THE FUTURE OF ENERGY EFFICIENCY IN THE STEEL INDUSTRY

Bettadapura Lakshminarayana, American Iron and Steel Institute

INTRODUCTION

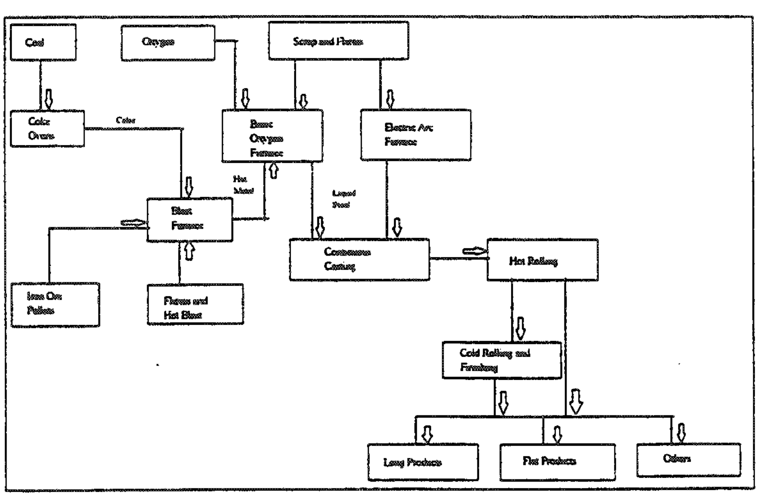
Steel is present in every aspect of our lives, in all industrial, transportation sectors as well as in households in United States. The American steel industry today can be counted among the most productive, efficient and technologically advanced in the world. Steel combines low cost with attractive engineering properties and is the most recycled of all materials. Despite these appealing characteristics of steel, the steel industry has confronted significant challenges from other competitive materials. To keep abreast with the competition it faces, pursuit of research and development activities is an absolute necessity. This competition has forced the steel industry to address many issues that here to fore were deemed unimportant. One of these areas is energy efficiency.

Steelmaking energy costs comprise over 15 percent[1] of the manufacturing cost of steel. This compares to less than five percent for most other manufacturing industries. The U.S. steel industry, which accounts for about nine percent (1.8 quads/year) of the U.S. industrial energy use, has made considerable progress in the area of energy efficiency. Over the past 20 years, the U.S. steel industry has reduced its energy intensity by 43 percent[1]. The impact of energy usage on environment and the results of government regulations have made the industry concentrate more and more on the issues of energy efficiency. In addition, a possible energy shortage could become a global phenomenon in the 21st century if steps to conserve energy are not taken.

The risk in researching and adaptating new technologies is greater in the steel industry than in many other manufacturing industries. Steelmaking is capital intensive in both equipment and processes. Government/industry partnerships can help reduce such risks. The Department of Energy's Office of Industrial Technologies (DOE/OIT) has been supporting energy efficient research relevant to the steel industry. Salient features of some of the projects will be explored in this paper. These endeavors bring together the collective resources not only of the government and the industry, but also of national laboratories, universities and advanced technology companies. Such efforts continued into 21st century will make the U.S. steel industry more environmentally friendly, energy efficient and globally competitive.

THE STEEL MAKING PROCESS

Figure 1. Flow Chart for Steelmaking



Before looking into the details of energy efficient technologies, it is necessary to understand the processes involved in steelmaking and finishing. The flow chart in figure 1 illustrates the basic steelmaking steps. The first process is converting iron ore into liquid iron in a blast furnace using coke and limestone. The next step is converting iron to steel by blowing oxygen. The liquid steel is cast into slabs, blooms and billets in continuous casting machines. The cast slabs, blooms and billets are rolled to different products. In non-integrated steel mills the steel scrap and iron bearing materials are melted in electric arc furnaces to obtain liquid steel. The most energy intensive processes in a steel plant are in the primary area consisting of cokemaking, ironmaking, steelmaking and casting. As such, the energy research priorities are in this primary area although research is also being undertaken in the rolling mills. The environmental impact is also higher in the primary area due emissions of pollutants.

ENERGY SCENARIO IN STEEL PLANTS

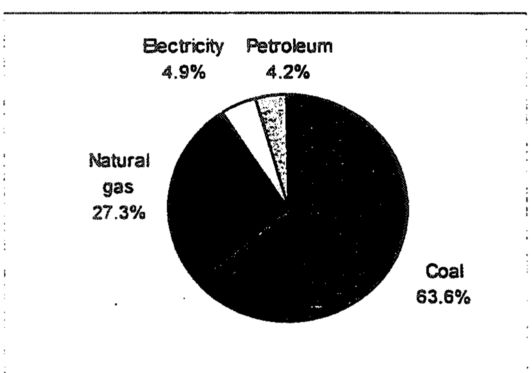
Table 1. U.S. Iron and Steel Industry Energy Consumption

Fuel	Total for the Industry (10^{12} Btu)
Coal	698.41
Coke (Imported)	149.05
Electricity (with losses)	464.85
Natural Gas	403.45
Fuel Oil	48.00
Petroleum Coke	10.00
Oxygen	46.51
Purchased Steam	4.00
Blast Furnace Gas	205.15
Coke Oven Gas	136.98
Subtotal	**2166.40**
Less Recovered Energy	
Blast Furnace Gas	205.15
Coke Oven Gas	136.98
Subtotal	**342.13**
Net Total	**1824.27**

As already mentioned, steel is an energy-intensive industry. Table 1 shows the U.S. iron and steel industry's total energy consumption by fuel type in 1994.

Source: Energy and Environmental Profile of the U.S. Iron and Steel Industry, U.S. Department of Energy, 1996

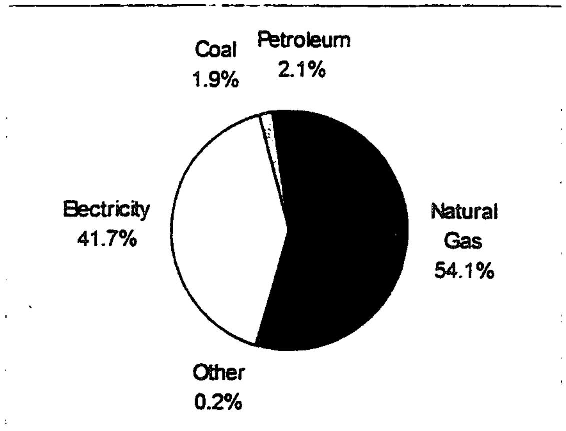
Figure 2. Energy Forms Used By Integrated Steel Producers-1994



The total energy consumption for 1994 was 1.82 quads. Nearly half of the industry's energy is derived from coal used for both generating electricity and for making coke for blast furnaces. The percentages of energy forms utilized are shown in figures 2 and 3.

Source: "Energy: Consumption, Cost and Conservation in Steel Industry," A.P. Martocci, *AISE Annual Conference, 1995*

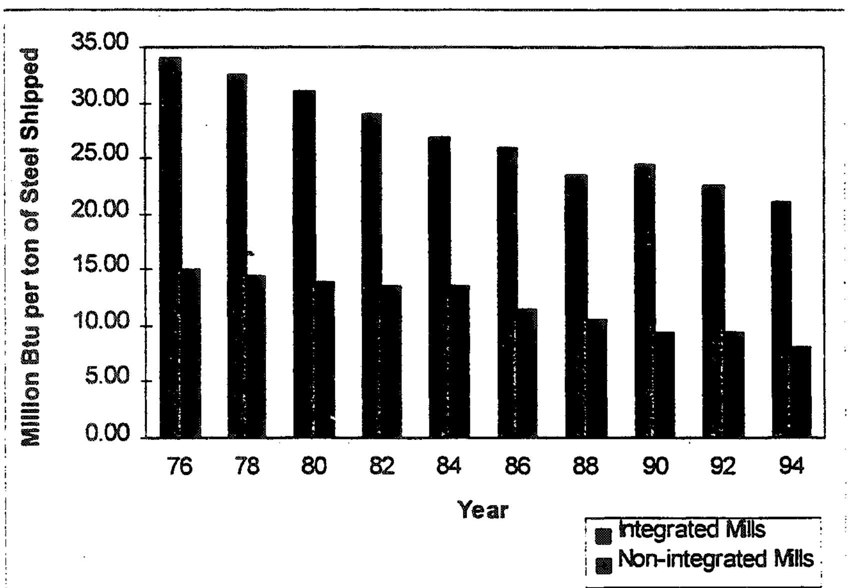
Figure 3. Energy Forms Used By Non-Integrated Steel Producers-1994



Source: "Energy: Consumption, Cost and Conservation in Steel Industry," A.P. Martocci, *AISE Annual Conference, 1995*

Over last two decades, the use of natural gas and electricity has increased while the use of coal has declined due to the developments in blast furnace injection technologies and increased production of steel through electric arc furnace route. In 1994, the energy intensity for the steel industry was 18.93 million Btus compared to 31.71 million Btus per ton product shipped in 1974[2]. In spite of the trend of the steel industry to move towards value added products which required more energy input, the reduction in energy intensity has been achieved through the elimination of inefficient processes such as basic open hearth steelmaking, ingot casting and soaking pits. Other factors contributing to the drop in energy intensity are the increase in electric arc furnace steelmaking and the consolidation of the steel industry to the more productive and modern plants due to global competition. Increased capacity utilization is a major factor in reducing energy consumption. The average energy intensity in the U.S. steel industry over the last 20 years is shown in figure 4.

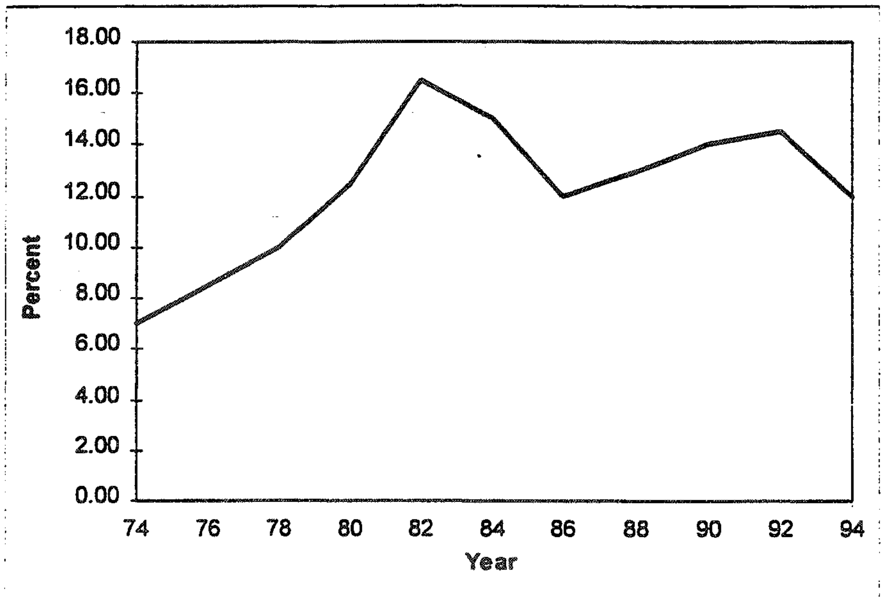
Figure 4. U.S. Steel Industry Average Energy Intensity



Source: Energy and Environmental Profile of the U.S. Iron and Steel Industry, U.S. Department of Energy, 1996

One of the factors that encouraged energy efficiency in the steel industry was the increasing cost of the energy. The average industrial energy cost in the U.S. increased more than 500 percent from $0.83 to $5.3 per million Btu between 1970 and 1993[3]. In today's economy, the energy cost is $50 per ton or more depending upon the production flow and the location of the plant[2]. In addition to fluctuating energy costs, new legislation aimed at reducing reliance on foreign energy sources had significant effects on the industry. This forced industry to adopt energy efficiency technologies in the eighties leading to reduced energy costs. The energy cost as a percent of operating cost over the past 20 years is shown in figure 5.

Figure 5. Energy Costs as a % of Operating Costs



Source: "Energy: Consumption, Cost and Conservation in Steel Industry," A.P. Martocci, *AISE Annual Conference, 1995*

THE U.S. STEEL INDUSTRY TODAY

The American steel industry is now among the most efficient steel producers in the world. Its current productivity is estimated to be equal to that of Japan. New process technologies such as continuous casting have improved the quality of the products and have increased yields.

In spite of the phenomenal developments in the industry, the search for more energy efficient technologies continues since energy sources are dwindling world over. Since about 70 percent of the energy required to produce steel is consumed to make liquid steel, it is to the front end of the process that one must look for energy efficiency. In the past, a number of improvements have been made, such as increased blast temperature, oxygen enriched blast and high top pressure, to reduce the coke rate and thereby increase the energy efficiency of the blast furnaces. A record blast furnace natural gas injection rate of 300 lb/NTHM has been reported resulting in a coke rate of 600 lb/NTHM with productivity increase of about 40 percent and in turn improving energy efficiency[4].

Oxy-fuel burners are being used in the electric arc furnaces for melting the scrap and thereby supplement the power input. Use of twin shell electric arc furnaces and scrap preheating using off-gasses are some other efforts employed for energy efficiency. A very promising technology that is being adapted increasingly is the technology of post-combustion. In this technology, the heat content of off gases are recovered by combusting with in the furnace. This technology is expected to save 40 kWh per charge ton in electric arc furnaces in addition to reduction in tap to tap time[7].

The demand for alternate iron units for the industry continues particularly in the electric arc furnace sector. A number of processes for producing Direct Reduced Iron/Hot Briquetted Iron (DRI/HBI) are undergoing trials. Midrex and Corex processes seem to be among the promising technologies. In the Corex process iron ore is reduced using non-coking coals, whereas in Midrex process natural gas is used for reduction of ore. Table 2 shows the world DRI production by process in 1995.

Table 2. World DRI Production by Process in 1995

Process	Production (Million Metric Tons)
Midrex	19.86
HYL III	5.76
HYL I	2.39
SL/RN	1.02
Others	1.64
Total	30.67

Source: "Alternate Irons Defined and Explained." Adam Ritt, *New Steel, October 1996*

Recent developments in more efficient casting technologies include intermediate and thin slab casters. Some steel mills have installed thin slab casters and connected tunnel furnaces leading to continuous processing in place of batch processing and thereby avoiding reheat furnaces. Another potential development is strip casting which eliminates intermediate processing resulting in savings in energy by eliminating reheat furnaces and hot strip mills.

In rolling and finishing, sensors and controls has been a major focus of activity. These sensors are expected to cut down-time by conducting an on-line instead of an off-line analysis, thereby saving energy and increasing productivity. A new type of single-phase motors have been developed that are 25 percent more efficient.

Recycling is receiving increased attention by the steel industry. In less than 10 years the recycling rate for appliances has jumped from four percent to about 61 percent[1]. Recycling not only reduces the energy needed for disposal, but also saves valuable virgin resources. In addition, it also reduces landfill volume.

GOVERNMENT/STEEL INDUSTRY R&D PARTNERSHIPS

In the process of restructuring and reengineering the steel industry during the 1980s, the academic research facilities and large industry laboratories were the prime targets for the funding cuts. This reduced the research capabilities of individual firms forcing them towards collaborative efforts. In the 1980s, workshops brought scientists and engineers in industry, academia and government together in an effort to encourage collaborative research.

In addition to collaboration within the industry, steel producers reached out to form partnerships with suppliers, customers and the government. In the mid-eighties, a White House report known as the Packard Report recommended increased collaboration between national laboratories, universities and industry to ensure a better utilization of federal research investments[1]. This report formed the basis for increased industry/government collaboration.

In 1986, the government established the "Steel Initiative" through which industry/government collaboration can function. Beginning in 1986, the Department of Energy and the American Iron and Steel Institute (AISI) jointly organized a series of workshops to define the technology needed to move towards energy efficient and environmentally-friendly steel plants[1]. This resulted in a series of studies that identified the research needs to meet this goal.

The Steel and Aluminum Energy Conservation and Technology Competitiveness Act of 1988, also referred to as the Metals Initiative, was signed into law on November 17, 1988. Two major purposes of this law are to increase the energy efficiency and enhance the competitiveness of the American steel, aluminum and copper industries and to continue research and development efforts begun under the Steel Initiative[5]. A number of research activities were carried out under the Metals Initiative program during the time period between 1988 and 1995.

In 1995, DOE/OIT reorganized into industry Vision Teams to facilitate closer interaction and to asses the needs of the energy intensive industries. With the formation of Vision Teams in support of the Industries of Future at DOE/OIT, these collaborations have widened in scope for the support of the development of Industry Roadmaps. The technology challenges that face the steel industry are being identified as also the future goals and strategies in these roadmaps. The research projects that will be supported by DOE will be based on the requirements of the industry, thereby paving the way for improved and fruitful partnerships.

RESEARCH WITH GOVERNMENT SUPPORT

A number of steel research projects have been and are currently undertaken under industry/government partnerships. Although some of them need more work for commercialization, they are technological success. The following projects are examples of the steel research carried out with a government partnership. It also describes the anticipated benefits[5].

The first of the foundation projects researched smelting technology to produce molten iron directly from domestic coal and iron ore pellets known as direct steelmaking. The first phase of the program achieved the design production rate of five tons per hour. In the second phase steel containing one percent carbon was produced, but equipment limitations prevented an increase in productivity. In the third phase, higher production intensities were achieved. Although the technology remains to be proven at the demonstration scale, the research has led to other related programs such as post-combustion. The post-combustion technology is gaining acceptance in electric arc furnace steel making. In electric arc steelmaking, post-combustion is estimated to save 40 to 60 kWh per ton with 6 to 7 percent increase in productivity. The technology is expected to be applied to basic oxygen furnaces (BOF) also.

Another facet of direct steelmaking is the recovery of iron units from waste oxides. In this technology, steel plant waste oxides are smelted with coal to produce molten iron, offgas with a fuel value, and zinc rich sludge. The pilot plant trials have proven the technology to be viable. With this technology, the valuable carbon content in the dust currently disposed of in landfills can be recovered resulting in 15 to 20 percent savings in energy. This will also conserve resources and zinc, an environmental pollutant is recovered. Application of this technology to process four million tons of waste oxides would save about $100 million in disposal cost and provide operating benefit of about $116.7 per ton of molten pig iron[8]. The process offgas has fuel value that can be used for other heating purposes. The pilot-scale development has been completed.

A third project is the production of clean black scrap and zinc metal from galvanized scrap. The process consists of stripping zinc from galvanized scrap in hot caustic and electrowinning the zinc from the solution. The technology has been proven in pilot-plant stage and its demonstration on larger scale is being tried. Application of this technology to about 5 million tons of galvanized scrap is expected to yield an energy savings of 50 trillion Btus. In addition, savings in operating costs and reduction in zinc imports are also expected. The technology is also environment-friendly. With the elimination of zinc from the offgases, the BOF dust can be charged into the blast furnace to recover iron units. This technology is expected to be commercialized in the next 2 to 3 years.

A fourth project is the advanced process control for the steel industry. This project is aimed at developing sensor and control technologies for a range of processes from steel making to rolling and finishing. The tasks are in different stages of progress. Two of the tasks are complete and the sensors and gauges have been deployed on site. The annual energy savings potential is 6.13 trillion Btus, in addition to a reduction in production costs.

It is clear that government support has been forthcoming for research in energy efficiency as well as in risk prone areas. At the same time, government support is helping the steel industry to be competitive by aiding basic research. In addition to these industry/government partnership projects, the industry itself has begun a number of research projects including work on direct iron smelting, direct rolling, pre-heating and pre-reduction for energy efficiency and heat recovery in electric arc furnace steelmaking.

FUTURE STEEL MAKING TECHNOLOGIES

The steel industry is going through a technological revolution. Compared to the changes that took place a decade or two ago, the current technological changes are taking place fast. This is due to the competition and globalization of the steel industry. The technology drivers that influence the future steelmaking technologies that make the steel plants as profitable business are:

* Capital cost;
* Raw materials demand;
* Environmental impacts; and
* Customer requirements.[6]

All the above drivers are influenced by energy efficiency either directly or indirectly. Generally, the technology that reduces or eliminates energy intensive steps like cokemaking and blast furnaces also reduces the capital cost. Shortages of raw materials like coking coal and high quality scrap will lead researches in the direction of energy efficient and fewer processing steps. The efforts to combine the AISI-DOE smelting process with the Hoogovens Cyclone Furnace is an excellent example of research towards energy efficiency. It is well known that energy efficiency has a direct impact on the environment.

A number of alternative-iron processes such as Romelt, Corex and Cyclone furnace have built-in systems for waste energy utilization. The 1994 Canadian Metals Industry study on present and future use of energy in the Canadian steel industry indicates a reduction of about 48 percent in energy consumption for integrated mills and 61 percent for minimills. Table 3 shows the projected energy consumption.

Table 3. Present and Future Use of Energy in Canadian Steel Industry

Year	Integrated (Million Btu/ton) Crude Steel	Minimill Long Products (Million Btu/ton) Crude Steel	Minimill Flat Products (Million Btu/ton) Crude Steel
1989	22.70	9.50	10.80
2000	16.20	6.00	5.80
2010	11.90	4.70	4.20

Source: "Energy: Consumption, Cost and Conservation in Steel Industry," A.P. Martocci, *AISE Annual Conference, 1995*

In the above table, 1989 is taken as the base year. The year 2000 represents energy use with the best known technologies in operation. The year 2010 shows energy use with promising technologies being researched or developed today. This clearly establishes the applicability of the study to the steel industry as a whole.

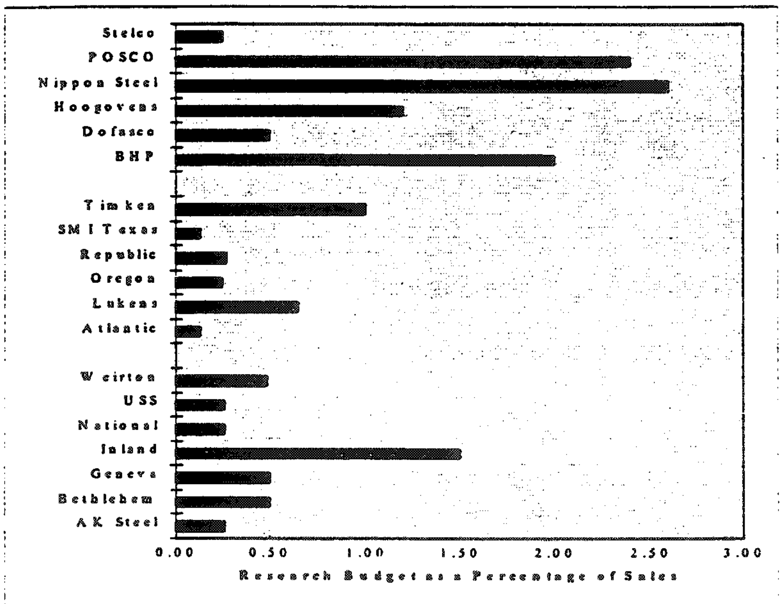
Some of the research priorities identified by the industry are as follows:

* Cleaner and energy efficient iron making processes;
* Recycling of in-plant wastes;
* Improved iron units for EAF and BOF charge;
* Flexible steel making processes to optimize resources and energy;
* Advanced process controls;
* Production rates of continuous casters;
* Strip casting; and
* Efficiency in utilities.

The list is not an exhaustive one, but shows the research trends addressed in both the short and long-term. All the above research priority areas involve energy efficiency either directly or indirectly.

Figure 6 shows the research budget as a percentage of sales for selected steel companies. The research budget as a percentage of sales of the American steel industry is much lower compared to the world-wide budget. Out of the total budget, the share of energy efficiency technologies could be a small percentage unless the energy efficiency is a part of the total technology. This situation makes the government/industry partnerships all the more essential for the U.S. steel industry to be competitive.

Figure 6. Research, Development and Technology Budget as a percentage of sales



Source : "Future Steel Making Technologies and the Role of Basic Research", R.J. Fruehan, *Iron and Steelmaker, July 1996*

Examples of technologies that are being tried elsewhere in the world include the injection of waste plastics into blast furnace with benefits such as reduced coke consumption. About 30 percent of energy content of the plastics is used thermally, with the remaining energy in the top gas[4]. The environmental impacts of this technology are being studied in Europe Another technology that is being tested is a twin-electrode d-c furnace. Benefits claimed of this technology are a 30 percent reduction in power consumption and 40 percent increase in productivity[4].

CONCLUSIONS AND OUTLOOK

Despite its resurgence, The U.S. steel industry continues to face significant challenges, one being the cost of energy. The industry has worked at reducing energy consumption and costs over time, yet energy efficiency efforts need to be continued.

The pressure to meet the challenges of the 21st century will demand efficient utilization of resources including energy. In doing so, there will be increased opportunities for partnerships between government, academia and industry. This in turn will leverage research and development investments.

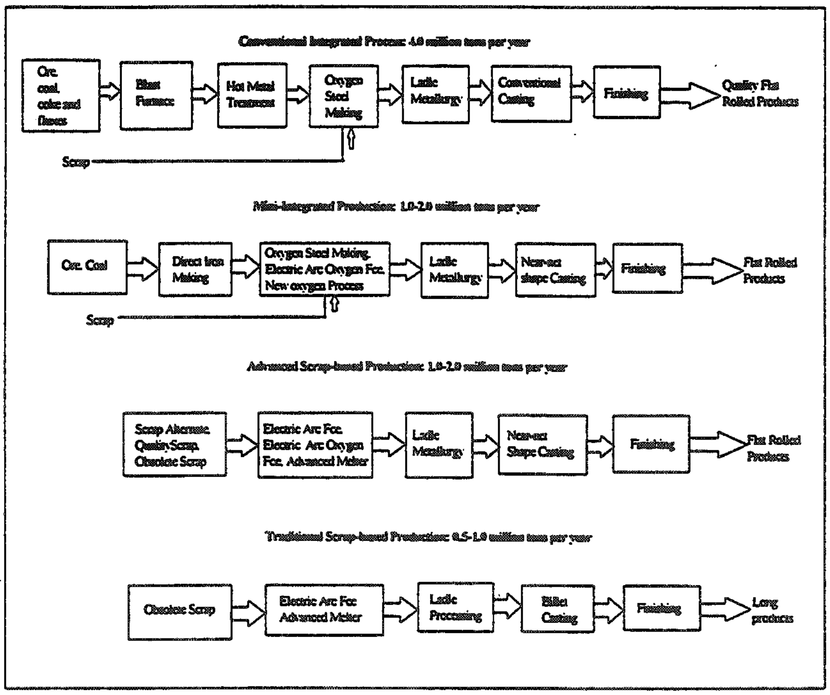
To achieve the goals of energy efficiency, high priority energy efficiency action plans need to be developed and implemented. This will include setting energy efficiency goals for the equipment and processes for both old and new steel plants. The energy cost reduction has to be addressed on both the fronts of energy unit cost and energy consumption. Energy unit costs are, however, subject to market forces as well.

The future steel making processes will have either energy efficiency technologies incorporated into the existing ones and/or a few of the conventional energy intensive processes skipped. There will be an outsourcing of operations between integrated and non-integrated mills. This would eliminate inefficient processes and plants.

Figure 7 shows the types of steel plants that may exist in the early 21st century. Efficient use of capital through high facility utilization rates and of energy through more efficient processing technologies would be the characteristics of successful future steel mills.

Some of the government actions could change the path of energy efficiency activities. Deregulation of electricity and the consequent availability of cheap power could have an impact on the steel industry. Non-integrated producers who use about 40 percent of their energy input in the form of electricity could have even more competitive edge over the others. The new Clean Air Act of 1990 would probably add net cost to all the producers. This makes energy efficiency all the more important in the future.

Figure 7. Steel Making Routes of the Future



Source: "Future Steel Making Technologies and the Role of Basic Research," R.J. Fruehan, *Iron and Steelmaker, July 1996*

Overall, the energy related activities and research will form an important part of the new technology development programs for the steel industry. The future of energy efficiency activities as well as the steel industry itself, will largely depend upon the collaborative efforts within the industry as well as between industry and outside resources, instead of on the efforts of individual companies. International affiliations and the transfer of technologies will be the norm, creating opportunities for international cooperation at here to fore unknown levels.

ACKNOWLEDGMENTS

The author would like to take this opportunity to express his gratitude for the support and guidance from the following persons.

1. Scott Richlen, Steel Team Leader, DOE/OIT.
2. Gobind Jagtiani, Program Manager, DOE/OIT.
3. Lawrence Kavanagh, Vice President, Manufacturing and Technology, AISI.
4. William Obenchain, Manager, Manufacturing and Technology, AISI.
5. Bill Gaylord, Program Manager, Vista Technologies, Inc
6. Tina Kaarsberg, Senior Professional, Vista Technologies, Inc.
7. Debra Crawford, Junior Professional, Vista Technologies, Inc.

The author also expresses his gratitude to American Iron and Steel Institute, Vista Technologies, Inc. and DOE/OIT for permission to publish this paper.

REFERENCES

1. Steel: A National Reource for the Future, AISI and SMA, May 1995
2. Energy and Environmental Profile of the Iron and Steel Industry, 1996, DOE/OIT.
3. State Energy Price and Expenditure Report, 1995, DOE/EIA.
4. Developments in the North American Iron and Steel Industry-1996, N.L. Samways, *Iron and Steel Engineer, February 1997*
5. Metals Initiative Annual Report-1995, DOE/OIT
6. Future Steelmaking Technologies and the Role of Basic Research, R.J. Fruehan, *Iron and Steelmaker, July 1996*
7. Recent Developments in Post-Combustion Technology at Nucor Plymouth, Daughtridge and Mathur, *Iron and Steelmaker, February 1995.*
8. Recovery of Iron, Carbon and Zinc from Steel Plant Waste Oxides Using AISI-DOE Smelting Technology, B. Sarma, K.B. Downing and E. Aukrust, *Iron and Steel Maker, December 1996.*