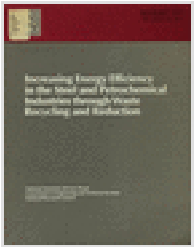

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INCREASING ENERGY EFFICIENCY IN THE STEEL AND PETROCHEMICAL INDUSTRIES THROUGH WASTE RECYCLING AND REDUCTION

Report of the
Committee on Industrial Energy Conservation

National Materials Advisory Board
Commission on Engineering and Technical Systems
National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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ABSTRACT

This report addresses energy conservation opportunities in the U.S. steel and petrochemical industries. The primary focus is on the potential for waste minimization and waste utilization to improve energy efficiency. Areas especially recommended for inclusion in steel industry research and development programs are refinement and reuse of scrap, including physical separation, hydrometallurgical separation, and pyrometallurgical separation; techniques for near-net-shape forming, such as electromagnetic casting, spray casting, and twin roll casting; processes to produce steels low in nitrogen and carbon in an electric arc furnace to expand the use of scrap; improved instrumentation and control procedures to eliminate defects in cold-rolled and hot-rolled slabs and sheets; cost-effective technologies for the recovery of energy in waste streams; and low-cost, high-temperature metallic and ceramic materials for use in recuperators.

The petrochemical industry already follows energy-conserving practices to a high degree; however, a critical problem of the industry involves the treatment and disposal of hazardous wastes. Since incineration is the preferred method of disposal, and since the disposal of hazardous wastes is an important problem facing the nation as a whole, further research on the science base underlying the incineration process is recommended.

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EXECUTIVE SUMMARY

The Office of Industrial Programs (OIP) in the U.S. Department of Energy is charged with evaluating new and existing technologies, economic elements, and legislated directives that could encourage or enhance energy conservation in the industrial sector of the economy. To carry out this charge, OIP has funded a variety of projects and studies. The National Research Council's Committee on Industrial Energy Conservation has, at the request of the Department, assessed various parts of OIP's activities, including those for specific industrial segments as well as the overall program.

This report is directed at energy conservation opportunities in the steel and petrochemical industries. Both of these industries consume large amounts of energy, and the committee examined the potential of waste recycling and waste reduction in improving their energy efficiency.

The steel industry is an important segment of the U.S. economy. It is beset by a wide range of stresses, from changing technologies to reductions in demand to foreign competition. Savings in energy consumption could be an important factor in revitalizing the industry, but better utilization of energy would not by itself be enough to increase its international competitiveness.

The committee reviewed industry trends and practices and explored four areas that could lead to reduced energy consumption: recovery of waste energy; process improvements to increase yield and decrease metallic wastes; increased recycling of scrap; and improved pollution-abatement techniques. Revolutionary advances in these areas are not anticipated, but incremental advances could still provide significant improvements in energy utilization. A reduction of more than 0.3 quad of energy is possible (out of the present 1.7 quads consumed annually by the industry) if the technological improvements identified here are pursued.

The committee specifically recommends that OIP consider the following areas for inclusion in its research and development programs: refinement and reuse of scrap, including research on physical separation, hydrometallurgical separation, pyrometallurgical separation, and the effects of residual containments in scrap; development and improvement of near-net-shape forming techniques such as electromagnetic casting, spray casting, and twin roll casting; development of processes; development and demonstration of improved instrumentation and control procedures to identify and eliminate defects in cold-rolled and hot-rolled slabs and sheets; development of cost-effective technologies for the recovery of energy in waste streams; and the development of low-cost, high-temperature metallic or ceramic materials for use in recuperators. In addition to these, the committee feels it is particularly important to develop processes to produce steels low in nitrogen and carbon in an electric arc furnace to expand the use of scrap.

The petrochemical industry is one of the largest energy consumers in the nation, using in recent years some 6.1 quads annually. Although only a few projects relating to this industry have been funded by OIP, the industry itself has addressed energy conservation through its heavy investment in proprietary processes for a constantly expanding line of products.

The committee reviewed technology needs in the petrochemical industry with respect to waste reduction and recycling. It concluded that the industry follows energy-conserving practices to a commendable degree; approximately 95 percent of the energy content of the feedstocks used can be recovered or recycled within a given plant. The treatment and disposal of hazardous wastes is the most critical problem facing the petrochemical industry. Since incineration is the preferred method of disposal, and since the disposal of hazardous wastes is an important problem facing the nation as a whole, the committee concluded that there is a need for further research and development on the science base underlying the incineration process. The committee recommends that research on this science base be pursued by the Environmental Protection Agency, the Department of Defense, and other offices within the Department of Energy.

Chapter 1

INTRODUCTION

In July 1978 the U.S. Department of Energy's Office of Industrial Energy Conservation Programs was directed to examine and take appropriate action concerning

- Existing but underutilized technologies whose implementation could be stimulated by an identifiable federal action;

- New technologies from research, design, and development (RD&D) that provide advanced concepts with proven economic and technical feasibility in industrial operating environments;

- Economic incentives, such as tax credits, that reward industrial actions in the national interest;

- Other actions that have been legislated to establish requirements and motivation for industry; and

- A market-oriented commercialization effort to ensure accelerated transfer of technologies to specific related industrial users and the maximum implementation of these technologies with regard to fostering energy conservation by the industrial sector.

Since this program was initiated, the federal government's cumulative investment has been more than $200 million, and more than 200 projects have been undertaken by DOE's Office of Industrial Programs (OIP). These projects have been carried out by industrial companies, consulting firms, research institutes, universities, and government laboratories.

In 1980 the National Research Council was asked by DOE to evaluate the Industrial Energy Conservation Program. The Committee on Assessment of the Industrial Energy Conservation Program, appointed within the National Materials Advisory Board, performed a series of evaluations during the period 1980-1985 and documented its findings in five reports:

- An Assessment of the Industrial Energy Conservation Program, Volume 1: Summary (September 1981; Publication NMAB 395-1)

- An Assessment of the Industrial Energy Conservation Program, Volume 2: Final Report (May 1982; Publication NMAB 395-2)

- Critique of Department of Energy—Office of Industrial Programs Fiscal Year 1982 Research and Development Programs (September 1982; Publication NMAB 407-1)

- An Assessment of the Industrial Energy Conservation Program for the Pulp and Paper and General Manufacturing Industries (June 1983; Publication NMAB 407-2)

- Assessment of the Industrial Energy Conservation Program: FY 1985 and Planned 1986 (August 1985; Publication NMAB 429-1)

Following its assessment of the FY 1985 and planned FY 1986 Industrial Energy Conservation Programs, the committee directed its attention to an evaluation of energy conservation opportunities in the steel and petrochemical industries. Both of these industries are large energy consumers, and the possibility of increased energy efficiency through waste reduction and waste recycling was selected as a focal point for the assessment. In addition, the steel industry was chosen because of its importance to the national economy and the strong pressures it is under from foreign competition. The committee sought to determine if there were technological needs that could be addressed by OIP that would lead to more efficient energy use by the steel industry and, if adopted, would improve its competitive position. Throughout its history, OIP has funded only a few projects relating to the petrochemical industry. It seemed propitious to review this industry's technology needs with respect to waste reduction and recycling to determine if energy conservation opportunities existed.

In Chapter 2 of this report the committee's review of energy conservation opportunities through waste reduction and recycling in steelmaking is summarized. Chapter 3 contains the committee's assessment of the petrochemical industry.

Chapter 2

THE STEEL INDUSTRY

Steelmaking is currently the nation's fourth largest industry, based on annual revenues. It is an industry in transition in the United States, with structural changes through plant shutdowns and corporate mergers, plant modernizations that incorporate advanced technologies, and adjustment in pricing and products to meet the challenges of internal and external competition. Even though steelmaking capacity has dropped from a record 160 million tons in 1977 to about 130 million tons in 1986, and domestic production in 1985 was only 88 million tons, steelmaking is still one of the nation's major consumers of energy. In 1985 the steel industry in the United States consumed 1.7 quads of energy (*1*). This represents over 6 percent of the industrial consumption of energy in the country.

Reduction of energy consumption by more than 0.3 quad is possible, based on the technological improvements identified in this report. Yield improvements could save 0.1 to 0.15 quad, increased and better utilization of scrap could lead to the saving of an additional 0.20 to 0.22 quad, and improved pollution-abatement techniques could save on the order of 0.02 quad. If energy prices begin to climb, these additional savings can be important to the vitality of the steel industry.

Among the trends in the steel industry are the efforts to convert from integrated steelmaking, which begins with raw iron ore and produces a wide variety of products using a batch production process, to a continuous production process that is more streamlined and versatile. Direct-reduction methods using coal rather than coke to produce molten metal are being investigated. This use of coal instead of coke will no doubt reduce energy consumption, although not significantly.

Production in the United States is steadily increasing in minimills, which use scrap steel as their raw material and make a limited line of fairly simple products such as wire rods and reinforcing bars. New types of furnaces and metal-casting methods can further increase the efficiency of minimills and expand their product lines. Specialty steel plants, which make alloys and stainless steels with such properties as corrosion resistance and high strength-to-weight ratios, have also increased production in recent years.

In 1976 the Committee on Technology of the International Iron and Steel Institute (IISI) published a review of energy use in the iron and steel industry. This work was based on an analysis of model plants, and thus it established the "ideal" scenario for energy use in steelmaking. In 1982 an updated study (*2*) was published by IISI based on analyses of hypothetical "reference" plants that would permit operators to compare their performance with the reference plants. The reference plants were an integrated facility (blast furnace-basic oxygen furnace) and two electric arc furnaces (one fully scrap fed) that were used as the basis for comparison. In addition to identifying technically proven items that would be considered commercially viable, the report also identified a number of "technically unproven" systems that could further improve energy utilization with economically attractive rates of return.

Figures 1 and 2 show the configuration of the integrated and electric arc reference plants. Integrated production of raw steel is based on smelting ore in the blast furnace using coke as the primary fuel and then refining the steel in basic oxygen vessels, with a few remaining open hearths still in operation. In 1985 about 66 percent of all domestic raw steel was produced in integrated facilities so defined. This percentage is expected to decrease by 1995 to about 60 percent as existing open hearths are retired and replaced, mostly by electric furnaces using scrap as their principal source of iron units.

Electric arc furnace (EAF) production utilizes electrical energy to both melt scrap and to refine the liquid steel. In recent years oxy-fuel burners have been used to supplement the electrical energy. The trend has also been toward melting in one vessel and refining in a second vessel, using electrical energy as the primary heat source. Electric arc furnace production is used exclusively in minimills and is the predominant method of production for specialty steelmakers. Figure 3 shows the energy consumption for these plants. Primary energy losses for the integrated reference plant are shown in Table 1. The overall energy consumption for this reference plant is 4597 Mcal/tcs.

The Office of Industrial Programs has sponsored a number of projects relating to energy use by the iron and steel industry. These projects and their goals are summarized in Table 2. Considerable progress has been made toward the development of a base of technology and options for improved energy utilization by the industry. As capital improvements are being made in existing plants, some of these changes are being adopted. Better energy utilization by itself is not sufficient to enhance the international competitiveness of the iron and steel industry.

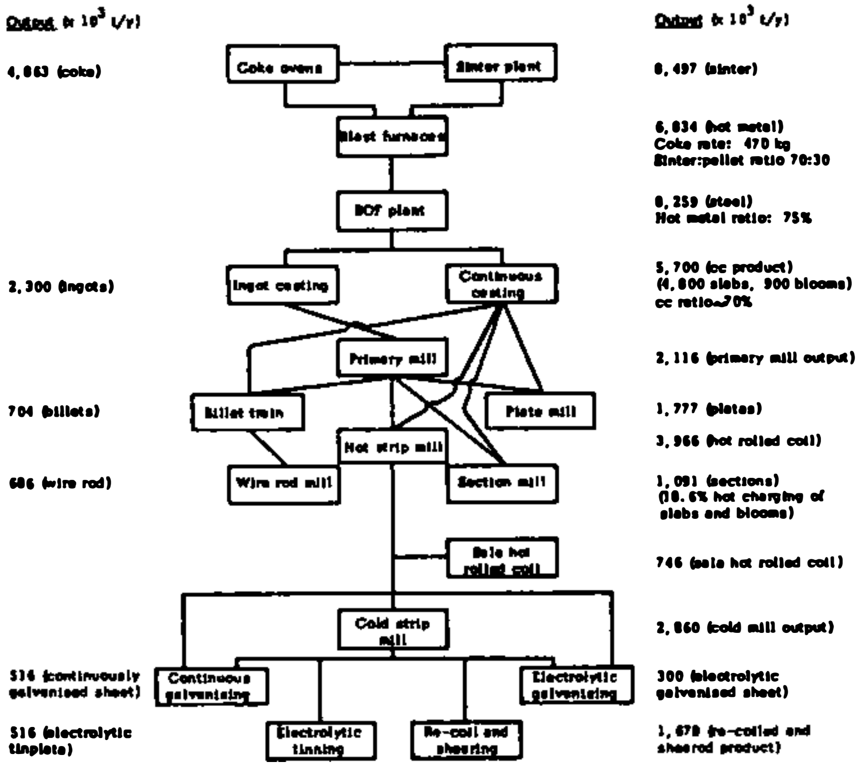

FIGURE 1 Outline configuration of the integrated reference plant.

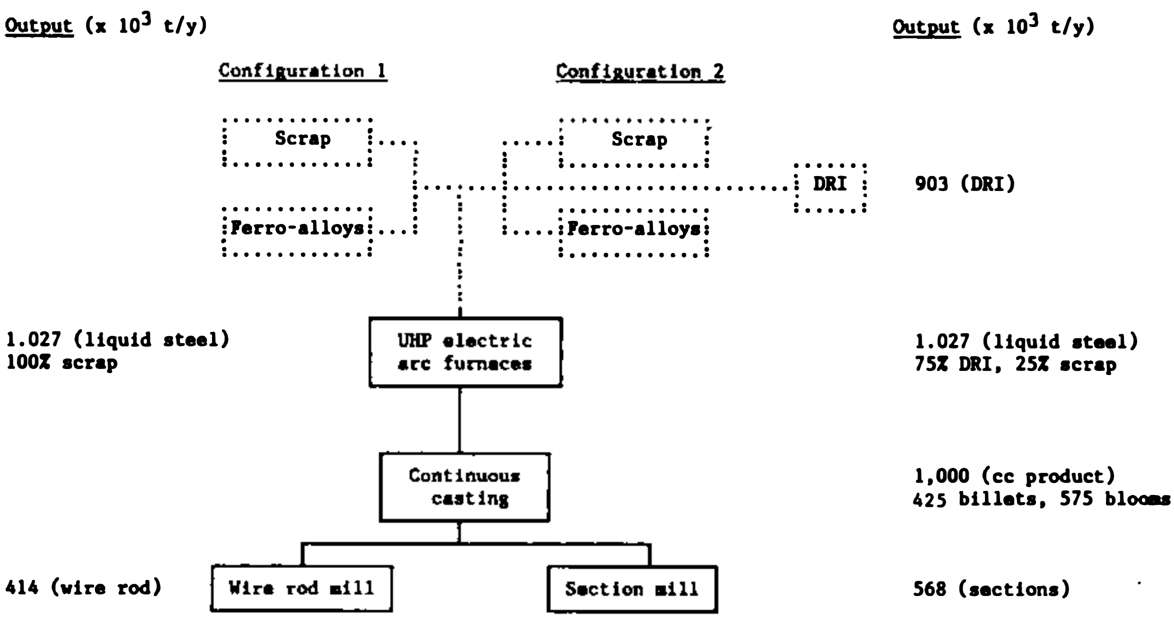

FIGURE 2 Outline configurations of the electric arc furnace reference plants.

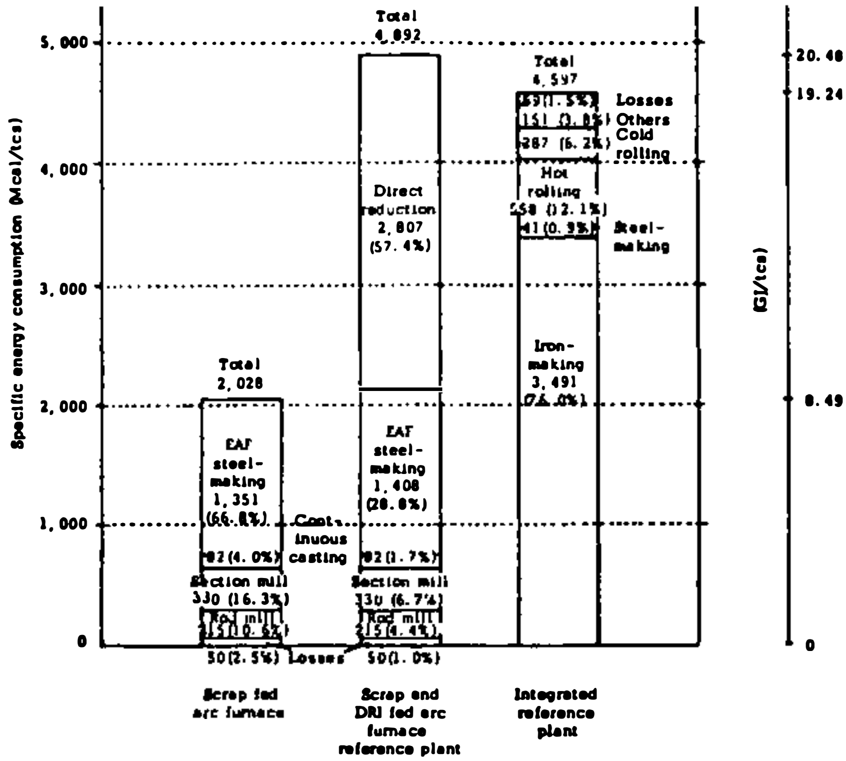

FIGURE 3 Energy consumption in the reference plants.

TABLE 1 Energy Losses for Integrated Reference Plant

Source	Energy Loss Mcal/tcs[a]	Energy Loss MBtu/tcs[b]
Coke oven and by-product plant	515	2.04
Sinter plant	433	1.72
BOF and continuous casting operations	703	2.79
Hot rolling	558	2.21
Cold rolling	287	1.14
Boiler plant	26	0.10
Other operations	45	0.18
Total	2567	10.19

[a]Mcal/tcs = 10^6 calories per ton of cast or raw steel
[b]Mbtu/tcs = 10^6 British thermal units per ton of cast or raw steel

The possibility that collaboration between federal laboratories, universities, and industry could assist in solving the long-range problems of the domestic steel industry has been suggested by members of the Presidential Committee on Industrial Competitiveness, George A. Keyworth, Science Advisor to the President, and Howard M. Love, Chairman of the National Intergroup. During the period from May to September 1984, four task groups under the direction of a joint steering committee made an intensive and well-documented search for new approaches in steelmaking, casting, product development, and control engineering. As a result of these studies, opportunities for long-range and novel technological development were identified in two areas: the direct production of liquid steel from iron ore and the casting of near-net-shape solids from molten metal. OIP has incorporated these suggestions into its current program.

ASSESSMENT OF TECHNOLOGICAL OPPORTUNITIES

The committee undertook a review of the trends and practices within the industry that relate to energy use to determine what, if any, efforts could be undertaken by DOE's Office of Industrial Programs to assist steelmakers in reducing energy consumption or in using it more effectively.

Based on its studies, the committee focused its attention on yield improvements, waste utilization, and scrap recycling. A meeting was convened in Washington to receive and discuss input from persons knowledgeable in the current waste and energy issues facing the steel industry and on the status of technology relevant to these problems. Representatives from the Office of Industrial Programs participated in the meeting, along with J. Elliott (Massachusetts Institute of Technology), V. Foltz (ARMCO), R. Landreth (Inland Steel Co.), and T. Weidner (Bethlehem Steel Corp.) as invited speakers.

The efficient use of energy in ironmaking and steelmaking has been under study by the industry for a number of years. This report identifies where DOE can play a role in achieving implementation of new technologies for effective energy use in the iron and steel industry and where DOE can assist in the development of these technologies through generic research and development that augments and complements the efforts of the industry and others. Based on the background information previously described and several other published reports (4,5), the committee chose to direct its attention to four areas that appear to have promise for energy reduction in steelmaking:

- Energy and heat cascading and/or recovery

- Decreased generation of metallic wastes by process yield improvements

- Increased recycling of scrap by improving scrap quality and/or developing new processes that can economically and thermally utilize a higher ratio of scrap than the present BOF

- Improved treatment of sludges and dusts to make them more amenable to recycling

TABLE 2 Projects Sponsored by the Office of Industrial Programs Relating to Energy Use in the Iron and Steel Industry

Program	Objective
Formcoke	Develop environmentally acceptable coke manufacturing process
Coke pellet process	Develop environmentally acceptable coke manufacturing process
Blast gasification	Produce low- to medium-Btu gas using idle blast furnace capacity
Coke dry quench	Modify coke oven batteries to permit recovery of heat resident in coke
Direct smelting of iron	Develop process for direct production of steel without a blast furnace
Cupola furnace modification	Permit off-gas recovery and combustion in cupola operation
Hot inspection and scarfing	Develop process for inspection and correction of flaws in hot steel slabs to permit continuous processing to flat rolled product
Computer control	Develop hierarchical computer control system for energy management in integrated steel mills
Iron particle melting	Develop mathematical model for electric furnace operations optimizing energy requirements for melting direct-reduced iron ore and steel scrap
Electric arc furnace modeling	Develop computer model using new control methods
Slot forge furnace	Develop and demonstrate modifications to improve furnace efficiency
Fluidized bed heat treatment	Demonstrate commercial-scale furnace of fluidized bed heat treatment of metal parts
Nitrogen-based carburization	Develop and demonstrate nitrogen-based atmosphere for carburization of steel parts
High-temperature sensors	Develop sensors to obtain real-time process for on-line analysis and control
Thin strip casting	Develop twin moving mold and planar flow wheel casting techniques for thin strip steel

Source: An Assessment of the Industrial Energy Conservation Program (*3*)

A discussion of each of these areas follows, with recommended actions or projects that could be undertaken by the Office of Industrial Programs to enhance the technology base available to the steel industry for more effective energy use.

WASTE ENERGY RECOVERY

Potential improvements for energy recovery from waste streams can be divided somewhat arbitrarily into four categories:

1. Technically proven concepts that cannot be adopted in a specific plant because of plant-specific problems such as product mix, space availability, logistics, etc.

2. Technically proven concepts that are not being adopted but that probably would be if demonstrated in a wide variety of realistic, real-plant situations

3. Technically proven concepts that are being adopted by the industry as financing permits

4. Technically unproven concepts

Clearly, the Office of Industrial Programs has no role to play in category 1 and 3 concepts. Energy conservation via category 2 items would be enhanced by DOE funding of demonstration projects, but this appears to be outside the scope of the high-risk, high-payoff philosophy of the department. (A complete listing of new but technically proven concepts that could be demonstrated is available in the IISI report.) Category 4 items clearly fall within the scope of OIP's current charter.

The committee was advised during its deliberations that making use of the energy from waste gas streams had an important conservation potential but that it needed further technological development and verification. This is consistent with the IISI report (*2*). The IISI identified the following waste-gas energy-saving potentials that require further development:

- For the integrated plant (estimated savings are shown in parentheses)

—Coke oven gas sensible heat recovery (19 Mcal/tcs)

—Blast furnace and BOF slag sensible heat recovery (30 Mcal/tcs each)

—Axial top pressure turbine operation with hot, dry cleaned gas (20 Mcal/tcs)

- For the scrap and directly reduced iron-fed electric arc furnace plant

—Steam-cooled walled panels

The IISI report further concludes that, in general, when choosing between a variety of energy-saving options, it is advantageous to concentrate on waste energy sources that are large; associated with a gaseous phase; suitable for recycling rather than recovery; and, in case of sensible heat recovery, at a high temperature.

In January 1982, the Gas Research Institute (GRI) published a report that included an assessment of how energy could be used more effectively in ironmaking and steelmaking (*5*). With regard to energy recovery and reuse, the report recommends the following as areas needing research:

- Development of low-cost metallic materials with high-temperature strength, creep resistance, and resistance to high-temperature corrosion

- Development of high-velocity burners that can accept high air preheat temperatures and provide high turndown capability, and demonstration of such high-velocity burners on reheat furnaces, soaking pits, and annealing furnaces

- Demonstration of plate- and fin-type or other compact, high-effectiveness recuperators on annealing furnaces

- Investigations of ceramic materials to characterize mechanical and thermal properties and development of improved fabrication and repair techniques

Additional areas recommended in the GRI report for research and demonstration on waste heat recovery include

- Development of low-cost, more compact waste heat boilers

- Improvements in flame control capabilities when using higher temperature preheated air to ensure satisfactory furnace operation

- Methods to reduce ambient air infiltration into furnaces to minimize dilution of waste gas streams

- Use of electric arc furnace exhaust gases to preheat scrap (*6*) and also the use of BOF off-gases for scrap preheating

- Use of Freon or other bottoming cycles to recover heat lost from areas such as furnace walls and BOF hoods

Research started at GRI in 1986 on a gas-fired scrap melter with an integrated heat recovery system and on a gas-fired hot metal transfer system with heat recovery.

WASTE HEAT ENERGY

An attractive use of waste energy that has been developed but may need a demonstration in the United States to fully document its advantages is scrap preheating with the off-gas from an electric arc furnace. A typical heat balance for an EAF indicates that up to 20 percent of the energy (100 kWh/ton) leaves the furnace as hot gases; this is enough energy to potentially preheat the scrap to 650°C (1150°F). Scrap preheating in Europe, for example, is accomplished in the charging bucket with a special hood. Reductions in energy consumption (50 kWh/ton), electrode consumption (2 to 3 lb/ton), and melting time (6 to 8 minutes) have been observed. In addition, the zinc content of electric furnace dust, a hazardous waste, is increased, which makes it a marketable product.

WASTE REDUCTION THROUGH PROCESS YIELD IMPROVEMENT

Figure 3 shows that the energy consumption for a modern, energy-efficient integrated steel plant would be 19.24 GJ per metric ton of cast (raw) steel; for a modern, energy-efficient electric arc furnace scrap-based steel plant it would be 8.49 GJ per metric ton of raw steel.

Energy statistics specifically for integrated production or electric furnace production are not available. However, from a reported average of 29.0 GJ per metric ton (25 MBtu/short ton) of shipped product in 1985, factored by the percentage of integrated and EAF production, one can estimate the average energy consumption for domestic integrated EAF production in 1985 as 28.1 and 13.6 GJ per metric ton, respectively. These differences represent the relative degree of modernization and energy efficiency of the average domestic steel plant compared to the hypothetical state-of-the-art plants depicted in the 1982 IISI study (*2*).

Integrated production accounted for slightly more than 80 percent of the energy consumed by the domestic steel industry in 1985.

Yield Performance

Yield performance is the decimal ratio of finished tons to raw steel tons expressed as a percentage. Table 3 shows that, in the past 10 years, average domestic steel production yields have increased from 70 percent to 83 percent. This increase is highly correlated ($r = .996$) with the increase in percentage of steel continuously cast. For every percent increase in raw steel continuously cast, product yield has increased almost one-half percent. This is somewhat misleading. Probably less than half of the improvement in yield can be attributed directly to continuous casting. The rest is a reflection of corollary improvements in downstream processes and the closing of older facilities.

In 1985, the industry continuously cast 44 percent of the raw steel production and exhibited a raw-steel-to-product yield of 83 percent.

Potential Energy Savings

Baseline figures of 25 GJ per metric ton of raw steel for integrated production and 13 GJ per metric ton for EAF production are used here to analyze the effect of incremental yield improvements on energy conservation for the industry. This provides a conservative estimate of potential savings.

TABLE 3 Industry Yields and Continuous Casting Ratios

Year	Yield[a]	Percent Continuous Casting
1975	69	9.1
1976	70	10.5
1977	73	12.5
1978	71	15.2
1979	74	16.9
1980	75	20.3
1981	73	20.3
1982	82	29.0
1983	80	32.1
1984	80	39.6
1985	83	44.4

[a]Yield calculations do not take into account annual inventory variations.

By 1995, total domestic shipments (demand - imports + exports) is projected to be no more than 63 million metric tons. At current yields this equates to a raw steel requirement of 76 million metric tons. Sixty percent of these shipments is expected to be produced by integrated plants, principally in the form of plate and light flat-rolled products. The remaining 40 percent will be produced in electric arc furnaces. This production ratio and the baseline figures given project an annual energy consumption by the domestic steel industry of 1,760,000 GJ or 1.67 quads if the raw-steel-to-product yields were to remain the same.

If yields were improved to 100 percent, annual energy requirements would be reduced by about 0.2 quad. This level of improvement, while unrealistic, provides an absolute limit on achievable savings through yield improvements alone.

Sources of Yield Improvements

There are three potential areas for further yield improvements in the industry. The first is to continue the installation of state-of-the-art continuous casters for slabs and blooms. Minimills or specialty mills that can utilize billet casters are now almost 100 percent cast. A practical limit is for 90 percent of all steel to be continuously cast.

(Section size and order size constraints will preclude certain products from being continuously cast.) Increasing the casting ratio to 90 percent should increase overall yields to 90 to 91 percent, with a consequent energy savings of 0.1 quad. No new technology is needed to achieve these energy savings. In fact, since 1985, additional casting facilities have either been installed or plans have been announced to increase the level of casting capacity to 70 percent of the projected 1995 raw steel requirements for integrated plants.

A second potential area for yield improvements is the modernization of downstream rolling and processing facilities and improvement in practices related to these facilities. There is no single generic need in this area. Rather, the requirements to achieve improved yields are specific to each facility and operation. Application of current best practices could probably improve overall yields an additional 2 to 3 percent, both in integrated plants and in specialty plants. Some improvements will occur as a higher percentage of capacity is taken over by new minimills.

The third potential area for yield improvements, which to some degree overlaps the preceding two, is near-net-shape casting. Successful development of thin slab casting or strip casting could supplant conventional slab casting and could avoid the need for modernizing certain downstream facilities. It is estimated that thin slab casting could provide 2 to 3 percent added yield savings over slab casting for light flat-rolled products. On the basis of the preceding analysis, the potential energy savings from yield improvements alone would be about 0.02 quad.

To summarize, energy savings of the order of 0.10 to 0.15 quad are potentially available through the improved yield performance of domestic steel plants. The bulk of this improvement is attainable through the application of currently available continuous casting and process technology.

SCRAP RECYCLING (*7,8*)

The U.S. steel industry consumed 1.7 quads of energy in 1985, which represents over 6 percent of the industrial consumption. Producing steel from scrap requires less than 45 percent of the energy needed to produce it from ore. The major method of using scrap is an electric arc furnace, which accounted for about 34 percent of steel production in 1985. If electric furnace steel production could be increased to 50 percent of the total production, 0.20 to 0.22 quad of energy could be conserved. Increasing scrap consumption in the BOF or the development of other scrap-based steelmaking technologies would also conserve energy. For a significant increase in electric steelmaking to occur, there must be sufficient scrap of reasonable quality available, and the products then can be produced in an electric arc furnace expanded to include low-carbon and lower nitrogen steels.

There is a tremendous surplus of scrap in the United States. It is estimated that in 1985 over 120 million tons of obsolete scrap (excluding home scrap and prompt scrap) were generated and only 36 million tons were sold to the U.S. industry. The scrap industry exported about 9.5 million tons. It is estimated that there are 744 million tons of scrap available; this figure could be disputed regarding what is actually recoverable, but there is no doubt that there are adequate quantities of scrap available and that every year the United States generates more scrap than it uses.

The next question concerns scrap quality. Scrap in steel plants is of two general types: home scrap generated in the plants and purchased scrap. Home scrap currently represents about 40 percent of the steel industry scrap requirement, and it is of good quality. However, as more continuous casting is put into production, the amount of home scrap will decrease. Purchased scrap can vary in quality. The major element of concern is copper; the copper content of typical types of purchased scrap is listed in Table 4.

Currently many of the products produced in electric furnace shops are simple shapes such as reinforcing bar and angles, for which copper, nickel, and molybdenum are not a major concern. However, if electric furnace steel production is to increase significantly, it will be necessary to produce more of the critical grades. For example, drawing steel for automotive and appliance use is a major product. Acceptable levels of copper and other residual elements for drawing steel are listed in Table 5. It can be seen that these levels are far below the levels present in most commercial scrap. Since the copper is often present as a physical mixture or as composite layers, physical and hydrometallurgical separations could possibly remove much of it.

TABLE 4 Copper Content of Commercial Scrap

Scrap Type	Percent Copper
Manufacturers' bundles	0.07
Number 1 heavy	0.18
Number 1 bundles	0.20
Shredded	0.23

Source: Inland Steel 1983

TABLE 5 Maximum Levels of Residual Elements for Drawing Steels

Type	Maximum Percent					
	Cu	Ni	Cr	Mo	Sn	Total
Deep drawing steel	0.06	0.1	0.07	0.02	0.01	0.12
Drawing quality, commercial quality tin (MR)	0.1	0.1	0.07	0.03	0.015	0.16
Tin (critical application)	0.06	0.04	0.04	0.02	0.02	0.16

It is clear that the steel industry can conserve energy by producing more steel from scrap. In addition, scrap represents a competitive advantage for U.S. steel producers over most other countries. However, whereas the availability of scrap is great, the amount of quality scrap available may not allow producers to substantially expand the use of scrap in steelmaking. This problem was recognized as a major one by the Steel Industry/Federal Laboratory Task A Advisory Committee ("Keyworth Steel Initiative"). That committee recommended a major four-point program for scrap at a funding level of about $400,000 to $500,000 per year. The program dealing with scrap refinement consisted of

- Physical separation—A project to improve physical separation initially looking at the effect of magnetic flux and improved sighting methods, to be done by Inland Steel Company with input from the Institute of Scrap Iron and Steel

- Hydrometallurgical separation—Work on leaching of scrap with various reagents, to be done at Idaho National Laboratory

- Pyrometallurgical separation—Examination of the thermodynamics, kinetics, and feasibility of sulfide treatments for removing copper, to be done by Carnegie-Mellon University; consideration of other novel methods, such as formation of complex halide vapor species and novel fluxes, to be done by Argonne National Laboratory

- Residual elements—Examination of the entire question of residual elements, such as maximum copper levels, what other elements are of concern, residual levels of elements in various scrap forms, what can be achieved by scrap blending, and the economics of improved physical separation and other new treatments, to be done by an appointed task force

As of December 1986 this program has not been implemented.

The greater use of scrap in steelmaking is potentially a significant method of reducing energy consumption by industry. There is adequate scrap available, but the quality of the scrap may not allow for significant growth of electric-furnace steelmaking to new product areas. There are at present no major research efforts in the area of improving scrap quality.

For scrap-based electric furnace steelmaking to increase its share of steel production significantly, it will also be necessary to expand the range of products that can be produced. Currently, very little cold-rolled sheet is produced in EAFs because the steels produced there normally have nitrogen levels higher than is acceptable for this product. Steels produced in a BOF generally have lower nitrogen contents. An alternative to EAF steelmaking using scrap is the use of large-furnace induction melting of the scrap plus coke plus silicon to provide the charge for the BOF.

Cold-rolled sheet used in the automotive and appliance industries, for example, represents a large percentage of total steel production. Therefore, processes must be developed for producing steels with low nitrogen contents in the EAF. Likewise, there is an increasing demand for low-carbon steels (less than 0.03 percent). At present these steels have to be produced in a BOF. Processes should be developed for the production of low-carbon steels in an EAF to use more recycled scrap.

IMPROVED POLLUTION-ABATEMENT TECHNIQUES

The U.S. iron and steel industry uses a variety of waste treatment techniques common to many industrial manufacturing operations. Included are wastewater treatment by flocculation and precipitation for removal of contaminants prior to discharge to municipal treatment systems or to surface waters, land-filling of solid wastes, particularly fly ash materials and oily mill scales, removal of particulate matter from off-gas streams via scrubbers and/or electrostatic precipitators, and deep-well injection of process wastewaters with high chloride content, which cannot be easily treated or effectively recycled to the steelmaking process. In general, these waste-abatement processes used by the iron and steel industry are mature, proven technologies that have been in use for many years.

Overall, the energy consumption for pollution abatement in the iron and steel industry constitutes only a small fraction of the total energy used in this industry. In general, less than 2 percent of total energy consumption is utilized in pollution-abatement activities, with by far the largest part of this being for movement of relatively high-temperature off-gases from the various steelmaking processes.

Efforts toward improved pollution abatement in this industry have been driven by the opportunity for recycling and reuse of waste materials containing valuable raw material components rather than by the economics of energy conservation per se.

Gas Handling

The high pressure drop required for efficient operation of both cyclone separators and wet scrubbers results in a large energy use for gas handling, and the level of energy required is further exacerbated by the need to cool the gases, which can reach temperatures of 3000°F, prior to treatment for removal and recovery of the particulate matter.

At present, volumetric cooling with ambient air is frequently practiced at dilution ratios as high as 100 to 1, thereby greatly increasing the size of the equipment required as well as the horsepower required to move the off-gases through the particulate-removal equipment. Another significant issue in the reuse of off-gases and reclamation of waste heat in those gases is the submicrometer-size particulate matter they contain. This particulate matter is typically between 1 and 2 percent up to 44 μm, with an average of 2 to 10 μm. Impurities in this particulate matter frequently restrict the potential use of the hot gases, and therefore the challenge is the removal of the submicrometer-size particulate matter without loss of the sensible heat content of the gas.

Indirectly related to gas handling is the fact that electric arc furnace dust has been listed by the Environmental Protection Agency as a hazardous waste under the regulations of the Resource Conservation and Recovery Act. This extremely fine dust, ranging in size from 0.1 to 10 μm, is formed in the electric furnace by metal vaporization, subsequent reaction with oxygen within the furnace, and deposition on condensed nuclei. It is considered a hazardous waste because of the presence of leachable metals such as lead, cadmium, and chromium. Since disposal is a problem, energy-efficient processing techniques need to be investigated to upgrade these particulate wastes to useful products. As noted earlier, it has been reported that scrap preheating using the off-gases from an EAF reduces the amount of dust and increases the zinc content, which possibly makes the dust marketable.

Wastewater Handling

A typical steel mill consumes between 35,000 and 80,000 gallons of water per ton of finished product, primarily for cooling uses. Configuration of the mill and the type of process employed can have a significant effect on the volume of water used and the volume of water discharged through the waste-treatment process. Horsepower requirements for wastewater treatment per se are generally not excessive, although significant quantities of compressed air are needed for extended aeration of oily mill wastes from pickling operations and hot-rolled waste.

Deep-Well Injection

Strong pickling wastes may contain up to 10 percent hydrochloric acid, for which the only effective disposal technique is deep-well injection. Energy requirements for this operation depend heavily on subsurface geological configurations and the resultant pressure required to force the waste material into the subsurface strata, but these are not significant in terms of overall energy use.

Sludge Handling

Sludges from classification and other collection processes in some cases are difficult or costly to recycle because of their moisture content. These materials frequently contain moisture in the 30 to 40 percent range, and the ability to further dewater these materials would reduce the heat requirements when they are recycled. The potential energy reduction in this area is significant; even though dewatering processes have been extensively studied, a further review of dewatering techniques is probably warranted.

Oily Mill Wastes

A review of alternate techniques involving solvent or detergent cleaning of oily mill wastes to permit recycling rather than disposal in a landfill seems appropriate because it may offer a combined benefit of additional waste reduction along with reduced energy consumption.

Summary of Pollution-Abatement Techniques

The most significant potential for improvement in the area of pollution abatement appears to be in the area of recovery of contaminated dust from high-temperature gas streams at process temperature, which would permit these gases to be reused as fuel or to preheat scrap materials being recycled. With the energy consumption for pollution abatement representing only between 1 and 2 percent of total energy for steel manufacturing, the potential returns do not appear to be sufficient to justify significant effort in this area. The ultimate usefulness and attractiveness of energy-reduction techniques will be offset by added capital requirements for their implementation, and this will compete with capital requirements for process modification.

RECOMMENDATIONS FOR THE OFFICE OF INDUSTRIAL PROGRAMS

Even though revolutionary advances in steelmaking processes, waste reduction, and scrap reuse are not anticipated, many suggestions have been made by various groups for technological advances that, if adopted, could improve energy use by the iron and steel industry. As a result of its review of published information and discussion with individuals knowledgeable about the status of technology applicable to the industry, the committee recommends that the following areas be considered for inclusion in research and development programs of the Office of Industrial Programs:

1. Research and development tasks identified as a part of the Steel Initiative should be incorporated in OIP's program, even if special additional funding is not appropriated by Congress. In particular, program plans should be advanced by OIP for (a) refinement and reuse of scrap as described in the four-point program recommended by the Task A Advisory Committee, encompassing research on physical separation, hydrometallurgical separation, pyrometallurgical separation, and effects of residual contaminants in scrap and (b) development and improvement of near-net-shape forming techniques such as electromagnetic casting, spray casting, and twin roll casting.

2. In addition to the recommendations related to the recycling of scrap, it is particularly important that processes should be developed to produce steels low in nitrogen and carbon in an EAF to expand the use of scrap.

3. Improved instrumentation and control procedures in downstream areas, aimed at identifying and eliminating defects in cold-rolled and hot-rolled slabs and sheets, should be developed and demonstrated.

4. Development of cost-effective technologies for the recovery of energy in waste streams should be pursued. Applications within the steel industry should be included as a part of OIP's waste heat recovery projects. Particular attention should be directed to the removal of contaminated dusts at process temperatures so that the gases can be reused without reheating as well as to the use of EAF off-gas directly for preheating scrap.

5. Research should also be directed toward lower cost ceramic materials for use in recuperators as well as toward metallic materials. The development of low-cost recuperators that can operate reliably under the thermal, chemical, and erosive conditions characteristic of iron and steel operations is an attractive objective. This will require the identification and development of both low-cost, high-temperature materials (metallic and/or ceramic) and methods to fabricate them into suitable recuperator designs. In particular, the committee suggests that OIP pursue this objective primarily by supporting activity to explore the potential for this use of the materials or processes emerging from existing extensive high-temperature materials development programs such as those of DOD or other elements of DOE. Cooperative activities to modify the products of such programs might then follow.

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Chapter 3

THE PETROCHEMICAL INDUSTRY

The petrochemical industry is one of the nation's largest energy consumers; in 1984 a total of 6.1 quads of energy, including 2 quads as feedstocks, was consumed by those companies included in Standard Industrial Classification 28 (*1*). Companies within the industry invest heavily in technology, and the success of the industry is built on cost-effective proprietary processes to produce an ever-expanding array of products for the commercial and industrial marketplace. Since the petrochemical industry possesses a strong technology base, it has addressed energy conservation mainly on its own; only a few projects relating to this industry have been undertaken by the Office of Industrial Programs.

The results of a previous review of OIP's projects for the chemical industry are summarized in an earlier report (*2*). As a part of its review of efficient energy use through waste reduction and recycling, the committee undertook a brief review of current practices within the petrochemical industry to determine if there were unfilled technology needs that should be addressed by OIP. A meeting was convened in Washington for the committee to gather information from persons knowledgeable in energy use, waste recycling, and waste treatment technologies of the industry. E. Kranz (Stone and Webster Engineering Corp.), D. Maisel (American Institute of Chemical Engineers), A. Manchester (Hercules Inc.), V. Stewbart (Dow Chemical), and M. Throdahl (formerly Monsanto Company) participated as invited speakers.

From the information presented, the committee concluded that

1. The most critical problem currently facing the petrochemical industry is the treatment and disposal of hazardous wastes. Incineration is the technology of choice used by the industry to solve these problems.

One reviewer of this report has provided the following information, which the committee endorses. Most petrochemical plants are associated with petroleum refineries, and it is often possible to dispose of petrochemical wastes in the petroleum refinery; for example, the petroleum coking process can be quite effective in destroying many potentially hazardous petrochemical waste products. This can be possible both in the delayed coking process as well as the fluid bed coking process. In a flexicoking-type process where the coke is burned in a fluid bed regenerator, even more opportunities are presented for incinerating petrochemical wastes. Combining petrochemical waste with coking merits further study and analysis.

2. The petrochemical industry has adopted and practices energy-conserving process technologies. In general, all material wastes are recycled and all process heat is recovered and reused until it becomes impractical, inefficient, or uneconomical to do so. Greater than 95 percent of the energy content of the feedstocks can be recovered in the products or can be recycled within the energy used by a given plant.

Given these inputs, the committee reviewed recently published information on incineration (*3-8*). There is a common thread among these references: that is, incinerators for the disposal of hazardous organic wastes can be designed, constructed, and operated satisfactorily, but such techniques are still an art rather than a science. There is a need for further R&D on the science base underlying the incineration process, especially on the combustion itself, materials interactions with the combustion environment, automated systems for process control, identification and control of incomplete combustion, and other downstream systems. The treatment and effective disposal of hazardous wastes are important health, environmental, and economic problems facing the nation, and the committee recommends that the need for further research on the science base underlying incineration technology be investigated by other offices in the Department of Energy, the Environmental Protection Agency, and the Department of Defense. Smaller companies within the chemical industry are in particular need of additional knowledge to assist them in dealing with the problems of hazardous wastes.

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Appendix

BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS

DAVID L. MORRISON received his M.A. and Ph.D. (chemistry) degrees from Carnegie Institute of Technology. He worked for Callery Chemical Company and Battelle Memorial Institute prior to joining IIT Research Institute in 1977 as executive vice president, and where he is now president. He is a member of the American Association for the Advancement of Science, American Chemical Society, and American Nuclear Society. His research interests include energy and environmental research; technology and environmental impact assessment; research and development planning; nuclear reactor safety analysis; radiochemistry; and research management.

HARRIS M. BURTE received his Ph.D. degree in chemical engineering at Princeton University. He is a Chief Scientist of the Air Force Materials Laboratory at Wright-Patterson AFB, Ohio. He has been active in many areas of materials and manufacturing R&D and in interactions between technology and society, and he currently serves as an adjunct professor of engineering at Wright State University. He is a member of the American Chemical Society, Fiber Society, American Institute of Aeronautics and Astronautics, and American Institute of Mining, Metal and Petroleum Engineers, and he is a fellow of the American Society of Metals. His research interests are properties of materials, textiles, plastics, metals, ceramics, and nondestructive evaluation.

RICHARD FRUEHAN received B.S. and Ph.D. degrees (metallurgical engineering) from the University of Pennsylvania. He worked at the Fundamental Research Laboratory for U.S. Steel Corporation before joining Carnegie-Mellon University, where he is Professor of Metallurgy and Materials Science and director of the Center for Iron and Steelmaking Research. He is a member of the TMS and the Iron and Steel Society (ISS) of AIME and is a Distinguished Member of ISS. His research interests include the physical chemistry and process dynamics of metal refining processes, metal-ceramic joining and reactions of liquid metals with second phases.

NOEL JARRETT received his M.S. degree from the University of Michigan in chemical engineering. He worked as a sales engineer at Freedom-Valvoline Oil Company before joining the Aluminum Company of America, where he is now technical director for chemical engineering at the Alcoa Laboratories. He is a member of the National Academy of Engineering, American Society of Metals, American Institute of Chemical Engineers, American Institute of Mining, Metallurgical, and Petroleum Engineers, Electrochemical Society, and Sigma Xi. His research interests are electrochemical cell development, optimization of the Hall-Heroult process, coker reactor, cell development of Alcoa Smelting Process, pollution control by scrubbing of chlorine from furnace effluent, and high-purity aluminum via crystallization.

FRITZ KALHAMMER received his Ph.D. degree from the University of Munich. He is Vice President, Management and Utilization Division of the Electric Power Research Institute. He worked in solid-state research and development at Philco Corporation and as senior physical chemist and manager of the Electrochemistry Laboratory of SRI. His research interests include physical chemistry, storage, conversion, conservation and utilization of energy.

ALLEN M. KOLEFF received a B.S. degree (chemical engineering) from Illinois Institute of Technology. He is currently director of energy and environmental technology with Stone Container Corporation and previously held senior engineering positions with AE Staley Manufacturing Company. He is a member of the American Institute of Chemical Engineers, Technical Association of the Pulp and Paper Industry and the American Paper Institute's Energy Policy Committee. His research interests include development and application of new environmental processes and equipment and new approaches to energy source planning.

ADOLPH J. LENA received his D.Sc. degree (metallurgy) from Carnegie Institute of Technology. He is currently Executive Vice President and Chief Operations Officer of Carpenter Technology. He is a member of the American Society of Metals. His research interests are physical metallurgy of alloys and stainless steels, magnetic and electrical alloys, and tool steels.

ROBERT B. ROSENBERG earned his Ph.D. degree (gas technology) from the Illinois Institute of Technology. He is currently Senior Vice President for Member and Industry Relations at the Gas Research Institute. He is a member of the American Gas Association, the Combustion Institute, American Institute for Chemical Engineers, Air Pollution Control Association and is active in international R&D Associations. His research interests include development of new equipment, consulting, environmental studies, and new natural gas supplies and efficient utilization of natural gas.

DAVID K. SNEDIKER holds a Ph.D. degree (physical chemistry) from Pennsylvania State University. He is currently Vice President, Quality, for the Battelle, Columbus Division. His previous employment was at

General Electric Company as a physical chemist and as research chemist at the National Bureau of Standards. He is a member of the American Association for the Advancement of Science, the American Chemical Society, and the American Society of Lubrication Engineers. His research interests include hot atom chemistry of condensed systems, especially organometallic compounds; Mössbauer spectroscopy; tribology, especially fundamentals of rolling friction; solid lubricant technology; and elastohydrodynamics.

JULIAN SZEKELY received his B.Sc., Ph.D., and D.Sc. (engineering) degrees from Imperial College, University of London, England. He taught at Imperial College and at State University of New York at Buffalo before taking up his current position as Professor of Materials Engineering at Massachusetts Institute of Technology. He is a member of the National Academy of Engineering, American Institute of Chemical Engineers, British Institute of Chemical Engineers, and American Institute of Mining, Metallurgical, and Petroleum Engineers. His research interests include materials processing, mathematical and physical modeling of processing operations, and energy, environmental, and societal aspects of materials processing operations.

ROGER L. WHITELEY holds a B.S. degree in Civil Engineering and an M.S. degree in Mechanics from Rensselaer Polytechnic Institute. Before his retirement in 1984, he was Vice President, Production Technology at Bethlehem Steel Corporation. He is currently Associate Director of the Center for Innovation Management Studies located at Lehigh University. He is a member of the American Institute of Mining, Metallurgical, and Petroleum Engineers. His research background includes sheet steel metallurgy, forming and fabrication of metals, instrumentation and automation of steel mill processes and systems analysis. His current research interests are focused on management policies and practices related to the industrial innovation process.

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15. Supplementary Notes

16. Abstracts This report addresses energy conservation opportunities in the U.S. steel and petrochemical industries. The primary focus is on the potential for waste minimization and waste utilization to improve energy efficiency. Areas especially recommended for inclusion in steel industry research and development programs are refinement and reuse of scrap, including physical separation, hydrometallurgical separation, and pyrometallurgical separation; techniques for near-net-shape forming, such as electromagnetic casting, spray casting, and twin roll casting; processes to produce steels low in nitrogen and carbon in an electric arc furnace to expand the use of scrap; improved instrumentation and control procedures to eliminate defects in cold-rolled and hot-rolled slabs and sheets; cost-effective technologies for the recovery of energy in waste streams; and low-cost, high-temperature metallic and ceramic materials for use in recuperators.

The patrochemical industry already follows energy-conserving practices to a high degree; however, a critical problem of the industry involves the treatment and disposal of hazardous wastes. Since incineration is the preferred method of disposal, and since the disposal of hazardous wastes is an important problem facing the nation as a whole, further research on the science base underlying the incineration process is recommended.

17. Key Words and Document Analysis. 17a. Descriptors

energy conservation
industrial energy conservation
steel industry
petrochemical industry
waste heat recovery
steel scrap recycling
industrial waste reduction
pollution abatement
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