POLLUTION PREVENTION AT A PROFIT IN THE PRODUCTION OF IRON AND STEEL

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ABSTRACT
Many different processes and flow sheets exist for the production of iron and steel. These individual processes and process combinations consume differing amounts of energy and result in differing carbon dioxide emissions, greatly complicating evaluation of new, energy conserving technologies. Not only does a large array of competing energy saving technologies exist, but these technologies must be applied to this diverse set of production facilities.

A methodology now under development for performing a multiple pathways analysis that characterizes both energy usage and carbon emissions is described in this article. This methodology can examine multiple options at each step in the process for the production of iron and steel, and the potential economic and pollution prevention opportunities that each may have. A first order estimate of the role of energy and materials conservation in returning historical investment is also provided, demonstrating past pollution prevention at a profit. Finally, a preliminary analysis of selected strategies for further pollution prevention at a profit in the production of iron and steel is provided.

INTRODUCTION
On April 23, 1993, the 23rd anniversary of Earth Day, President Clinton committed the United States to reduce America's emissions of greenhouse gases (GHGs) to their 1990 levels by the year 2000. This commitment aligned the US position with the Framework Convention on Climate Change[1] agreed upon during the 1992 Earth Summit in Rio de Janeiro. Six months later, in October, 1993, President Clinton and Vice President Gore unveiled the Climate Change Action Plan (CCAP) that they estimated would reduce American GHG emissions to their 1990 levels by the year 2000, while saving the federal government $800 million dollars annually.[2] Since the drafting of the CCAP, it has become clear that the US cannot achieve this goal using only the **voluntary** pollution-prevention-at-a-profit programs outlined in the CCAP. Consequently, the Clinton Administration is considering other measures, including binding commitments, that would lower US GHG emissions to the 1990 level early in the 21st century.

It was estimated in the CCAP that 85 percent of the US GHG emissions (on a carbon equivalent basis) were carbon dioxide, resulting primarily from the combustion of fossil fuels. The remaining 15 percent result from emissions of gases with significant global warming potential. As shown in Table 1, the iron and steel industries alone account for two percent of the US total primary energy consumption, which results in over three percent of the US energy-related GHG emissions. [3,4]

Estimates of energy consumption by the US iron and steel industry show reductions ranging from about one percent per year over the past several decades[5,6] to over 40 percent[7] for 1975 through 1994. Historical data reported by the American Iron and Steel Institute (AISI) for 1975, 1980, 1985, 1990 and 1995[8] are examined in this paper to quantify the energy conservation per ton of crude steel (CS) produced in the US and the commensurate reductions in carbon emissions and fuel and materials costs which have occurred over the past twenty years. A procedure is then presented for estimating the potential for further reductions in energy usage per ton of crude steel produced and resulting carbon emissions and cost reductions. Finally, some *preliminary* results are presented for the potential for pollution prevention at a profit in the US iron and steel industry.

Table 1. Overview of US Energy Use and Carbon Emissions

Sector (SIC)	Energy Consumption (Quads)	Carbon Emissions (Mtons)	% of Total
Overall US Total[3]	90.9	1,723	
Industrial Total[3]	33.8	562	33
Iron and Steel (331)[4]	1.8	55.1	3.2
Chemicals (28)[4]	5.5	80.0	4.6
Petroleum Refining[4]	5.9	57.6	3.3
Pulp and Paper(26)[4]	3.3	90.4	5.2
Cement (32)[4]	0.3	23.0	1.3

1975 - 1995

The historical data is examined in the following section to calculate energy consumption reductions per ton of crude steel produced, as well as carbon emission reductions and the resulting pollution prevention at a profit which may have occurred.

Fuel and Material Consumption

The historical fuel and materials consumption figures for US iron and steel production are available annually from the AISI.[8] Values for the various fuel and other material inputs consumed and US crude steel production figures for 1975, 1980, 1985, 1990 and 1995 are presented in Table 2.

Carbon Emission, Energy and Cost Factors

Carbon emission, energy and cost factors employed in the calculations in this paper are presented in Table 3. Assumptions used to develop specific factors were as follows:

Carbon Emissions

- Except as noted, carbon emission factors are from reference 3.
- All coal is 75% carbon and all carbon is released to the environment as CO_2. This is a small over estimate of carbon emissions, as a small amount of carbon remains in the steel and in the chemicals produced from the coke oven liquor.
- The total carbon emissions associated with coke consumption are the ratio (CCR) of coal used to produce coke divided by the coke produced, times the amount of coke consumed, times 75% carbon in the input coal. This allows for a charge to the iron and steel industry for coke purchases.
- Fuel oil is high-sulfur number 6 residual fuel oil which contains 85% by weight carbon, has a specific gravity of 0.96 and a heating value of 146,000 Btu per gallon. [10]
- Natural gas is pure methane and there is 12 pounds of carbon per 359 standard cubic feet.
- Average emissions for US electricity generation are 352 pounds (160 kg) carbon per MWh. [11]
- Carbon emissions for oxygen production are associated with energy consumption of 260 kWh per ton of oxygen produced (0.4 kWh per nm^3). [12]
- Limestone is 12% carbon by weight.
- Lime production from limestone requires 1/3 ton of coal per ton of lime produced, resulting in total emissions of 0.44 tons carbon per ton lime produced.
- Direct reduced iron (DRI) production requires 8.6 MBtu per ton (10 GJ/tonne [13]) which is primarily derived from natural gas resulting in emissions of 0.144 ton carbon per ton DRI produced.
- Pellet production accounts for 0.06 ton carbon per ton pellets.
- Sinter production results in emissions of about 0.1 ton carbon per ton sinter.
- Emissions associated with transportation and mining are not included in this analysis.

Energy

- Energy factors were taken from reference 9, except as noted above.

Table 2. Fuel and Materials Consumption in US Iron and Steel Production

Input	Input Units	Year				
		1975	1980	1985	1990	1995
coal for coke	kton	75,515	58,446	34,266	33,807	26,239
coke produced	kton	51,556	42,128	23,948	24,032	19,253
coke consumed	kton	49,393	39,276	25,996	27,605	24,568
other coal	kton	3,101	3,011	2,495	1,485	1,509
fuel oil	kgal	1,449,211	700,345	233,397	302,000	167,228
natural gas	Mft^3	576,939	560,312	347,775	393,647	414,802
purchased electricity	MkWh	40,336	43,585	44,060	37,355	35,863
oxygen	Mft^3	230,477	214,446	163,489	199,416	288,103
limestone	kton	2,247	1,023	760	728	1,241
lime	kton	7,110	6,446	4,611	4,462	3,898
carbon steel scrap	kton	56,341	58,950	48,453	46,144	57,200
stainless steel scrap	kton	754	1,501	1,127	1,020	1,200
alloy scrap	kton	1,859	1,700	1,446	870	870
iron scrap	kton	3,454	3,274	1,415	656	880
other scrap	kton	1,220	1,735	1,008	1,399	1,600
direct reduced iron	kton	516	715	349	781	1,650
natural ore	kton	NA	NA	3,300	2,791	1,385
pellets	kton	69,816	72,562	57,055	66,758	74,564
sinter	kton	35,279	27,901	17,928	13,491	13,847
crude steel production	kton	116,642	111,835	88,259	98,906	104,930

Costs

- Fuel and materials costs presented in Table 3 are at 1995 average prices.
- Capital costs presented in Table 4 have been adjusted for inflation.
- Fuel costs are from reference 3.
- Other materials costs are from reference 14, except as noted.
- Scrap is assumed to have an average cost equal to that of number 1 heavy melting steel scrap.
- Costs for sinter, pellets and ore are from reference 15.

Pollution Prevention at a Profit

Based upon the fuel and material inputs, carbon emission and energy factors, and crude steel production figures presented above, energy consumption fell in the 1975 to 1995 time frame from 2.81×10^{10} to 1.72×10^{10} Btu per thousand ton (Btu/kton) of crude steel produced - a decrease of 38.7 percent - and carbon emissions were reduced from 0.77 to 0.47 tons carbon per ton of crude steel - a 39.8 percent reduction, see Table 4. This energy reduction per ton of crude steel is in very good agreement with "more than 40% reduction in energy consumption per ton of steel shipped" reported by Martocci[7] for the 1975 to 1994 time frame. The total energy consumption for crude steel production in 1995, the product of the unit energy and the total annual production, equaled 1.81 Quads. While firm 1995 energy use statistics are not available, this calculated value is close to the 1.82 Quads reported for total crude steel production in 1994[9]. (The 1994 production was 4% less than the 1995 production.) Assuming a constant 100,000 tons per year of crude steel production, total carbon emissions in 1995 were over 30 million tons less than what would have been expected at 1975 energy consumption rates. At the same time, 1995 fuel cost savings of almost $2 billion, and fuel and materials cost savings of almost $1.4 billion were achieved.

Table 3. Carbon Emission. Energy and Cost Factors

Input	Input Units	Carbon Emission	Energy Rate	Cost	
		kton C / Unit	Btu/unit	$/MBtu	$/unit
coal for coke	kton		2.68×10^{10}	1.75	46.900
coke produced	kton				
CCR = ton coal / ton coke	kton/kton				
coke consumed	kton	CCR*0.75	CCR x 2.68×10^{10}	CCR*1.75	
other coal	kton	0.75	2.68×10^{10}	1.48	39.664
fuel oil	kgal	0.0034	1.46×10^{8}	2.55	372
natural gas	Mft^3	0.0167	1.00×10^{9}	2.28	2.280
purchased electricity	MkWh	0.176	1.05×10^{10}		49.600
oxygen	Mft^3	0.00275	1.83×10^{8}		575
limestone	kton	0.12	0		4,160
lime	kton	0.44	0		52.310
scrap	kton	0	0		122,750
direct reduced iron	kton	0.144	0		111.000
natural ore	kton	0	0		18.000
pellets	kton	0.06	0		28.000
sinter	kton	0.1	0		10.000

Table 4. Annual Emission Reductions and Operating Savings and Capital Expenditures

	Year				
	1975	1980	1985	1990	1995
Energy Consumption (10^7 Btu / ton CS)	2.81	2.41	2.12	1.97	1.72
Carbon Emissions (ton C / ton CS)	0.77	0.66	0.57	0.53	0.47
Annual Energy savings (M1995$ / 100,000 tons CS)		$623	$877	$1,522	$2.066
Annual Material and Energy Savings (M1995$ / 100.000 tons CS)		($141)	$93	$1,952	$1.374
Annual Carbon Emission reductions (Mton C / 100.000 tons CS)		10.6	18.6	22	27.9
Capital Expenditures (M1995$)	$6707	$4883	$1976	$2682	$2,395

Significant capital investment was made by the US iron and steel industry for new productive capacity, replacement of aging capacity, and increased labor productivity between 1975 and 1995. As shown above. this investment has also resulted in large improvements in energy efficiency and reductions in carbon emissions. The data - a portion of which is shown in Table 4 - can be used to estimate the net present value of the investment made after credit is taken for energy and materials savings. The net present value analysis of only total investments and energy and materials savings suggests that these savings contributed substantially to the profitability of the industry, with over 60% of the present value of the investment returned through savings in energy and materials.

THE FUTURE

Electric arc furnace (EAF) production increased from under 20 percent to over 40 percent of total steel production and continuous casting from less then 10 to over 90 percent of US steel production from 1975 to 1995. [8] It is, thus, unlikely that the tremendous savings in energy and the reductions in carbon emissions that these technologies have brought to iron and steel making can be projected to continue in the future. There are, however, many technologies in use in other countries or under development, that might result in significant energy savings and pollution prevention at a profit. The IISI, for example, enumerates eight technologies that are in use in the production of crude steel in Europe for reducing carbon emissions. [11] Only one of these, coal injection into the blast furnace, is practiced in the US, and of the 47 US blast furnaces, only 15 furnaces at 7 sites are equipped for coal injection. These 15 furnaces account for about one third of US hot metal production. Based on the European experience, substantial potential exists for increasing the amount of injection at these facilities and for extending the technology to other furnaces.

The CANMET study of the Canadian iron and steel industry showed very significant energy reductions were possible in that country between 1990 and 2020 using technologies with reasonable rates of return. [16] This analysis was based upon a mathematical model for integrated and EAF steel plants which followed from an earlier IISI study[17] of energy consumption in iron and steel production. The complexity and interactions of new processes added to the flow sheet for iron and steel production necessitates such a model approach. The following sections describe the methodology employed in this work to analyze the potential for future energy and carbon emission reductions, and the results of some preliminary assessments.

Technical Options

A large number of options that could be applied to reduce energy consumption and carbon emissions was identified by searching the open literature. These options are presented in Tables 5 and 6 along with estimates for their energy-conservation and carbon-emission-reduction potentials and costs. Entries are from actual installations when data were available or from engineering calculations when plant data were unavailable.

Conservation Supply Curve Methodology

Conservation supply curves were developed in the 1970's as a means of representing the aggregate energy conservation potential of energy efficiency technologies and measures. [23,24] Specifically, the conservation supply curve shows the cumulative energy savings available at a given level of average cost, e. g., dollars per million Btu. Conservation supply curves are created by ranking options by their cost of conserved energy, which accounts for both the costs associated with implementing and maintaining a particular technology or measure and the energy savings associated with that option over its lifetime.

The ranked options can then be added to the curve in order of increasing average cost. With each increment of average cost, the available increment of energy savings is added to the curve. Care must be taken in constructing the curve to avoid double-counting in cases where the application of one option either affects or depends on the implementation of other options. This is an important issue and is not trivial to implement. For example, in the case of a steel plant, energy efficiency may be improved by coal injection, replacing coke utilization. This, however, changes the analysis of conservation measures at the coke plant. Similarly, blast furnace gas may be used in a power boiler, but this reduces its availability for coke oven underfiring or for the hot blast stoves.

The conservation supply curve method is an important policy tool, because of its value in showing conservation potential. However, improperly constructed it can mislead the policy debate. Therefore, a simulation model of iron and steel production has been constructed to assure that proposed conservation options are properly represented. Furthermore, a model is essential to clarify the impact of conservation measures on net CO_2 emissions.

Table 5. Energy-Conserving and CO_2-Emission Reducing Technologies for Integrated Steelmaking

Option	Energy Savings	CO_2 Reduction (% of total emissions)	Operating Cost Savings	Retrofit Capital Cost	New plant Capital Cost	Remarks	References
Conversion of open hearth to basic oxygen furnace steelmaking						No open hearth facilities operating in the US since 1992.	
Iron Ore preparation							
Pelletized ore feed						Use of pelletize ore feed increasing. Sinter is only 17% of the blast furnace feed (1994) and has been declining since 1980.	
Sinter plant heat recovery	0.39 GJ/tonne sinter	0.3%		2-3 US$/tonne sinter		Based on recovery system at Hoogovens, The Netherlands.	18,9
Sinter feed material optimization							
Coke Preparation							
Coke plant dry quenching	800-1200 MJ/tonne (400-500 kg steam/tonne coke, or 80-100 kWh/tonne coke)	0.7%	increase	depends strongly on lay-out of coke plant	~90-100 US$/GJ-saved energy	Very expensive, also reduces dust emissions.	19
Variable speed drive coke oven gas compressor	6-8 MJ/tonne coke	0.001%		0.3 US$/tonne coke		Data based on actual experience at Hoogovens, Netherlands. Savings depend on load variation.	18
Coke moisture control	300 MJ/tonne						
Iron Making							
Pulverized coal injection into blast furnace	0.6 GJ/tonne hot metal (1.08 kg coal/kg coke)	1.5%	10% increase	50-55 US$/tonne coal injected	1994 coal injection was only 2 kg/tpi [9]	Assumes injection of 130 kg/tpi, 6.9 GJ/tonne coke.	18,19
High-levels of coal (400 kg/tonne) injection						Long term option. Currently the highest possible injection levels without rebuilding are 180 kg/tonne hot metal. Current efforts are aimed at increasing this to 250 kg/tonne hot metal. Injection levels of 400 kg/tonne hot metal would require rebuilding of the blast furnace.	

Table 5. Energy-Conserving and CO_2-Emission Reducing Technologies for Integrated Steelmaking (continued)

Option	Energy Savings	CO_2 Reduction (% of total emissions)	Operating Cost Savings	Retrofit Capital Cost	New plant Capital Cost	Remarks	References
Iron Making (continued							
Blast furnace top pressure recovery turbine	23-30 kWh/tonne hot metal (~80-100 MJ/tonne hot metal) 80% utilization	0.9%		20-28 US$/tonne hot metal [20]		Savings and costs depend on pressure in BF, capacity of BF and gas cleanup system. Energy savings based on Hoogovens actual data.	18,20
Recovery blast furnace gas during charging	66 MJ/tonne hot metal (3.2 PJ at 1994 prod.)	0.2%				Normally losses of 1.5% of total production.	18
Recuperator hot blast stove	< 80 MJ/tonne hot metal	0.2%		18-20 US$/GJ-saved		Cost data based on Hoogovens.	18
Off gas recycling							
Improved blast furnace process control						Experiences in Finland have lead to reduction of coke use and increased productivity.	16
AISI smelting reduction	4-6 GJ/tonne hot metal	10-14%		Option for 2010	160 US$/tonne hot metal	Replaces coke ovens and blast furnace. Assumes 21.95 GJ/tonne hot metal in 1994 [9]	21 + own estimates
Romelt smelting reduction						Romelt saves no energy (uses 40-45 GJ/tonne hot metal) due to very high coal and oxygen use, but is a recycling process for zinc containing mill dusts.	own estimates
CCF smelting reduction	8-10 GJ/tonne hot metal	20-25%		Option for 2010	150-180 US$ /tonne hot metal	Replaces coke ovens, ore preparation and blast furnace.	21 + own estimates
DIOS smelting reduction	2-5 GJ/tonne hot metal	5-13%		Option for 2005-2010	150-200 US$ /tonne hot metal	Replaces coke ovens, ore preparation and blast furnace.	21 + own estimates
Corex smelting reduction	3-6 GJ/tonne hot metal	7-15%			210-250 US$ /tonne hot metal	Replaces coke ovens and blast furnace.	16, 21 + own estimates
Basic Oxygen Furnace							
BOF gas + sensible heat recovery	< 916 MJ/tonne crude steel [16]	2.6%	material losses reduced to 1% [22]	13 US$/tonne crude steel		Retrofit costs based on Hoogovens retrofit of two convertors.	22, 16
Casting							
Increased continuous casting to 100%	2.48 GJ/tonne crude steel	1%	reduced material losses are important (not accounted for)			Assume that current continuous casting ratio of 89.5% (1994) increases to 98%.	16

Table 5. Energy-Conserving and CO_2-Emission Reducing Technologies for Integrated Steelmaking (continued)

Option	Energy Savings	CO_2 Reduction (% of total emissions)	Operating Cost Savings	Retrofit Capital Cost	New plant Capital Cost	Remarks	References
Casting (continued)							
Efficient ladle preheating and drying	Energy use can be reduced to 0.02 - 0.03 GJ/tonne crude steel by using recuperative burners/computer control.					No data available on energy use in ladle preheating in the US. Generally up to about 0.06 GJ/tonne crude steel.	19
Ladle processing						Ladle refining may increase scrap use BOF, however, scrap use in BOF is quite high. Higher scrap use is only feasible using fuel injection into BOF.	
Rolling							
Hot connection	< 0.8 GJ/tonne hot rolled steel	2%				Assuming 60% of hot rolled intake is treated and a transport temperature of 700°C.	11
Efficient reheating furnaces	1.4 GJ/tonne hot rolled steel	6.4%				Current energy use is 3.2 GJ/tonne [9] CO_2 savings assumes 88.5 Mtonnes are treated in hot rolling mill.	19
Efficient power use in the hot strip mill	95 kWh/tonne hot rolled steel (340 MJ/tonne hot rolled steel)	4.7%				Current hot strip mill energy use in U.S. is 200 kWh/tonne (720 MJ/tonne) [9] CO_2 savings assumes 88.5 Mtonnes are treated in hot rolling mill. A hot strip mill can use about 105 kWh/tonne (378 MJ/tonne) (Hoogovens).	19
Thin slab casting	2.6 GJ/tonne hot rolled steel	7.1%	cost reduction of 20-25%	replaces casting and hot strip mill	30-60% lower, depending on capacity	Assumes 60% of strip can be treated. Current processes include CSP, ISP, ConRoll.	21
Heat recovery at the annealing line	82 MJ/tonne hot rolled steel	0.06%		0.9 S$/tonne (Extra costs compared to standard annealing mill)		Energy savings based on actual experience at Hoogovens. In US, estimated 13 Mtonnes production in 1994 [25] Total savings in US would be 1.1 PJ.	18,19
General O&M							
Good housekeeping	0.4 - 0.6 GJ/tonne crude steel (2% savings following experiences in European Union)	2%	N.A.	N.A.		Typically 2-5% savings.	
Energy monitoring and management system	~0.3-0.5% of total energy use	0.3 - 0.5%		0.15 US$/tonne crude steel		Savings will depend on current degree of energy management systems.	18

Table 6. Energy-Conserving and CO_2-Emission Reducing Technologies for EAF Steelmaking

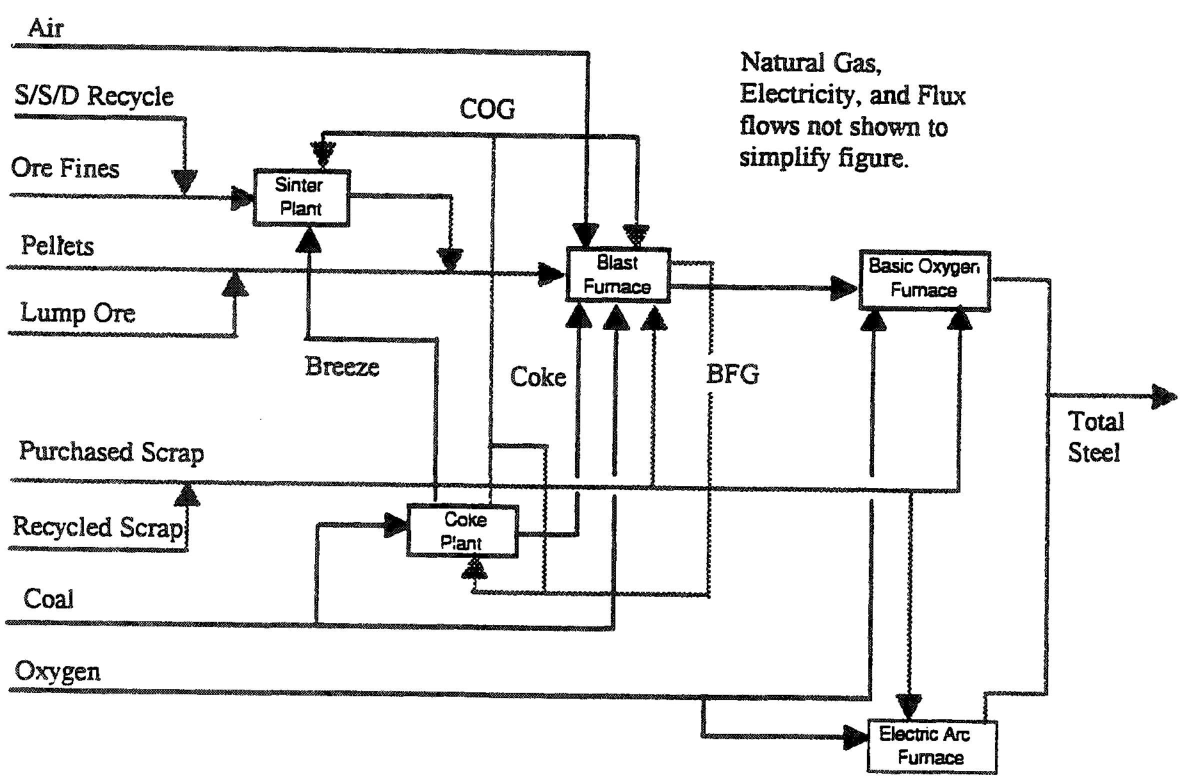
Option	Energy Savings	CO_2 Reduction (% of total emissions)	Operating Cost Savings	Retrofit Capital Cost	New plant Capital Cost	Remarks	References
Coal and oxygen injection							
Natural gas and oxygen injection	20-30kWh/tonne crude steel	0.4%				35.87 Mtonnes EAF production [25]	
Foaming slag							
High power furnaces	2kWh/tonne crude steel per 2 MW						
DRI feed stock						Use of DRI or another Fe-feedstock is considered to upgrade the quality of the product, as is need to cast in thin slab casters. At 15% DRI-addition electricity consumption will be slightly lower. However, DRI production consumes about 11 GJ natural gas/tonne and 110 kWh/tonne DRI.	
Stirring gas injection	5-30kWh/tonne crude steel	0.1 - 0.6%					
Oxy-fuel burners	4.4 kWh/tonne crude steel for each Nm^3 O_2						
Scrap pre-heating	< 90kWh/tonne crude steel increased fuel use	< 1.5%					
Improved process control	8-38kWh/tonne crude steel	0.2 - 0.8%					
Cooling of furnace walls and roof	0.24 GJ/ tonne crude steel 46 kWh/ tonne crude steel	1.4%					
Energy optimized furnace							
Shaft furnace (Fuchs)	< 100 kWh/ tonne crude steel (increased NG use of 0.25 GJ)	< 1.6%				Operating at Sheerness, UK.	
DC-arc furnace	< 150 kWh/ tonne crude steel	< 3.0%	lower				
Casting and rolling						Similar technologies can be applied as in integrated plants, although CSP is favorable at low capacities.	

Integrated Steel Plant Model

Model development is the art of balancing the need for detail against the cost of obtaining and representing that detail. All models experience revision in scope as they are applied to increasingly complex problems. At this early stage of model development the model is able to represent the overall effects on materials and energy use of many changes in steel plant operations. For many other changes, additional enhancements will be required, but the structure of the current model can readily support such enhancements. As emphasized above, the model provides a generic context for testing the application of energy conserving technologies with the resulting changes in materials and energy flows used to calculate the net effect on CO_2 emissions.

The model is being developed as a series of linked spreadsheets. Each major process in steel manufacture is modeled on a separate sheet of an Excel workbook. For clarity, each spreadsheet represents a unit operation model as a simple line diagram of the process. In addition to the process models, an overview is presented on a separate sheet showing the major energy and materials links between processes. Figure 1 shows this overview diagram somewhat simplified for legibility. The individual process models are linked by materials and energy flows. Figure 1 shows that the model represents an extended integrated steel plant in that both a basic oxygen furnace (BOF) line and an electric arc furnace (EAF) line are used. The key input to the model is total net production requirement in tons per day. At the overall plant level, the user can specify the mix of BOF and EAF production. All other parameter selections are made on the specific process sheets. The process models currently include coke plant, sinter plant, hot blast supply, BOF, EAF, and blast furnace. Models for casting, forming and finishing will be added.

Figure 1, Overview of Integrated Steel Plant Model



The model was originally conceived as a single plant model. However, to check model precision, it was treated as a model of overall US steel production. That is, the total average daily production (tons per day) was input on the overview along with the 1995 mix of BOF and EAF production, and the model was used to calculate the material inputs, energy use, and CO_2 emissions. The results were compared against AISI statistics for 1995. Initially, some coefficients were adjusted to force agreement with the statistics. Essentially, this amounts to calibrating the model to current operating practice. This exercise produced two very useful results. First, the calibrated model can be regarded as representative of average plant practice so that subsequent analysis on the individual plant level is calibrated to that practice. Second, it suggests that the model may be useful at the overall industry level to examine the impact at that level of changes in technology. We are aware of the risks here because of plant diversity, but believe this approach to have promise in policy evaluations.

In general, the model traces material and energy flows through the plant using the principles of mass and energy conservation supplemented by coefficients from representative industry practice. For instance, the blast furnace has 10 materials inputs, including iron sources, fuels, oxidants, and fluxes. Consumption of each material input is calculated in proportion to the hot metal production according to representative practice. The hot metal production is determined by input requirements for the BOF that, in turn, are determined by the share of production allocated to the BOF. Default coefficients selected to represent average practice may be replaced by user-selected values. Co-products, such as blast furnace or coke oven gases and slag, are also calculated. The utilization of byproduct gases is particularly important to the plant energy balance. Further development of the model is now focused on its role as a context for evaluating conservation options, such as those presented in Table 5. In some cases, model refinements are required to properly represent a technology. Additional development needs include a parallel cost model and modules for upstream and downstream activities to better represent full life-cycle implications.

Some interesting results have been obtained with the current model. Examples include estimation of the CO_2 reduction benefits of increased coal injection, changes in the mix of BOF and EAF output, changes in scrap feed to the BOF, and the use of top gas pressure recovery on the blast furnace. These results are presented using the model as a model of the industry as a whole calibrated to 1995 operations as described above. An increase of coal injection from the current average level of about 50 lb. coal per ton of hot metal to a technical limit of about 400 lb. coal per ton of hot metal results in a carbon emission reduction of 3.0 million tons or about 6% of current emissions. An increase in EAF production from the current 40% level to 45% of total steel production will result in a reduction of about 2.4 million tons of carbon per year or 5% of current emissions. Increasing scrap feed to the BOF is a similar strategy to a shift to EAF. An increase from 10% of feed as scrap to 20% of feed as scrap results in a reduction of 4 million tons of carbon per year. As a final example, the universal application of top gas turbines to recover energy from blast furnace gases would reduce carbon emissions by about 0.5 million tons per year.

Conclusions

Our analysis to date has demonstrated that energy and materials savings associated with steel plant capital investments since 1975 have contributed substantially to the recovery of those investments, assisting the industry in achieving profitable operation. At the same time, those investments have dramatically reduced energy use and the associated carbon emissions. The evaluation of new investment opportunities that offer energy conservation benefits is essential to understanding the potential for further emission reductions. However, the diversity of the industry and of the available technologies makes such an evaluation very challenging. A promising approach is to develop conservation supply curves using a mass and energy balance model to evaluate individual technologies in the context of an integrated plant. Such a model is also useful to obtain first order estimates of possible benefits these technologies may offer when applied industry-wide.

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