleanup Hot Furnace and Combustor Exhaust Gases</u>

Sensible heat associated with the high temperature of gaseous combustion products is lost when these gases are dumped to the atmosphere, or is not fully recovered when these gases have to be cooled before entering the conventional dust collecting systems. Also, energy recovery techniques are often not cost effective or thermally efficient when the gas stream has a high particulate level. It therefore follows that the use of high temperature particulate system will allow a cost effective utilization of the full potential of heat recovery in an industrial process, and thereby optimize fuel economy of the process based on heat recovery. For instance[4] flue gases from most electric arc melting furnaces and, to a lessor degree, reheating furnaces contain particulates which prevent heat recovery from these high temperature heat sources. Cooling is generally required before hot gases can be passed through the dust collection system.

Particulates in gases at temperature less than 700°F can be removed by using conventional bag houses, electrostatic precipitators, or other type of filter media; however, for higher temperatures, hot gases have to be cooled by admixing with cool air, water injection, or by indirect cooling. Evidently, the development of a high temperature (1400-2000°F) particulate removal system that has a relatively low pressure drop (3 to 7 inches water) could be very beneficial economically[4]; primarily when used in the electric arc melting furnaces used in steel industry, and secondarily when used in the aluminum melting, glass melting and blast furnaces, fluidized bed heating devices, waste incineration equipment, pulp and paper industries and steam generation.

Natural gas by itself does not guarantee a clean discharge gas stream because of the possible entrapment of process material during the application of heat in the furnace. Gas streams with high particulate content are difficult to handle in convective heat exchangers because particles fallout is expensive to remove. Development and use of hot gas cleaning system will permit better utilization of the conventional heat recovery systems such as recuperators, cogeneration and work preheating systems. Improvement in thermal efficiency of 10 to 30 percent, and in throughput of 10%,[4] of the base process is anticipated. In the case of electric arc steel melting furnaces a heat recovery of 0.38 MMBtu/ton from the flue gases[4] (based on a 2000 to 700°F temperature drop) is potentially achievable.

In addition, such gas cleanup technology will allow fuel switching. For instance, if a high temperature ash separator technology could be developed to separate ash directly from the hot combustor exhaust (order of 2800°F), it would be tremendously useful for reducing deposits in industrial boilers; reducing wear in industrial gas turbines; and, within reason, allowing use of high ash fuels. In the case of waste-to-energy conversion systems, an ash separator, designed for high temperature operation (order of 2200°F), could be introduced between an external combustor/combustion chamber and a boiler or a gas turbine, for reducing the problems of deposit and wear inherent with these systems and thus improving their ability to use high-ash wastes and waste-derived fuels.

In 1985, approximately 30 million tons of steel[4] was produced in the electric arc melting furnaces which accounted for one-third[4] of the total steel produced in USA. Based on 0.38 MMBTU/ton of heat recovery the potential of energy savings through successful commercialization of this technology, in the electric arc steel melting furnaces alone, is 12.9 trillion BTU per year in the use of electricity. By permitting the use of conventional heat recovery and airhandling equipment which require clean exhaust, the technology will also help keep significantly lower capital, operating and maintenance costs.

(10) <u>Low Temperature Combustion</u>

Energy is saved when excess air for combustion is reduced. It will be desirable to advance techniques for direct heating applications wherein the combustion flame temperature, and therefore the excess air level, is significantly reduced. Typical applications for such techniques is paper and food drying. Avoidance of high temperature will improve product quality in many drying and low temperature applications mainly in the paper & pulp and food industries.

About 7%[4] of the energy used by industrial sector is taken up by the heating applications in the range of 600 to 1000°F. Most of the low temperature direct heating applications use either heated air, or dilution air mixed

with the combustion gases, controlled to operate within the required temperature limits. In such cases, the methods of combustion which would eliminate the need of excess dilution air to supply low temperature flue gases (e.g. gas recirculation) can offer significant fuel savings. These methods will also reduce the NO_x emissions to a large extent; not only because of the lower achievable flue gas temperatures, but also because of the possible reductions in the large quantities of hot air traditionally used in various drying and other low temperature processes.

By offering the ability to apply the heat uniformly, the technology will also help to improve the product quality; thus resulting in reduced product rejections and, in turn, in saving the energy that would have otherwise been wasted in producing the rejected items. It is therefore conceivable that through improvements in the product quality and reductions in the energy costs the technology could contribute significant reductions in the product costs.

Anticipated national energy savings through successful commercialization of this technology is 11 trillion BTU per year in reduced consumption of natural gas.

(11) Oxygen Enrichment of Combustion Air: Waste Heat Driven

Significant energy savings can be achieved if energy efficient technologies can be developed for producing oxygen enriched air through the use of energy contained in the gaseous exhaust stream from an industrial furnace. The application for this oxygen enriched air would be to enhance combustion of a new charge of fuel in the same furnace and through this integrated process achieve an overall reduction in the required fuel.

The capital cost of an oxygen enriched combustion system (35-100% oxygen) is estimated to be roughly one-third to one-quarter[17] of that of an equivalent recuperator-hot air burner system for retrofit applications. Fuel savings with oxygen enriched combustion systems are often much greater than those with the recuperator systems. Since the operating cost savings of oxygen enriched combustion systems are strongly dependant on the oxygen-to-fuel ratio, both the current and the future costs of fuel and oxygen need to be considered[17] for economic evaluation of these systems. Consequently; means to produce oxygen with the minimum energy cost (minimum energy consumption) will enhance the ability of the oxygen enriched combustion system to continue to remain cost effective even as the fuel prices go up.

Energy to produce oxygen enriched air could be reduced appreciably[4] through the development of an exhaust-heat driven oxygen production process which uses different materials for the absorption-desorption cycle, or thermal swing, provided the energy consumed by the process is competitive with the other available alternatives such as electrically-driven, pressure swing absorption etc. This reduction will be additional[4] to the energy savings that the oxygen enriched air will provide through the improvement of heat transfer in various high temperature industrial furnaces that are driven primarily by radiant heat. Furthermore, with the oxygen generation done on-site, the costs of transportation, storage and handling, associated with the purchased oxygen, will be eliminated.

Potential energy savings through successful commercialization of this technology, for the heat transfer improvement in the container glass industry alone, is 6.5 trillion BTU per year in reduced consumption of natural gas.

A.2 The following R&D opportunities were based on the analyses of information obtained from an extensive literature search, other programs, and contacts with researchers in industry:

(12) Adjustable Cofired Combustors/Combustion Chambers for Burning Wastes and Waste-Derived Fuels

Cost of landfill disposal is rising steeply as close-in sites are being exhausted, and costs of $8 to $10 per ton are not uncommon[18] in metropolitan and suburban areas. The mandated provision of satisfactory emission controls makes the upgrading of conventional incinerators a very uneconomic alternative. In this context, it is safe to predict that sophisticated utilization of industrial wastes will continue to gain support, and will become competitive with the landfill disposal as credits for energy and reclaimed materials continue to mount.

The combustion technologies germane to the energy production using waste as fuel fall into three types: (1) combustion of the gases and dried slurries from anaerobic digestors; (2) direct combustion of waste; and (3) combustion of the oil, gases and/or chars derived from pyrolysis of waste. The technology development under this R&D area should focus on the direct combustion of industrial plant wastes (ie industrial waste paper, petroleum, plastic, rubber, corrugated card board) and textile and allied products (clothing strips, food processing wastes -- particularly corn cobs, peanut hulls and olive pitts, and, to some degree, combusted wastes), and the combustion of solid fuels and oils derived from pyrolytic convertors and anaerobic digestors. The municipal solid wastes (MSW) are usually incinerated or converted to refuse-derived fuels (RDF)[18] by air classification of shredded MSW which are then employed as supplementary fuels in coal burning utility boilers. A caveat is[18] that the alkaline components in coal ash provide some protection against the acidic constituents normally present in the combustion products of

MSW. The utility applications of direct combustion of MSW are supported by the DOE's Clean Coal Technology Program and the DOE (Conservation) - SERI MSW Program. Like wise, technologies for direct- combustion of agricultural and wood-related processes wastes are addressed by other DOE programs.

Anaerobic digestors have been found to be[18] technically feasible but economically untenable at present. This is because only 28% of the organic components is converted into methane; the remainder goes to CO_2 or is not converted and must be disposed off with the digestion liquor. This liquor is however dried and converted to a solid fuel which can be cofired with coal or gas for generation energy.

At present there are four pyrolysis processes[18] that have been demonstrated on a significant scale. These are the Monsanto Langard system, the Occidental Petroleum flash pyrolysis process, the air-fed Torrax process of Carborundum, and the oxygen-fed Purox system of Union Carbide.

The Monstanto process uses a rotating kiln and air as the oxidant and is designed to operate at a non-slagging temperature. It produces char which must be landfilled and a low-heating-value fuel gas of about 100 BTU/SCF which is then burned in an after burner for the recovery of heat in a waste heat boiler. A 1000 tpd demonstration plant is being operated experimentally by the city of Baltimore. It has encountered numerous operating problems, stemming partly from the partial fusing of inorganic components which deposit on the refractory walls and constrict the passage. Monstanto has withdrawn from the project, and the City is trying to modify the process to make it workable.

The Occidental Research process is a low-temperature flash pyrolysis process which produces predominantly a combustible liquid. A liquid fuel is desirable because it is more easily stored and transported. However, this combustible liquid is viscous, highly oxygenated tar acid rather than hydrocarbon oil; it is corrosive and tends to polymerize when stored hot. It is proposed to feed it to utility boilers in an admixture with fuel oil in which it is immiscible. A 200 tpd demonstration plant has been constructed with EPA support in the San Diego county.

The Torrax pyrolysis process is conducted in a shaft furnace which accepts unshredded refuse. It employs preheated air instead of oxygen to attain a slagging hearth temperature. It produces a 100 BTU fuel gas rich in nitrogen. There are no Torrax plants being built in the United States, but one is under construction in Europe.

The Purox system developed by Union Carbide is a slagging pyrolysis process which employs oxygen for the partial combustion of residual char at a hearth temperature of 3000°F. The nitrogen-free pyrolysis gas has only 6% the volume of incinerator stack gases of equivalent energy release, and it is thus economically feasible to scrub the product gas free of acidic contaminants. The Purox gas has a heating value of 350 BTU/ SCF, and it burns with the same flame temperature as natural gas. This makes it a versatile, transmittable fuel which can be employed as a sole fuel in standard utility boilers, and can therefore command energy credits equivalent to fuel oil or natural gas.

Three types of burners are presently used for burning wastes i.e., the conventional dutch oven, the suspension burner, and the fluidized bed. Only the fluidized bed appears to have the combustion zone residence times[19] sufficient to burn waste which varies greatly in particle size. It is very sensitive, however, to variations in[19] flow rates, reaction temperatures and chemical compositions, thus requiring better systems for combustion control. The dutch oven is presently the most used burner. The efficiency of waste combustion, in terms of the ratio of the total heat that is released, to the total heating value contained, is perhaps the worst and least controllable oven the ranges of burner output levels. The suspension burner has good heat release rates due to the effective fuel/air mixing and relatively short combustion zone residence times[19]; but this places strict limitations on the fuel size variations.

From examination of literature it appears that sufficient burner technology exists in industry for burning low-BTU waste gases and the low-BTU gases from coal conversion processes. Maxon corporation is marketing a series

of low-BTU gas burners[20] which have been shown to effectively burn producer gases (coal gases) with calorific values as low as 150 BTU/ft^3, gases from corn cobs, wood waste and carbon black furnaces with calorific values as low as 70 BTU/ft^3, and waste hydrogen from refinery operations or chlorine production, etc.

While utility applications of waste burning technologies are supported by the DOE's Clean Coal Technology Program, and the knowledge base to commercialize MSW combustion technologies is being developed by the OIT-MSW program, the waste cofiring technology applications to industrial processes and the site specific waste-to-energy conversion plants need to be addressed.

OIT can play a significant role in waste-to-energy conversion, by undertaking research that would lead to the development of adjustable, high intensity combustors/combusting chambers suitable for: (1) direct combustion or cofiring of plant wastes and the textile and allied products wastes collected and refined onsite; and (2) combustions of waste-derived liquid and solid fuels obtained from central waste-to-fuel preparation plants. Asphalt may also be included as a fuel. These combustors may be cofired with natural gas and will be installed external to the driven equipment (ie, boiler, dryer, or turbine) such that the combustion is completed within the combustion chamber. Cyclonic/high swirl and oxygen enriched air designs may be used.

IGT is currently developing a vertically mounted cyclonic combustors for burning certain liquid and gaseous wastes with natural gas as the supplemental fuel. The combustor is designed for application to waste waters containing 40 to 50% organics and inorganics, low BTU gases with heat contents between 55 to 65 BTU/SCF, and CC14.

An important outcome of decentralizing the waste fuel preparation, allowing the direct combustion of wastes at individual plant sites, will be that a better control over the waste fuel quality would be exercised. This is because an on-site system will allow more discriminating waste collection and preparation systems which could be devised to correspond more closely to the designs of the waste burning combustors or combustion chambers used.

Since particle size and chemical composition of the waste are open to variations, an adjustability of the burner, within the reasonable limits of input variations, is an essential design factor. By adjustability it is implied that the combustor's residence time is adjustable in accordance with the prescribed limits imposed by the normal variations in the fuel characteristics. In addition, the combustor's thermal output should be controllable depending on the equipment to be driven. The local combustion efficiencies in the combustor should be optimal while maintaining a stable flame. Cofiring with the natural gas should be incorporated in the combustor's design so that the combustor can offer an effective and efficient response to the normal load variations, and that an appropriate flame stability may be maintained at all times. From the environmental standpoint, particulate emissions and corrosion appear to be the major concerns. To reduce the particulate loading, a high-temperature ash separator or other means of separation will be required between the combustor and the driven equipment.

It has been estimated that by burning plant trash alone a total energy savings of about 1.4 quads per year[19] could be achieved in the United States. This estimate includes the direct burning of plant wastes and the burning of fuels derived by processing plant wastes through anaerobic digestors and pyrolytic convertors. The energy savings is expressed in the form of reduction in the national use of primary fuels, and is expected to come about by direct burning of the trash in central energy conversion plants and by burning fuels derived from the centrally collected trash in various industrial plants across the country. Likewise the textile and allied products wastes also offer significantly large potential for energy savings. It is conceivable that a significant amount of direct burning of wastes can be shifted to the on-site burning at source plants. With the introduction of proposed direct burning combustors, the source plants could be encouraged to use these combustors in conjunction with the commercially available shredders, dryers and separators and convert waste to energy on-site. The combination of direct combustion of wood related waste and plant trash could provide 2.35 quads of energy[19] .

Given that the proposed combustors will not be designed for gaseous products from anaerobic digesters and pyrolytic convertors, and that their use will be restricted to individual plant sites, it can be concluded that these

combustors could harness only a small proportion of the total energy savings potential. Assuming a 10% claim, the proposed combustors could contribute about 235 trillion BTU per year of energy savings by burning plant trash and wood related waste.

(13) Excess Oxygen Control for Multi-burner Boilers and Furnaces

In Industrial furnaces (specially the non- recuperated furnaces) and boilers, unusual excursions in excess air can cause substantial increases in fuel consumption or formation of pollutants due to incomplete combustion. Propensity of such excursions is greater in the centrally-controlled multi-burner systems where maldistribution of fuel or air, and any unequal wear in industrial burners, could go unnoticed. For instance, in non-recuperated furnaces running at "off optimum" air/fuel (A/F) ratio, the fuel consumption in a burner could double[22] either if the burner ran with excess air levels of 30% or alternatively operated in a rich zone with air deficiencies of about 20%. It is therefore very desirable to accomplish individual burner control in the multi-burner combustion systems which would allow each burner to operate close to the optimum A/F ratio (set to accommodate atmospheric and fuel variations in addition to usual load variations).

Currently used stack gas monitoring techniques can not provide individual burner control when applied to a multi-burner boiler or a furnace. Instead, the burners are centrally controlled by monitoring O_2, CO_2 and opacity at stack. These techniques do not allow for flue gas stratification, air infiltration, infiltered air stratification and air/fuel (A/F) excursions in individual burners, which could easily occur due to maldistributon of the combustion air or the fuel. As a consequence, these techniques, if applied to multi-burner combustion systems, could suffer from the onset of the localized incomplete combustions which, in turn, would manifest into significant formation of gaseous pollutants.

Theoretically, all the problems associated with the stack gas monitoring techniques can be solved by using the non-intrusive flame sensing techniques in which the presently available IR and UV detectors could be employed to develop output signals that are proportional to the rate of formation of hydroxyl radical (OH) and carbon dioxide at each burner individually. However in practice, these spectral techniques, when applied to multi-burner systems, experience the difficulty in calibrating caused by the interference by the background radiation, and also the difficulty in establishing an easily workable control algorithm. As a result, the spectral techniques, when applied to the multi-burner systems, could be useful only for the burner diagnostics e.g., to pinpoint poor oil atomization, burner wear, etc.

Conclusively, a new multi-burners A/F control approach, that can overcome the limitations of the stack gas monitoring and the spectral flame sensing techniques, could offer very high return on investment to the high-temperature furnace or boiler operators, as well as provide a significant potential for large energy savings, both in the industrial and the utility sectors. For example; a system can be developed in which a sample from each burner exhaust is withdrawn, cooled and fed to an individual O_2 sensor-controller. The controller compares O_2 in the exhaust gas to a preset set point, and produces a corrective control (feedback) signal acting to trim the "primary" A/F ratio over a restrictive range. While this controller plays only a secondary role, the primary role is played by an A/F ratio controller which meters fuel and air fairly accurately without recourse to the O_2 feedback signal. In boilers, the A/F ratio controller varies the ratio according to loading only. This is because at loads below about 60% of rated capacity the A/F mixing starts to become inefficient[22] and the excess air level has to be increased. The O_2 controller, on the other hand, will correct the A/F ratio to compensate for the variations in other parameters such as fuel heating value, fuel viscosity, air temperature, air humidity, etc. The O_2 controller will accomplish this by continuously monitoring the data on combustion products and transmitting these data to the A/F ratio controller so that the latter can refine the air-flow setting accordingly.

Overall energy use by the utility boilers (where multi-burner systems are generally used) and the industrial boilers amount to about 25 quads per year. Based on an estimate of only 1% energy savings, as applied to natural gas and fuel oil and coal fired boilers, the energy savings potential of this technology is about 190 trillion BTU per year.

(14) High Luminosity - High Temperature Natural Gas Burners

Radiation is considered to be the primary mode of heat transfer in an industrial heating equipment, provided[23] the load has a fairly high emissivity (or more accurately, absorptivity). This is generally the case in boilers and industrial furnaces, particularly when the furnace is for high temperature processing where the load absorptivity would generally rise[23] with the temperature. Even at low processing temperatures, a large temperature difference between furnace and load can make up for the reduced load absorptivity. By maintaining a sufficiently high furnace temperature (and corresponding flame temperature) a high radiation heat transfer to load[23] can be maintained. By increasing the temperature difference between flame and load and the flame emissivity, the heat transfer to furnace fabric and load can be increased leading to substantial improvements in the equipments' thermal efficiency.

Effect of increased flame emissivity on the thermal efficiency however is somewhat limited to a certain value beyond which the thermal efficiency ceases to improve appreciably. There appear to be two main reasons[23]. Firstly, there seems to be a close trade off between the increase in heat transferred from flame, and the resultant reduction in heat transferred from furnace walls due to greater fraction being intercepted by the flame. Secondly, the flame temperature is lowered, seemingly due to higher thermal load to flame induced by high emissivity. According to information on a high luminosity gas burner which Tokyo Gas Company developed[24] for applications to non-recuperated industrial furnaces, insufficient increments in thermal efficiency were observed at flame emissivities greater than 0.5 and it was further concluded that for further increase in thermal efficiency air preheating would take the precedence.

It is reasonable to assume that the radiant heat transfer in a large furnaces is essentially temperature-governed, whereas the same in a small furnaces is emissivity-governed. It can therefore be concluded that the burners with the flexibility of changing the flame temperature and/or the flame emissivity could substantially increase the heat transfer to furnace load, regardless of the furnace size or whether the furnace is recuperated or not.

Preheating or oxygen enrichment of combustion air could be used as the methods to increase the flame temperature[23] whereas cracking of natural gas into carbon particles (greater than 1000°C required for cracking)[24] could be used to increase the flame luminosity (emissivity). Highly luminous flame is achieved due to the generation and burning of carbon particles, in addition to the emissions from CO_2 and H_2O.

High radiation burners could be designed for retrofitting recuperated industrial furnaces by including the air preheat and natural gas cracking features. The burner design should be such that the combustion is completed within the burners with low emissions (e.g., a staged combustion design). Turn down could be accomplished not only by metering the fuel and air supply but also by reducing the amount of natural gas cracking (controlling the flame emissivity). In the case of industrial boilers and non-recuperated furnaces, these burners could be designed to operate with oxygen-enriched combustion air and natural gas cracking. Where industrial furnaces are not recuperated, and economic or other reasons do not allow the use of the recuperators or oxygen enrichment equipment, natural gas cracking burners could be designed to operate with the outside air for combustion.

When used as retrofits the gas cracking burners will improve thermal efficiency of the existing recuperated or non-recuperated industrial furnaces and boilers. When used to develop new industrial heating equipment, these burners will allow reduction in equipment sizes corresponding to the same thermal capacities and thus help to reduce the costs and improve the competitiveness of new equipment outside of the United States.

If a constant fuel supply is maintained a significant increase in production rate is possible through the implementation of high luminosity-high temperature gas burners. By holding production rate constant and assuming a 5% incremental fuel savings attributed to luminosity improvement alone, this technology can potentially save 18.3 trillion BTU per year for the major energy consumers in the manufacturing sector.

(15) Variable Flame Length and Shape/Advanced Control System

Typical cement kilns currently in use utilize a coal burner to provide the necessary heat for clinker production. These burners usually are designed to produce a flame of fixed length and shape, and, thus, a fixed temperature. Over time, feed material composition can vary, and the feed rate itself may be changed to account for fluctuations elsewhere in the process. The combined effect of the constant flame temperature, varying feed rate and composition, and changing thermal loss rates can result in increased energy consumption and inconsistent product quality. Also, overheating of the load will result in more maintenance and downtime as well as decreased thermal efficiency. Therefore, it would be beneficial to develop a burner which could operate efficiently at varying loads[4]. This would require that the flame length and shape could be set according to the process parameters at a particular time. A control system would also be required to characterize the operating condition (temperature, material flow rate, etc.) and adjust the flame setting accordingly.

The resulting optimal firing rates and combustion process improvements would give an estimated 7.5% energy savings. In the case of producing cement using the wet process (36% of the total), energy consumption is 6 MMBTU/ton, or 116.42 trillion BTU per year. For the dry process, 4.3 MMBTU/ton is required, or 148.33 trillion BTU per year. The development of burners with variable flame length and shape, together with the necessary sensing and control systems, would save an estimated 19.85 trillion BTU annually in cement calcining.

(16) Melt Temperature Measurement and Prediction System

Methods currently used to melt glass result in large variations in temperature throughout the melt volume. Particularly in large melters, the relatively low thermal conductivity of glass results in high temperatures near the heat source and lower temperatures elsewhere. Energy efficiency could be improved if heat could be directed toward the cooler areas of the melt. Such a system would first require hardware and software which could measure temperatures at representative sites within the melt and predict the temperature at remaining locations[4].

Economic benefits of this technology increase with furnace size, but an average savings of 15% is estimated for a representative plant. Additional benefits of a temperature measurement and prediction system are improved glass quality, increased throughput, lower pollution, a lower degree of technical competence required of personnel, and reduced manpower requirements.

An increase in productivity is expected through the implementation of this technology. This increase in productivity, given a constant fuel supply, may also bring fuel savings due to reduced energy use per unit product. It is estimated that by maintaining a constant production rate the glass industry alone could realize a potential savings of 13.02 trillion BTU per year.

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APPENDIX B

APPENDIX B - ENERGY SAVINGS OF THE TOP INDUSTRIAL ENERGY CONSUMERS

Potential energy savings were calculated for five of the top energy-consuming industries. The industries were selected based on energy consumption as reported in the Manufacturers Energy Consumption Survey (MECS) 1991. Two other industry categories that were examined for potential energy savings are utility boilers and waste-derived fuel technologies

The selected industries were researched to identify the energy-intensive processes and equipment types most prominently used. Once identified, a thorough literature search was conducted for each process and equipment type. The literature search was directed to find the following: annual production by industry, current specific energy consumption by equipment type, process temperatures, and, where applicable, equipment type penetrations and fuel use. In many cases there were numerous sources identified for each of the above values. Selection of reported numbers varied based on relative age of the reports and reliability of the source. In some cases average values were used, particularly when reporting sources were felt to be competent.

Table B-1 summarizes of the estimated technical energy savings resulting from the 16 energy conservation opportunities. The "industry total" savings is estimated to be 713 trillion BTU/year. The "other industry total" (utility boilers, waste-derived fuel) is estimated to be 2,540 trillion BTU/year. Tables B-2 through B-4 show the detailed data on energy savings and include all references.

The 16 identified technologies were researched to estimate potential energy savings. Values of reduced specific energy consumption (SEC) were researched, referenced, and then compared with calculated theoretical minimum SEC values. In cases where the reduced SEC reported was lower than the calculated minimum SEC, an estimated value was used. The estimated values were calculated using the reduced SEC values given by reference 4 shown in Table B-2, and theoretical minimum values given by reference 1, also shown in Table B-2.

Energy savings resulting from the 16 technologies are presented in both a "technical" and "market" total. The technical total assumes a maximum penetration of 100% in the specific equipment type. The market total assumes a 40% penetration as an estimate of market acceptance. In some cases the market penetration is less than 40% due to varied penetrations of equipment or fuel types.

Equipment penetration values were applied to specific pieces of equipment where applicable. For example, approximately 36% of cement manufacturers use the wet process (and therefore a wet kiln), while approximately 64% use the dry process. Associated with these two different process types are two different energy consumption values.

A second penetration value worth noting was applied to furnaces in the container glass and blast furnace/steel mill industries. After consultation with industry personnel, a 50% penetration rate for the appropriate savings technologies was applied to the market savings values. This penetration is included to account for furnaces which are currently recuperated and therefore less likely to add additional energy savings technologies. Other penetration rates were applied in the calculation of the reduced SEC to account for savings technologies specific to certain fuel types (i.e., a natural gas savings technology is not applicable to an electric end use).

It should be noted that while neither the total technical nor the total market energy savings address interactive effects of the technologies, the technologies applied are not directly competitive. Because the 16 technologies are for the most part new (i.e., not currently used), calculating the interactive effects would be rather speculative.

The theoretical energy savings is calculated and totaled. This total represents an estimated maximum savings potential for the industries and equipment types selected. It is interesting to note that the overall technical energy savings represents approximately 55% of the overall theoretical energy savings for the equipment examined.

TABLE B-1.

SIC INDUSTRY	NEW TECHNOLOGY	TECHNICAL ENERGY SAVINGS (trillion Btu/year)
Integrated Paper (2621)	4,5,7,10	56.2
Paperboard (2631)	4,5,7,10	47.2
Chemical-Alumina (2819-1)	4,7	5.3
Chemical-Ethylene	2	42.1
Chemical-Methanol	2,5,7	4.1
Chemical-Ammonia	2,5,7	26.4
Petroleum Refining (2911)	2,7	86.9
Container Glass (3221)	1,3,4,11,14,16	44.5
Portland Cement (3241)	4,15	152.1
Blast Furnace/Steel Mills (3312)	1,3,6,7,9,14	242.8
Primary Aluminum	1,3,14	1.8
Secondary Aluminum	1,3,8,14	3.9
INDUSTRY TOTAL:		713
Utility Boilers	13	190.3
Waste Derived Fuel	12	2,350
OTHER INDUSTRY TOTAL:		2,540.3

To estimate the amount of energy savings which could be achieved by applying new technologies to utility boilers, a total utility fuel use was first obtained from literature[35]. Fuel savings percentages were then estimated for both natural gas and fuel oil boilers, resulting in the total energy savings for each technology as shown in Table B-3.

Annual Prod. (Mill. Tons)	Ref1	Process	Temp (F)	Equipment Used	Equip Pene-tration	Current SEC (MMBtu /Ton)	Ref2	Current Consumption (Btu*E12)	Technology Applicable	Change in SEC (MMBtu /Ton)	New SEC (MMBtu /Ton)	Percent SEC Reduc -tion	Ref3	Penetration		Energy Savings (Btu*E12)		Theo. SEC (MMBtu /Ton)	Ref4	Theo. Energy Savings (Btu*E12)	Theo. Energy Use (Btu*E12)
														Tech.	Mkt.	Tech.	Mkt.				
INTEGRATED PAPER: SIC 26 (2621)																					
34.04	29	Calcination	2192 to 2374 (34)	Rotary Kiln	100%	1.85	Ave.	62.97	ECO #4 (REF #18) Entrained Flow Calcination	0.33	1.53	17.6%	Est.	100%	40%	11.06	4.43	1.2	1	22.13	40.85
									ECO #7 (REF #4) Fluidized Bed	0.06	1.79	3.20%	4	100%	40%	2.02	0.81	1.2	1		
34.04	29	Evaporation		Evaporator	100%	3.93	Ave.	133.78	ECO #5 (REF #18) Submerged Comb. Inject	1.10	2.83	28.0%	18	100%	40%	37.46	14.98	1.07	1	97.35	36.42
34.04	29	Drying		Dryer	100%	3.3	4	112.33	ECO #10 (REF #37) Low Temp. Combustion	0.17	3.14	5.00%	Est.	100%	40%	5.62	2.25	1.56	1	59.23	53.10
					Subtotal (trillion Btu):			309.08								56.15	22.46			178.71	130.37
PAPERBOARD: SIC 26 (2631)																					
33.03	29	Calcination	2192 to 2374 (34)	Rotary Kiln	100%	1.68	Ave.	55.49	ECO #4 (REF #18) Entrained Flow Calcination	0.20	1.48	11.9%	18	100%	40%	6.61	2.64	1.28	1	13.21	42.28
33.03	29				100%	1.68			ECO #7 (REF #4) Fluidized Bed	0.04	1.64	2.40%	18	100%	40%	1.33	0.53	1.28	1		
33.03	29	Evaporation		Evaporator	100%	4.1	Ave.	135.42	ECO #5 (REF #18) Submerged Comb. Inject	1.03	3.08	25.0%	1	100%	40%	33.86	13.54	1.13	1	98.10	37.32
33.03	29	Drying		Dryer	100%	3.3	4	109.00	ECO #10 (REF #37) Low Temp. Combustion	0.17	3.14	5.00%	Est.	100%	40%	5.45	2.18	1.56	1	57.47	51.53
					Subtotal (trillion Btu):			299.91								47.24	18.90			168.78	131.13
CHEMICAL ALUMINA: SIC 28 (2819.1)																					
4.78	Ave.	Calcination	2192 to 2374 (34)	Rotary Kiln	100%	4.85	33	23.18	ECO #4 (REF #18) Entrained Flow Calcination	1.31	3.54	27.0%	18	60%	24%	3.76	1.50	1.31	1	16.92	6.26
4.78	Ave.				100%	4.85	33		ECO #7 (REF #4) Fluidized Bed	0.33	4.52	6.8%	4	100%	40%	1.58	0.63	1.31	1		
					Subtotal (trillion Btu):			23.18								5.33	2.13			16.92	6.26
CHEMICAL ETHYLENE: SIC 28 (2869.1)																					
15.3	33	Pyrolosis	1500 to 1800 (3)	Furnace	100%	19.4	33	296.82	ECO #2 (REF #18) Re-Radiated Plate Enhce	2.75	16.65	14.2%	Est.	100%	40%	42.08	16.83	13.91	1	84.00	212.82
					Subtotal (trillion Btu):			296.82								42.075	16.83			84.00	212.82
CHEMICAL METHANOL: SIC 28 (2869.2)																					
3.95	33	Reformer	1400 (3)	Reactor	100%	8.2	Ave.	32.39	ECO #2 (REF #18) Re-Radiated Plate Enhce	******											
3.95	33				100%	8.2	Ave.		ECO #5 (REF #18) Submerged Comb. Inject	0.78 ******	7.42	9.5%	Est.	100%	40%	3.06	1.22	6.65	1	6.12	26.27
3.95	33				100%	8.2	Ave.		ECO #7 (REF #4) Fluidized Bed	0.27	7.93	3.3%	4	100%	40%	1.07	0.43	6.65	1		
					Subtotal (trillion Btu):			32.39								4.13	1.65			6.12	26.27

Ave. = Average Calculated Value
Est. = Estimated Value
Field descriptions are provided on the following pages.

Annual Prod. (Mill. Tons)	Ref1	Process	Temp (F)	Equipment Used	Equip Pene-tration	Current SEC (MMBtu /Ton)	Ref2	Current Consumption (Btu*E12)	New Technology Applicable	Change in SEC (MMBtu /Ton)	New SEC (MMBtu /Ton)	Percent SEC Reduc -tion	Ref3	Penetration		Energy Savings (Btu*E12)		Theo. SEC (MMBtu /Ton)	Ref4	Theo. Energy Savings (Btu*E12)	Theo. Energy Use (Btu*E12)
														Tech.	Mkt.	Tech.	Mkt.				
CHEMICAL AMMONIA: SIC 28 (2873)																					
16	33	Reformer	1400 to 1500	Reactor	100%	10.1	Ave.	161.60	ECO #2 (REF #18) Re-Radiated Plate Enhce	******											
16	33		(3)		100%	10.1	Ave.		ECO #5 (REF #18) Submerged Comb. Inject	1.36	8.74	13.5%	Est.	100%	40%	21.76	8.70	7.37	1	43.68	117.92
										******											
16	33				100%	10.1	Ave.		ECO #7 (REF #4) Fluidized Bed	0.29	9.81	2.9%	4	100%	40%	4.69	1.88	7.37	1		
					Subtotal (trillion Btu):			161.60								26.45	10.58			43.68	117.92
PETROLEUM REFINING: SIC 29 (2911)																					
790	1	Reformer	1400 to 1500	Reactor	100%	0.44	18	347.60	ECO #2 (REF #18) Re-Radiated Plate Enhce	0.04	0.40	9.1%	Est.	100%	40%	31.60	12.64	0.36	1	66.39	281.21
790	1		(3)		100%	0.44	18		ECO #7 (REF #4) Fluidized Bed	0.01	0.43	2.3%	4	100%	40%	7.90	3.16	0.35596	18		
790	1	Heater	--	Heater	100%	0.79	18	624.10	ECO #2 (REF #18) Re-Radiated Plate Enhce	0.06	0.73	7.6%	Est.	100%	40%	47.40	18.96	0.6636	1	99.86	524.24
					Subtotal (trillion Btu):			971.70								86.90	34.76			166.25	805.45
CONTAINER GLASS: SIC 32 (3221)																					
14	31	Melt	2600 to 3000	Melt Furnace	100%	6.19	Ave.	86.66	ECO #1 Optimal Ht Trans												
14	31		(3)						ECO #3 (REF #18) Refract. Emissiv. Enhan	******											
14	31				100%	6.19	Ave.			1.05	5.14	17.0%	18	100%	20%	14.73	2.95	2.43	1	52.64	34.02
14	31								ECO #4 (REF #18) Entrained Flow Calcination	******											
14	31				100%	6.19	Ave.		ECO #14 (REF #18,#37) Hi Lum. Hi Temp Gas Burn	0.27	5.92	4.4%	18	100%	20%	3.78	0.76	2.43	1		
14	31					6.19			ECO #16 (REF #4) Temp Predict	0.93	5.26	15.0%	4	100%	20%	13.02	2.60	2.43	1		
14	31				100%	6.19	Ave.		ECO #11 (REF #4,#37) O2 air enrch	0.93	5.26	15.0%	4	100%	20%	13.02	2.60	2.43	1		
					Subtotal (trillion Btu):			86.66								44.55	8.91			52.64	34.02
PORTLAND CEMENT: SIC 32 (3241)																					
53.9	30	Calcination	2192 to 2374	Wet Kiln	36%	6	26	116.42	ECO #4 (REF #18) Entrained Flow Calcination	3.28	2.72	54.7%	18	100%	40%	63.65	25.46	2.52	1	67.53	135.83
53.9			(34)		36%	6	26		ECO #15 (REF #4) Variable Flame Lngth	0.45	5.55	7.5%	4	100%	40%	8.73	3.49	2.52	1		
53.9	30			Dry Kiln	64%	4.3	26	148.33	ECO #4 (REF #18) Entrained Flow Calcination	1.99	2.31	46.3%	18	100%	40%	68.65	27.46	2.52	1	61.40	135.83
53.9	30				64%	4.3	26		ECO #15 (REF #4) Variable Flame Lngth	0.32	3.98	7.5%	4	100%	40%	11.12	4.45	2.52	1		
					Subtotal (trillion Btu):			264.76								152.15	60.86			128.93	271.66

Ave. = Average Calculated Value
Est. = Estimated Value
Field descriptions are provided on the following pages.

Annual Prod. (Mill. Tons)	Ref1	Process	Temp (F)	Equipment Used	Equip Pene-tration	Current SEC (MMBtu /Ton)	Ref2	Current Consumption (Btu*E12)	New Technology Applicable	Change in SEC (MMBtu /Ton)	New SEC (MMBtu /Ton)	Percent SEC Reduc -tion	Ref3	Penetration		Energy Savings (Btu*E12)		Theo. SEC (MMBtu /Ton)	Ref4	Theo. Energy Savings (Btu*E12)	Theo. Energy Use (Btu*E12)
														Tech.	Mkt.	Tech.	Mkt.				
BLAST FURNACES/STEEL MILLS: SIC 33 (3312)																					
98.9	27	Heating	2100 to 2300 (3)	Soaking Pit	100%	1.5	5	148.35	ECO #1 Optimal Ht Trans												
98.9	27				100%	1.5	5		ECO #3 (REF #18) Refract. Emissiv. Enhan	0.32	1.19	21.0%	18	100%	40%	31.15	12.46	0.436	1	105.23	43.12
98.9	27				100%	1.5	5		ECO #6 (REF #4) Scale Free Re-Heat	0.42	1.08	28.0%	4	100%	40%	41.54	16.62	0.436	1		
98.9	27				100%	1.5	5		ECO #14 (REF #37) Hi Lum. Hi Temp Gas Burn	0.04	1.46	2.5%	Est.	100%	40%	3.76	1.50	0.436	1		
98.9	27	Reheating	1700 to 1800 (3)	Reheat Furnace	100%	2.05	Ave.	202.75	ECO #1 Optimal Ht Trans												
98.9	27				100%	2.05	Ave.		ECO #3 (REF #18) Refract. Emissiv. Enhan	0.43	1.62	21.0%	18	100%	20%	42.58	8.52	0.298	1	173.27	29.47
98.9	27				100%	2.05	Ave.		ECO #6 (REF #4) Scale Free Re-Heat	0.57	1.48	28.0%	4	100%	20%	56.77	11.35	0.298	1		
98.9	27				100%	2.05	Ave.		ECO #14 (REF #37) Hi Lum. Hi Temp Gas Burn	0.08	1.97	3.8%	Est.	100%	20%	7.71	1.54	0.298	1		
98.9	27	Annealing	1300 to 1700 (3)	Furnace	100%	1.27	Ave.	125.60	ECO #1 Optimal Ht Trans												
98.9	27				100%	1.27	Ave.		ECO #3 (REF #18) Refract. Emissiv. Enhan	****** 0.07	1.20	5.2%	18	100%	20%	6.53	1.31	0.0064	1	124.97	0.63
98.9	27				100%	1.27	Ave.		ECO #7 (REF #4) Fluidized Bed	******											
98.9	27				100%	1.27	Ave.		ECO #6 (REF #4) Scale Free Re-Heat	0.36	0.91	28.0%	4	100%	20%	35.17	7.03	0.0064	1		
98.9	27				100%	1.27	Ave		ECO #14 (REF #37) Hi Lum. Hi Temp Gas Burn	0.05	1.22	3.8%	Est.	100%	20%	4.75	0.95	0.0064	1		
98.9	27	Melting	[illegible]	[illegible]	[illegible]	[illegible]	Ave	57.00	ECO #9 (REF #4,#37) Clean-Up Hot Furn. Gas	0.38	1.32	22.6%	4	100%	40%	12.87	5.15	0.43	1	42.58	42.53
					Subtotal (trillion Btu):			533.69								242.83	66.43			446.05	115.75
PRIMARY ALUMINUM: SIC 33 (3334)																					
4.75	33	Anode Prod.	1200 (3)	Baking Furnace	100%	2.78	Ave.	13.21	ECO #1 Optimal Ht Trans												
4.75	33				100%	2.78	Ave.		ECO #3 (REF #18) Refract. Emissiv. Enhan	0.35	2.43	12.5%	18	100%	40%	1.65	0.66	1.846	18	4.44	8.77
4.75	33				100%	2.78	Ave.		ECO #14 (REF #37) Hi Lum. Hi Temp Gas Burn	0.03	2.75	1.0%	Est.	100%	40%	0.14	0.05	1.846	18		
					Subtotal (trillion Btu):			13.21								1.79	0.71			4.44	8.77

Ave. = Average Calculated Value
Est. = Estimated Value
Field descriptions are provided on the following pages.

TABLE B-2 ENERGY SAVINGS POTENTIAL: MANUFACTURING SECTOR

Annual Prod. (Mill. Tons)	Ref1	Process	Temp (F)	Equipment Used	Equip Pene-tration	Current SEC (MMBtu /Ton)	Ref2	Current Consumption (Btu*E12)	New Technology Applicable	Change in SEC (MMBtu /Ton)	New SEC (MMBtu /Ton)	Percent SEC Reduc -tion	Ref3	Penetration Tech.	Penetration Mkt.	Energy Savings (Btu*E12) Tech.	Energy Savings (Btu*E12) Mkt.	Theo. SEC (MMBtu /Ton)	Ref4	Theo. Energy Savings (Btu*E12)	Theo. Energy Use (Btu*E12)
SECONDARY ALUMINUM: SIC 33 (3341)																					
1.32	33	Melting	1460 (3)	Melt Furnace	100%	5.94	Ave.	7.84	ECO #1 Optimal Ht Trans												
1.32	33				100%	5.94	Ave.		ECO #3 (REF #18) Refract. Emissiv. Enhan	0.87	5.07	14.7%	18	100%	40%	1.15	0.46	1.0	1	6.52	1.32
1.32	33				100%	5.94	Ave.		ECO #8 (REF #18) Immersion Tube Melt	2.04	3.90	34.3%	18	100%	40%	2.69	1.08	1.0	1		
1.32	33				100%	5.94	Ave.		ECO #14 (REF #37) Hi Lum. Hi Temp Gas Burn	0.06	5.88	1.0%	Est.	100%	40%	0.08	0.03	1.0	1		
					Subtotal (trillion Btu):			7.84								3.92	1.57			6.52	1.32
					Total (All SIC Industries):			2996.92								713.52	245.80			1303.04	1861.74

TABLE B-3 ENERGY SAVINGS POTENTIAL: UTILITIES

Industry	Fuel Used	Fuel Penetration	Reference	Current Consumption (Btu*E12)	New Technology Applicable		Percent Fuel Reduction	Ref3		Energy Savings (Btu*E12)
ELECTRIC UTILITIES	Natural Gas	9.7%	35	2870	ECO #13 (REF #13,#37) Excess Oxygen Control		1.0%	Est.		28.70
	Fuel Oil	4.2%	35	1250	ECO #13 (REF #13,#37) Excess Oxygen Control		1.0%	Est.		12.50
	Coal	54.6%	35	16160	ECO #13 (REF #13,#37) Excess Oxygen Control		1.0%	Est.		161.60
	Total Utility Use (fired only):			19030				Total Utility Savings:		190.30

TABLE B-4 ENERGY SAVINGS POTENTIAL: WASTE-DERIVED FUELS

Alternative Energy Source	Equipment Used	Industry	Fuel Source	Ref3	Fuel Utilization Tech.	Fuel Utilization Mkt.	Energy Savings (Btu*E12) Tech.	Energy Savings (Btu*E12) Mkt.
WASTE-DERIVED FUEL ECO #12 (REF #37)	Various	Various	Plant Trash	35	100%	10%	1440	144
	Various	Pulp and Paper	Wood Related Wastes	35	100%	10%	910	91
					Total Waste Fuel Savings:		2350	235

Est. = Estimated Value
Field descriptions are provided on the following pages.

The amount of alternative energy available from industrial waste was calculated and tabulated in Table B-4. The total number of Btus available annually from plant trash and wood-related wastes was found in literature[36]. A 10% utilization factor was assumed to arrive at a total quantity of energy which could be utilized, thus displacing other energy sources if energy conservation opportunity (ECO) #12 was commercialized.

Field Descriptions for Table B-2

SIC Industry. This field indicates the four- or five-digit SIC industries for which energy savings are calculated for one or more applicable technologies. Note that for each SIC industry, subtotals are calculated for current consumption and potential savings.

Annual Production. This value is the most recent available data on the annual U.S. production of this industry. **Ref1** gives the reference number for this value. For example, the most recent literature (reference #33) gives an annual production of 3.95 million tons of methanol.

Process. The specific processes for each SIC industry to which new technologies are applicable are listed in this field. The number of processes range from 1 to 4 for each SIC industry.

Temperature. This field contains the operating temperature (or range of temperatures) at which each type of heating equipment operates. In brackets directly below each temperature is the reference number for this value or range.

Equipment Used. This field contains the common name for the heating equipment used for each process.

Equipment Penetration. In some processes, such as cement calcining, different types of equipment or processes can be used to perform the same task. For example, 36% of cement manufacturers use the wet process (and thus a wet kiln) while 64% use the dry process. Because the two process types differ with respect to energy consumption, both processes and the energy consumption of each is analyzed separately. This field indicates the percentage of the respective SIC industry which uses the particular type of equipment.

Current SEC. For each process within each SIC industry, a Specific Energy Consumption (SEC) value is listed. This value is representative of current equipment and operating practices. **Ref2** indicates the source of each SEC value. For some processes, an average SEC is computed from more than one source. In this case, the **Ref2** field will contain "Ave.".

Current Consumption. The total annual U.S. consumption of energy for each process (in trillion BTUs) is shown in this field. This value is obtained by multiplying the **Current SEC** by the **Annual Production.**

New Technology Applicable. For each specific process, one or more new technologies are listed as having energy-saving potential. The literature source of this proposed technology is shown immediately above the technology name. For example, "Fluidized Bed Combustion" is technology #7, as described in this document.

Change in SEC, New SEC, Percent SEC Reduction. For each proposed technology/process combination, a change in SEC has been estimated. For some processes, this change in SEC results from a **Percent SEC Reduction** applied to the **Current SEC.** For others, a **New SEC** is estimated and the change in SEC is calculated as the current SEC minus the new SEC. In some cases an estimated percent ("Est.") reduction in SEC was used. These values were estimated using the reduced SEC values given by reference 4, and theoretical minimum values given by reference 1. **Ref3** indicates the literature source of the energy-savings value.

Penetration: Technical and Market. For most processes, the **Technical Penetration** is 100%. That is, all of the equipment used for the process could theoretically employ the new technology. However, some portion of existing equipment may not be eligible for the new technology for some reason. For example, 40% of alumina kilns already

employ entrained-flow calcination. Therefore, only 60% of the potential market remains. **Market Penetration** is that portion of equipment which is assumed will actually adopt the technology once it is available. Market penetration is assumed to be 40%. Where technical penetration is less than 100%, market penetration is assumed to be 40% of the remaining market.

Energy Savings: Technical and Market. The **Technical Energy Savings** is calculated by multiplying the **Technical Penetration** value by the **Change in SEC** and the **Annual Production.** Similarly, the **Market Energy Savings** is calculated by multiplying the **Market Penetration** by the **Change in SEC** and **Annual Production.**

Theoretical SEC. This field indicates the minimum energy required to produce one unit of output. The source for this information is shown under **Ref4**. This value is the theoretical energy requirement for a process with 100% efficiency.

Theoretical Energy Savings. This value is the amount of energy which could be saved annually if the particular process could be made 100% efficient. This number is provided primarily as a comparison to the **Market Energy Savings**, to illustrate how close the proposed technology will bring the process to being 100% efficient.

Theoretical Energy Use. This value is obtained by multiplying **Theoretical SEC** by **Annual Consumption.** A process with 100% efficiency would use this amount of energy annually (industry-wide), as compared with the **Current Consumption** value.

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