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THE IRON AND STEEL INDUSTRY PROCESS MODEL

MASTER

by

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SUMMARY

THE IRON AND STEEL INDUSTRY PROCESS MODEL

The model depicts expected energy consumption characteristics of the iron and steel industry and ancillary industries for the next twenty-five years by means of a process model of the major steps in steelmaking from ore mining and scrap recycling to the final finishing of carbon, alloy and stainless steel into steel products, such as structural steel, slabs, plates, tubes and bars. Two plant types are modelled-fully integrated mills, and mini-mills.

User determined inputs into the model are:

(a) projected energy materials prices for the horizon

(b) projected costs of capacity expansion and replacement

(c) energy conserving options — both operating modes and investments

(d) the internal rate of return required on projects

(e) growth in finished steel demand.

Nominal input choices in the model are:

(a) Department of Energy base line projections for oil, gas, distillates, residuals, and electricity for energy, and 1975 actual prices for materials

(b) actual 1975 costs

(c) see attachment; new technologies can be added

(d) 15% after taxes

(e) 1975 actual demand with 1.5% growth/year

The model starts with base year (1975) actual performance of the industry; then given (a) thru (e) above, the model determines the pattern of operation and capacity expansion which minimizes the cost of meeting the given final demands for each of five years, each year being the mid-point of a five-year interval.

Output of the model includes:

(a) energy use by type, by process, and by time period, both in total and intensity (Btu/ton)

(b) energy conservation options chosen

(c) utilization rates for existing capacity, and the capacity expansion decisions of the model.

Energy Conservation Options

I. Raw Material Purchasing, Mining and Mine Mouth Processing

(a) Increased dependence on imported pellets and concentrates.

(b) Increased use of recycle, prompt, and obsolete scrap.

II. Raw Material Processing at the Plant

√(a) Dry coking process substituting for the conventional wet quenching process.* (5000)

III. Iron Production

(a) Substitution of coke for hydrocarbons as a source of BTU's.

(b) Substitution of powdered coal for coke as a source of BTU's.

(c) Operation of blast furnaces at higher temperatures to improve combustion efficiency (requires relining and rebricking).

√(d) Installation of bell-less tops.

√(e) Construction of new blast furnaces capable of higher top pressures.

(f) Increase burden quality by shift to high pellet charges.

√(g) Construction of the so-called "Jordan" blast furnace, which has been characterized as a coal gasifier with by-product iron.* (10,000)

IV. Steel Production

√(a) Higher scrap charges for BOF's by installation of scrap preheaters.* (4500)

√(b) Increased use of off-gases from other processes as a source of BTU's.

√(c) Substitution of BOF furnaces for the less sufficient open hearth furnaces.

*Requires expenditures of R&D before use; amounts, in thousands of dollars, in parentheses. Source-industry and government estimates.

√Qualifies for investment tax credit.

√(d) Conversion of open hearth furnaces to Q-BOF.

√(e) Increased use of oxygen injection.

√(f) Installation of hoods for collection of steel making off-gases on BOF's, open hearth, and electric arc furnaces.

V. <u>Casting and Forming</u>

√(a) Use of continuous casting of slabs* and billets. (13,000)

VI. <u>Finishing Mills</u>

√(a) Mono-beam reheat furnaces substituting for pusher type reheat furnaces.* ( )

VII. <u>Energy Conversion Processes</u>

(a) Increased use of low quality off-gases by blending with higher quality gases.

√(b) Co-generation of steam and electricity.

√(c) Use of coal off-gas boilers.

√(d) Use of gas turbines for co-generation.

*Requires expenditures of R&D before use; amounts, in thousands of dollars, in parentheses. Source-industry and government estimates.

√Qualifies for investment tax credit.

THE IRON AND STEEL INDUSTRY PROCESS MODEL

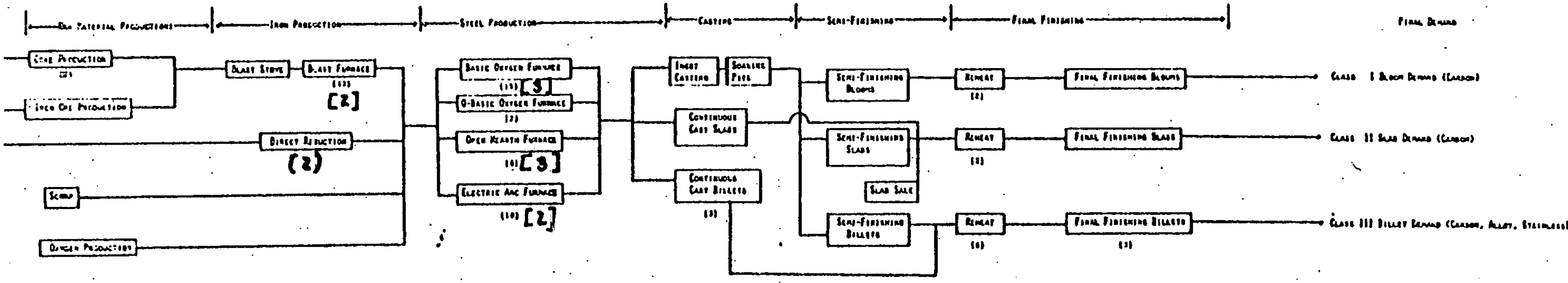
I. INTRODUCTION

The model is a dynamic activity analysis model of two types of mills in the Domestic Iron and Steel Industry* - integrated and mini-mills - whole activities are based upon the flow diagrams shown in Tables 1 and 2. In order to capture the bulk of the indirect energy used in the industry as well as the direct energy, the industry model includes extraction and transportation of the major raw materials - iron ore mining, concentrating and transportation, coal mining and transportation, and scrap "mining" and transportation. The two types of operations represented in the model are: (a) fully integrated plants which have the capacity to beneficiate iron ore, produce coke, convert iron ore to iron in blast furnaces, convert iron to steel by any of four types of steel furnaces, semi-finish and finally finish steel; (b) "mini-mills," which convert scrap to steel in electric arc steel furnaces.

Three types of steel are produced - carbon, alloy and stainless. Carbon steel is fabricated into three classes of products: (a) heavy structural steel, rails and other bloom based products; (b) plates, forms and other slab products; (c) tubes, bars, and other billet products. Mini-mills produce a more limited range of products, production being confined to structural bars and light forms. The mini-mills compete with the integrated mills for this particular demand. The specialty steels are made only in electric arc furnaces for quality control reasons.

*This is hardly a novel idea: the first to appear in the Operations Research literature was Tibor Fabian's effort 20 years ago!

Flowchart of Integrated Steel Industry

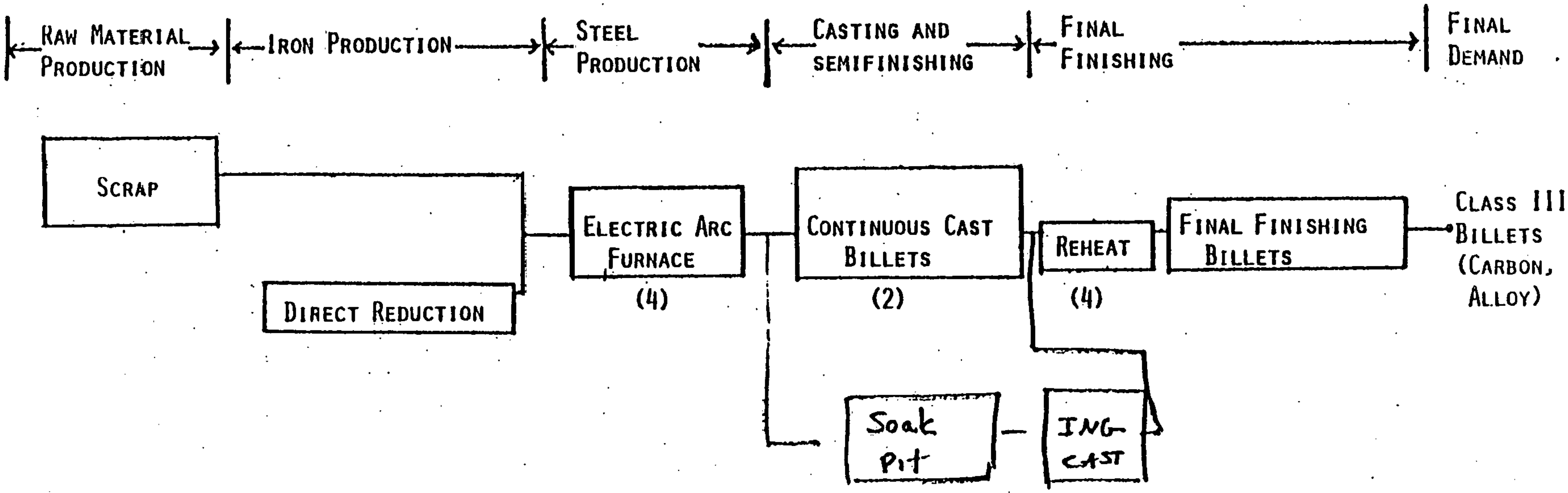


(Number of options in parentheses)

[number of vintages in brackets]

TABLE 1

FLOWCHART OF MINI-MILL STEEL INDUSTRY



(NUMBER OF OPTIONS IN PARENTHESIS)

TABLE 2

Capital stocks are vintaged, according to their ability to be retrofitted with more modern ancellary energy conservation equipment, as well as by size and age, which are reflected in higher operating and maintenance costs for older, smaller scale equipment. The number of vintages and the number of operating technology options are listed below each process in Table 1.

The demand for domestic steel, and the supply of both scrap and domestic iron ore are prices sensitive in the model, in that domestic steel competes for domestic demand with imports, while domestic ore competes with ore imports for the domestic ore demand. The exhaustible nature of domestic ore is reflected by constraints on the availability over the 25 year horizon of three "ore bodies," each with their own extraction costs. The supply of scrap's price sensitivity is based on a recent econometric study done by Hogan and Koeble (see Reference XXIII).

The model is a "technocratic" model of the iron and steel industry in that the industry is assumed to act collectively so as to minimize the cost of producing a given set of demands. Thus, it acts as if it were a cartel or monopoly, assigning units of output to the least cost available method for producing it, without regard for who owns the capacity being utilized.

To the extent that the existing steel industry departs from this mode of operation, the model departs from a positive description of industry behavior, and becomes instead a normative model. Certainly some departure from cost-inimizing behavior is observed in the industry - otherwise, more of the aller, less efficient capacity of the marginal producers would have been eplaced by the large, more modern units of the best practice plants and firms, tead of lingering around the industry, as these units are observed to do.

Nonetheless, market forces to work, even in an industry dominated by large firms, and such marginal plants cannot last forever by selling "below cost" to meet the competition; sooner or later, they will be closed down, and replaced with more modern equipment.

The model has five periods, each representing the middle year of a five-year interval; the planning horizon is 25 years. The initial capacities and demands are those for the industry in the 1974-75 time period.

The optimization problem is given: (1) the sequence of demands that must be met by domestic production or imports; (2) initial capacities, vintages and characteristics of the capital stock; (3) current and projected prices for all inputs including energy; (4) the available modes of operation for each of the activities; (5) an estimate of capital availability in the form of retained earnings and new issues to finance expansion and replacement of equipment (assumed to be a function of the final demand growth rates in the model and the historical relation between demand and capital availability); to choose the time sequence of production, capacity expansion, and the capacity retrofit decisions which minimize the present value of the cost of producing the demand, using as the discount rate the cost of capital for the iron and steel industry, taken as 15% after taxes.

Table 3 lists the energy flows for the entire industry in 1973, expressed in 10^6 BTU's per ton of finished steel produced.* Table 4 gives the operating options, retrofit opportunities, and capacity additions which can potentially contribute to total energy conservation in the industry, or reduce the

*Derived from data contained in: A Study of Improved Fuel Effectiveness in the Iron and Steel and Pulp and Paper Industries, Thermo Electron Corporation, Wortham, Mass., 1976; prepared for National Science Foundation's Office of Energy Policy.

TABLE 4

Energy Conservation Options

I. Raw Material Purchasing, Mining and Mine Mouth Processing

(a) Increased dependence on imported pellets and concentrates.

(b) Increased use of recycle, prompt, and obsolete scrap.

II. Raw Material Processing at the Plant

✓(a) Dry coking process substituting for the conventional wet quenching process.* (5000)

III. Iron Production

(a) Substitution of coke for hydrocarbons as a source of Btus.

(b) Substitution of powdered coal for coke as a source of Btus.

(c) Operation of blast furnaces at higher temperatures to improve combustion efficiency (requires relining and rebricking).

✓(d) Installation of bell-less tops.

✓(e) Construction of new blast furnaces capable of higher top pressures.

(f) Increase burden quality by shift to high pellet charges.

✓(g) Construction of the so-called "Jordan" blast furnace, which has been characterized as a coal gasifier with by-product iron.* (10,000)

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✓(a) Higher scrap charges for BOF's by installation of scrap preheaters.* (4500)

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√(f) Installation of hoods for collection of steel making off-gasses on BOF's, open hearth, and electric arc furnaces.

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VII. Energy Conversion Processes

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√(b) Co-generation of steam and electricity.

√(c) Use of coal off-gas boilers.

√(d) Use of gas turbines for co-generation.

*Requires expenditures of R&D before use; amounts, in thousands of dollars, in parentheses. Source-industry and government estimates.

√Qualifies for investment tax credit.

industry's dependence upon the hydrocarbons as a source of energy, as well as indicating which need R&D dollars prior to introduction.

A. R&D and Tax Considerations in the Objective Function of the Model

(i) R&D Considerations

The interplay between investment in R&D, investment in capacity of a new technology developed by the R&D, and the utilization of the technology in production can be characterized in the following way:

$$X_i^t \leqq \sum_{K=1}^{t-1} DR_i^K \; ; \; t = 2,3....j \quad X_i^0 = X_i^1 = 0 \tag{1}$$

$$C(DR_i^t) = a_i^t \, DR_i^t + \delta_i^{t-1} \, \$_{ii}$$

$$\delta_i^{t-1} = \begin{cases} 1 \text{ if } DR_i^t > 0, \text{ all } DR_i^\tau = 0 \text{ for } \tau < t \\ 0 \text{ otherwise} \end{cases}$$

where;

x_i^t = production, using the ith new technology, in t.

DR_i^t = durable resource investment in t, measured in capacity units of x_i. (Assets are assumed to have finite life.)

$C(DR_i^t)$ = total cost of investing in DR_i^t units, including capital and R&D costs.

a_i^t = capital cost per unit of DR_i^t.

$\$_i$ = the fixed investment in R&D necessary to bring technology to the market.

δ_i^t = the {0,1} integer variable.

The necessary lag between the R&D expenditure and the subsequent investment allowed in capacity is reflected by requiring the R&D expenditure to precede by one period the investment in capacity. This is in addition to the usual construction lag which separates the period when the investment decision is made and the initial utilization of that capacity.

The net effect of the {0,1} variable δ_i^t is to require that $\$_i$ be spent one period prior to the first investment in capacity, and two periods prior to first utilizing the capacity; once incurred, the only costs thereafter are the costs of capacity expansion and operation. The introduction of these fixed charges makes the cost structure non convex, causing the usual computational problems associated with such formulations.

This formulation permits the model to handle investment in durable resources using proven technologies and durable resources which need R&D before use in a symmetrical fashion. The only difference is in the necessity of spending the fixed charge $\$_i$. If the technology is already is use, then δ_i^t = 0 for all t.

No treatment of the R&D investment problem without explicit consideration of the uncertainty surrounding such projects is ever entirely satisfactory. However, the set of R&D projects typically found outside agencies such as the National Science Foundation are usually heavily in the Development, rather than the Research end of the spectrum. The projects funded by energy agencies are no exception to this rule; thus a model where the results of such investments are assumed certain (or more exactly, where the uncertainty associated with all projects is approximately the same) may not do much violance to reality.

The notation used to distinguish between old and new technologies is to partition the set M of technologies (durable goods investments) into two subsets: the existing technologies in the set $M - M_1$, which do not require any additional expenditures beyond the cost of purchasing capacity units to add to capacity, and the new technologies in the set M_1, which requires the expenditure of $\$_i$ before any units of capacity can be put in place.

(ii) <u>Tax Considerations</u>

The objective function which is minimized is the after-tax cost of meeting the demands.

The after tax cash expenditure flow in any period t is of the form $(1 - \tau) EX^t - \tau D^t + \alpha^t DR^t$, where τ is the profits tax rate, EX^t total current expenses in t, D^t allowed depreciation in t and $\alpha^t DR^t$ total expenditures on durable resources in t.* For tax purposes, R&D costs will be treated as durable goods and will be depreciated over a period equal to the life of the equipment developed.

In any given period "t," then, the objective function for the firms would be to minimize:

$$\Sigma_i (1 - \tau) EX_i^t + \Sigma_i \alpha_i^t DR_i^t + \sum_{i \in M_1} \delta_i^t \$_i - \mathop{\tau}_{i \in M} \Sigma D_i^t \qquad (2)$$

*To see this, suppose revenues in t are R. Then after tax cash flow profits are revenues, less current expenses, less profits taxes, less durable good expenditures: (assuming profits are positive).

The first term represents the after tax operating expenses for all technologies of the firm in t; the second, expenditures on capital equipment in t for all technologies; the third R&D expenditures in t for the new (M_1) technologies; the fourth,

$$(R^t - EX^t) - \tau(R^t - EX^t - D^t) - \alpha^t DR^t \qquad (3a)$$

If demand must be met at fixed prices, R is constant, and maximizing (a) is equivalent to minimizing (b);

$$(1 - \tau)\, EX^t - \tau D^t + \alpha^t DR^t \qquad (3b)$$

allowed depreciation on all capital expenditures prior to t (assuming depreciation is not allowed in the year of purchase) expressed as the reduction in tax liability. In the dynamic formulation, the private sector would discount future expenses by the cost of capital "r," and the firm would minimize the present value of (a) over a given planning horizon.

B. The Use of Activity Analysis in the Private Sector Model

The heart of the problem is to model the cost minimizing response of the private sector in such a fashion that all of the various substitutabilities and complementarities which exist in the production chain are explicitly spelled out. The methodology used is activity analysis.

As Table 5 shows, activity analysis has four building blocks; the "primitives" of the methodology, the activities themselves, which transform resources, or inputs, into products, or outputs, by means of a set of

ACTIVITY ANALYSIS

1. A set of Activities $[x^1, x^2, \ldots k \ldots]$ which produce distinct products, or outputs.

2. A set of resources $[1,2,\ldots i \ldots m]$ used by these activities, the availabilities $[b_1, b_2, \ldots b_i \ldots b_m]$ of these resources, and a set of prices $[P_1, P_2, \ldots P_i \ldots P_m]$ that give the cost per unit of each resources for additional units of resource.

3. For each activity, a set of technologies $[X_1^k, X_2^k, \ldots X_j^k \ldots X_{N_k}^k]$ to produce the output of activity k; each technology is characterized by a column vector whose elements a_{ij}^K give the units of the i^{th} input required per unit of the j^{th} technology for activity K. Each activity is characterized by a matrix A^k, the collection of technologies for the k^{th} activity. ($a_{ij}^K < 0$ denotes an output of a technology).

4. A set of final products $[1,2,\ldots,k,\ldots P]$, $K \epsilon K$ ...., and a set of demands $[R_1, R_2, \ldots R_K \ldots R_p]$ for each product, which are made price sensitive by including penalty costs for unmet demand, and/or the possibility of increased import substitution as domestic costs increase.

5. The resources are of three types: purchased inputs acquired from outside that are embodied in the product, intermediate products that have been manufactured in prior steps in the production process that are likewise embodied in the product, and durable resources (capital equipment) that are not directly consumed by the act of production. The unique characteristic of durable resources is that the purchase of a unit in time t makes that unit available in an interval $[t, \ldots T]$, the lifetime of the equipment.

TABLE 5

technologies, which represent alternate ways of obtaining the output from the set of inputs.

Resources can be categorized into three types: (a) purchased inputs indexed in the set I, (labor, material) acquired from outside the firm or organization at some given price or price schedule; (b) intermediate products, when they are the products of some activity within the firm or organization indexed in the set $\tilde{K}$ and in the set $\tilde{M}$ when considered as resources for subsequent activities; and (c) durable resources, or equipment, whose capacity is utilized by the activity, indexed in the set $M - M_1$ for existing technologies, and M_1 for new technologies. Durable resources have the distinct characteristic that additions to the stock of durable resources add to the capacity in all future time periods until the equipment is retired. The availabilties of the resources in all instances represent the stock of such resources on hand at the beginning of the period in question. They can be augmented during the period for the case of purchased inputs and intermediate products, but only with a lag in the case of durable resources. The lag represents the delay between the decision to invest in new capacity and time when the new capacity becomes available for utilization.

Four types of activities indexed on k are distinguished in the models: purchase of non-durable resources, denoted by $PI_{k\epsilon I}$; purchase of durable resources, DR_k that either require ($k\epsilon M_1$) or do not require ($k\epsilon M-M_1$) R&D expenditures prior to purchase; production activities which transform resources into intermediate outputs, denoted by X_j^k, k in the set $\tilde{K}$, and activities that transform resources into final outputs, again denoted by X_j^k, but k is in the set K.

Constraints indexed on i are of five types: <u>accounting</u> constraints $i \epsilon I$ which insure that the total utilization of a purchased input equal the total purchase of that input; <u>capacity</u> constraints $i \epsilon M$ which require that the level of an activity not exceed its capacity; <u>materials balance</u> constraints $i \epsilon \tilde{M}$ which insure that the input requirements for intermediate products equal their production from prior activities; <u>demand</u> constraints $i \epsilon K$ which insure that activities which produce final goods produce an amount sufficient to meet final demands, and <u>variable</u> constraints, which insure non-negative or integer values for the variables in the problem.

Typically, this optimization problem is a dynamic problem, i.e., the problem is to choose for n periods the mix of technologies, <u>et al.</u>, that will meet the sequence R^1, R^2,...R^T of time specific requirements at minimum cost. Cost then, is taken to be the present value of all costs over the horizon of n periods, with appropriate adjustments for the presence of the corporate income tax.

Since each technology has associated with it a set of resource requirements expressed in terms of units of capacity utilized and units of purchased inputs and intermediate products consumed, each has a cost. The optimization problem associated with the activity analysis is to choose that set of the activities, and set of technologies for the activities which satisfies the demand specified for the final products at minimum cost.

Choice enters the model via several routes: first, there may be several different combinations of activities which can produce the given product, each representing a different sequence of combination of activities. Second, even if there is a unique combination of activities which produce the product, there may be many possible technologies which can be chosen to accomplish each activity.

Equation (4) gives the statement of the private sector problem: the energy consumption pattern "PI_E^t" is split out in the objective function for use in the analysis of the model.

II. THE INTEGRATED MILL MODEL

The model is presented in 12 sections, each dealing with a major process block in Table 1.

A. Iron Ore Mining, Preparation and Shipment

Due to the variability of iron content in various iron ores and the requirement for inputs into the blast furnace with certain physical attributes, iron ore preparation is essential to the iron and steel making process. Prior to the 1960's, the bulk of U.S. iron ores were limonite and hemitite, with high ($\approx$ 60% Fe) iron content. Depletion of these ore sources has led to: (a) the use of relatively low grade (30% Fe) magnitite-bearing Taconite which is pelletized to increase the Fe content; (b) an increase in imports of higher grade iron ore. In 1974, the U.S. imported 35% of its iron ore (60% Fe) needs with 50% of the imports from Canada and 33% from Venezuela. 95% of domestic ores require beneficiation and agglormeration into pellets or sinter with an iron content of 60-65% Fe.[1]

As many investigators have pointed out, this gradual exhaustion of domestic ore reserves will have a profound effect on energy use in the iron and steel industry, since the higher cost per ton Fe equivalent of imported ore and pellets will alter the cost minimizing hot iron/scrap ratio. We have included in the model two import options: pellet imports and ore concentrates imports.

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[1] Ref. XVI, p. vl

Pellets (63% Fe) are assumed to arrive at lower lake ports at a 1975 delivered price of $30.00/ton.[1] 1975 ore concentrate prices (51.5% Fe) are assumed to be $18.75/ton.

All imported ores are assumed to be shipped by rail to the mills at a 1975 price of $.62 per ton (based on a 25% esculation in shipping costs since 1973). The only domestic energy charge is the BTU requirement associated with this transportation, estimated at 0.08×10^6 BTU per ton by Battelle.[2]

Domestic ore production is also in two forms - Pellets, and Concentrates. Energy and materials consumption per ton of pellets is as reported by Battelle[3] on page A-4 with labor and maintenance costs taken from Russell and Vaughan.[4] Ore concentrates consumption patterns per ton are based on Tables A-3 and A-5 of the same Battelle document.[3]

Costs for domestic ore activities are based on the same data used to estimate delivered import prices, with a fixed $1.00/ton differential to reflect preference for domestic ore by domestic iron and steel producers. The entries in the objective function for domestic ore production are "ore rent residuals," in that they are calculated by subtracting from market prices (which include rents on nonrenewable resources) the costs of the mining and processing variable inputs and an estimate of the capital recovery cost for ore processing. They thus represent the residual which accrues to the owners of the ore bodies themselves, to pay for exploration and development costs plus monopoly profits.

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[1] 1975 Minerals Yearbook, p. 727

[2] Ref. XIV, p. A-4

[3] Ref. XIV

[4] Ref. XI

Domestic ore bodies are exhaustable, and of varying quality. Estimates by the Bureau of Mines, are that approximately 9000 million tons of high grade ore remain in the United States which are minable at or near current costs. Further ore could only be obtained at higher cost. To reflect this, the model distinguishes between three domestic ore types:

(a) Ore similar in quality and cost to that now mined; cost per delivered ton is $23.00, and the quantity available is 4,500 x 10^6 tons.

(b) Lower quality ore, costing $38.00 per ton to mine, with 4,500 x 10^6 tons available.

(c) Lowest quality ore casting $50.00 per ton to mine, with 100,000 x 10^6 tons estimated to be available. (This constraint is never binding.)

North American reserves (mainly Canadian Taconites) amount to 36,000 x 10^6 tons;[1] hence no constraint is placed upon the amount of ore or pellet imports over the 25 year horizon.

Iron ore preparation consists of pelletization which occurs at the mine mouth and sintering which takes place at the integrated plant itself. Pelletizing occurs at the mine mouth because there is a 50-65% residual from the crude ore which, if transported, would make transportation costs prohibitive. A further advantage of mine mouth pelletization is the pellets' resistance to crushing which allows them to be transported over long distances, if necessary.

The fuel sources used in the process of pelletization are oil, natural gas, and electricity with oil and natural gas being substitutable depending upon

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[1] Ref. XVII, p. 303

availability and price. According to the Battelle[1] report, Table A-4, pelletization uses a total of 1.6×10^6 BTU per ton of pellets for concentration and pelletizing. Inclusion of the ore mining and mine mouth ore processing in the model while necessary to evaluate the full impact of energy conservation measures raises some BTU accounting problems, since mining and ore processing are not reported in SIC 3312 (the Iron and Steel SIC), but in SIC 1011. Hence, the energy consumption per ton of steel reported here includes energy which other analyses exclude, which accounts for our slightly higher energy/ton figures. Discrepancies between commonly reported figures and this analysis are noted in the text.

The sintering operation, which is necessary to convert ore fines into chunks suitable for feed into the blast furnaces, is based mainly on data contained in Russell and Vaughan[2] and the other sources indicated in Table 6. Current sinter capacity is 47 million tons.[3] The inputs to the sinter process are a mix of iron bearing materials such as sludge, ore fines, and flue dust, and ignition fuels such as natural gas, coke oven gas, and oil.

Ignition fuels consist of 50% natural gas, 47% coke oven gas (0.5×10^3 BTU per ft^3), and 3% #2 fuel oil. Electricity is utilized in the operation of the sinter process for power fans, drive equipment, etc. Agglomeration of iron ore fines is necessitated by the fact that otherwise, ascending gas in the blast furnace would discharge the particulates out the stack.

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[1]Ref. XVI

[2]Ref. XI

[3]Ref. XV, p. A-5

After ignition of the mixture in the sinter plant, combustion causes the agglomerating particles to form a cake which is then quenched with water and broken into pieces of about 4 diameter for introduction into the blast furnace (the iron content now approximately 60% Fe).

There has not been much attention given to fuel conserving options in the process of pelletizing and the sinter process due to the small consumption of energy relative to the iron and steel making process. One technique which may be adopted given the scarcity of natural gas is the employment of coal firing at pelletization plants. Some recent preliminary investigations[1] reveal fuel savings on the order of 4×10^{13} BTU of oil and natural gas per year for a complete conversion at all pelletizing plants, at a cost of around \$3.00 per BTU^6 for the coal gasification plant.

Table 6 summarizes the data currently entered in the model for iron ore mining, preparation and shipment. The Roman numberals refer to the various data sources used to arrive at the numbers; their listing is given. The abbreviations refer to the language used in the matrix generator accompanying this report.

B. Coke Production

The destructive distillation of a blend of coals in the coke ovens at 1650-2000°F produces a carbonaceous residue known as coke, the primary fuel for the blast furnace, which in turn is the source of iron for the steel making furnaces. Since the coke supply situation is one of the major problems facing the steel industry, a discussion of the source of coke is warranted.

[1]Ref. XVI, p. V-13

TABLE PRCCIO: **TABLE 6**

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* THIS TABLE STORES DATA FOR IRON ORE PROCESSING

		REF		SINT
CAPACITY			CAP	47000.0000
LIMESTONE	TONS	X	LMS	0.1100
STEAM	E6 BTU	X	STM	0.1000
RESIDUAL OIL	E6 BTU	X	PRH	0.0700
ELECTRICITY	E3 KWH	V	ELE	0.0390
LABOR	MAN-HRS	XI	LAB	0.1300
COKE OVEN OFFGAS	E6 BTU	X	COG	1.4600
PROCESS EFFICIENCY		XIV	PROEFF	1.0500
OPER. + MAINT.	$	XI	OAM	1.0000
		III	SORE	.76
			SINT	
		XIV	SCR	.12
		>		PELL
CAPACITY			CAP	70000.0000
INVESTMENT COST(NEW)	$		INVESTN	75.0000
RESIDUAL OIL	E6 BTU	X	PRH	.92
ELECTRICITY	E3 KWH	V	ELE	0.0930
LABOR	MAN-HRS	XI	LAB	0.2600
PROCESS EFFICIENCY		V	PROEFF	3.4500
OPER. + MAINT.	$	XI	OAM	2.0000
			LMS	
			STM	
			SORE	
			SINT	
			COG	
			SCR	
		>		SCRE
PROCESS EFFICIENCY			PROEFF	1.0000
ORE	TONS		SORE	1.
SINTERS	TONS		SINT	
			LMS	
			STM	
		XIV	PRH	.43
		XV	ELE	.025
		XI	LAB	.13
		XI	OAM	1.0
			COG	
			SCR	
		>		IMSCRE
			PROEFF	
			SCR	
			LMS	
			STM	
			PRH	
			ELE	
			LAB	
			OAM	
			COG	
			SORE	1.
			SINT	

In the blast furnace a chemical agent is required to reduce the oxides of iron to metallic iron; this agent is carbon which is provided by coke. For the production of coke an expensive low sulphur bituminous coking coal is required. With ninety percent of the U.S. reserves of low sulphur bituminous coals (located in the western part of the U.S.) not suitable for coking, the scarcity of coking coals is unquestionably a growing issue. Although a solution to this perplexing problem has been proposed (as we shall see later), there is not, as of yet, an economic method for producing coke from non-coking coal. Of the remaining 10% of U.S. reserves of low sulphur bituminous coals that are suitable for coking, 80% are located in West Virginia and Kentucky. The optimal blend of coals, as reported by Thermo Electron,[1] is 60% high volatile coal and 40% low volatile coal. At present, the average mix is 66% high volatile, 16% medium volatile, and 18% low volatile. If only high volatile coal were used, coke of a porous, weak nature would arise whereas the desirable characteristic is a firm, cellular mass of coke - which is a feature not possible with all bituminous coals. Two other desirable properties of coking coals are a low ash and sulphur content (about 8.1% and 1.3%, respectively); use of high ash and sulphur content coal will result in added slag in the blast furnace, increased coke expenditure, and decreased production. It should be noted here that coke consumption is almost directly proportional to output in the integrated steel mill, with the elimination of the hydrocarbon injectant modes of operation. Another relevant fact that is contributing to the integrated steel mill's problems is that the utilities are vying for low sulphur coal due to the scarcity of

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[1]Ref. X

natural gas and the environmental protection laws. Therefore, the problem of scarce supply of bituminous low sulphur coking coals has been compounded.

The process for manufacturing coke is as follows. A preparation facility receives the various coals suitable for coking, pulverizes and blends the high volatile, medium volatile, and low volatile coals to the requisite proportions. The crushed coal is transferred to the slot ovens located within the boundaries of the plant site and charged into the "by-product" coke ovens (so named "by-product" because of the recovery facilities for collecting the by-products such as light oils, tar, ammonia, and coke oven gas). Combustion air is heated in regenerators and mixed with under-fire fuels (of which 40% is recycled coke oven gas) for burning in the combustion chamber. Under normal operating conditions, the charge is heated 14-16 hours after which the coke is forced into waiting cars where it is water quenched to prevent combustion. A significant portion of the sensible heat is lost here (approximately 1.4×10^6 BTU per ton of coke) which can be recovered. After cooling, the coke is crushed and screened. The major portion of the coke is then transmitted to the blast furnace and the remaining fines are conveyed to the reclamation plant where this coke breeze is utilized as a fuel in the sintering operation. In summary, the outputs of the coke oven are: 1) coke, 2) a mixture of H_2 and CH_4 called coke oven gas with a heating value of 500 BTU per ft^3, 3) coke breeze, and 4) light oils and tars.

The primary problems of the steel industry vis-a-vis coke are as follows:

1. a dwindling supply of suitable, low sulphur bituminous coking coals,
2. a decreasing quality in the constituency of coke,

3. competition with utilities for bituminous coals, and

4. loss of sensible heat in the water quenching of coke.

The loss-of-sensible-heat problem and the decreasing-quality-of-coke problem can be somewhat obviated by a process called dry quenching which has been used with some success in Europe and the U.S.S.R., and is an option in the model. The dry quench process differs from the wet quench process in that the hot coke is dropped into a cooling chamber where by various means combustion is prevented and the coke is cooled, saving 1.2×10^6 BTU per ton of coke.[1] Capital costs are $123/ton[2] for wet coking, and a cost of $15/ton for retrofitting wet coke to the dry coke process.[3]

Table 7 displays the portion of the matrix generator dealing with coke production, and the references.

C. Blast Furnace

The primary function of the blast furnace is to produce pig iron for introduction into the steel making furnaces. The process of manufacturing pig iron involves input of a burden which may consist of agglomerated ores (pellets and/or sinter), lumped ores, scrap, and limestone and input of coke which supplies carbon monoxide gas which in turn combines with the iron oxides to form CO_2 gas and pig iron. The output of the blast furnace is pig iron, slag (formed from limestone combining with sulphur and other impurities), and an offgas with a heating value of 95 BTU per ft^3. During the process of making pig iron (which is tapped every three to five hours in quantities of 300-600 tons), the blast

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[1]Ref. XVIII, p. 28

[2]Ref. XX

[3]Average of costs given in Ref. XVIII and Ref. XVI

TABLE CHARCO. TABLE 7

* THIS TABLE STORES DATA FOR COKE PRODUCTION

				->		W
	CAPACITY				CAP	60000.0000
	INVESTMENT COST(NEW)	$			INVESTN	123.0000
	COKE	TONS			COKE	1.0000
650*	STEAM	E6 BTU	X		STM	1.1000
	RESIDUAL OIL	E6 BTU	IV		PRH	0.1700
	ELECTRICITY	E3 KWH	XVIII		ELE	0.0040
	COKING COAL	TONS	IV		CCO	1.4500
	LABOR	MAN-HRS	XVIII		LAB	.036
	OPER. + MAINT.	$	XVIII		OAM	.29
	WASTE HEAT	E6 BTU			WHT	7.0
	COKE OVEN OFFGAS	E6 BTU	X		COG	6.6700
\+				>		D
	CAPACITY				CAP	0.0
660*	INVESTMENT COST(NEW)	$			INVESTN	128.
	COKE	TONS			COKE	1.00
	STEAM	E6 BTU	XVIII		STM	-0.1
	RESIDUAL OIL	E6 BTU	IV		PRH	.17
	ELECTRICITY	E3 KWH	XVIII		ELE	.01
	COKING COAL	TONS	IV		CCO	1.45
	LABOR	MAN-HRS	XVIII		LAB	.06
	OPER. + MAINT.	$	XVIII		OAM	.05
	WASTE HEAT	E6 BTU			WHT	5.8
	COKE OVEN OFFGAS	E6 BTU	X		COG	6.67

furnace offgas is directed to a boiler which produces compressed air via a steam powered blower. Funneling the air through the four or five hot blast stoves provides for the necessary heat required in the blast which is blown in at a temperature of 1200-2000°F at the tuyeres near the bottom of the blast furnace. After tapping, the pig iron is transported to the steel-making furnaces.

Being the largest consumer of energy (41%) in the iron and steelmaking process, the blast furnace has received much attention.

Although the reduction of energy consumption in the blast furnace has been a target of numerous investigations, the primary purpose has been to examine methods by which the coke rate can be lessened, rather than a reduction in total BTU use/ton. Nominal average values of energy and non-energy inputs are those found in Reference V, p. 69.

Some systems for lessening the coke rate do not necessarily result in a lowering of the energy consumption per ton of pig iron produced. Various reasons for the coke rates having been reduced in years past are as follows:

1. installation of new blast furnaces with high top pressures,
2. improvement of old blast furnaces by retrofitting operations,
3. increased air blast temperatures,
4. optimization of burden, and
5. injection of hydrocarbons.

All these options are included in the model.

(i) Higher Top Pressures

The majority of blast furnaces operating today were installed prior to the 1950's and tend to operate with a top pressure of around 5 psig. The average coke rate of 1200 lb. coke per ton of pig iron can be reduced if the top pressure is increased. Thermo Electron reports that at the optimal wind rate, savings will amount to 100 lb. coke per ton of pig iron. With the installation of new blast furnaces, it is possible for the design to allow for higher top pressures. It is noteworthy that the Japanese have blast furnaces operating with top pressures as high as 32 psig. Capital costs of such new furnaces are assumed to be $46/annual ton of capacity.

(ii) <u>Higher Temperatures</u>

Relining and rebricking in existing blast furnaces allows for increased air blast temperatures. From 1958 to 1968 the average blast temperature has increased from 1230°F to 1550°F. This decreases the coke charge by about 30 lb/ton for each 100°F increase in blast temperature; temperatures of 2200°F are considered obtainable with relining at a cost of $5/ton capacity.[1]

(iii) <u>Bell-less Tops</u>

Optimization of burden is most easily achieved by utilization of bell-less tops. Three distinct advantages arise from the use of bell-less tops: 1) coke rate is lessened by 30 lb. coke per ton of pig iron, 2) low capital costs due to the structure of the bell-less top, and 3) the mix of the burden input is controllable. Capital and installation costs are assumed to be $18 per ton[2], although only 15% of existing furnaces can take the pressures.[3] Additional savings might be achieved by installing expansion turbines at a cost of 600/700 dollars/KW.

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[1]Ref. X, p. 5-17

[2]Ref. X, p. 6-9

[3]Ref. XVIII, p. 50,52

(iv) Hydrocarbon Injection, Coal Injection

Another means of reducing the coke rate is injection of hydrocarbons (mainly natural gas and oil). With approximately 70% of the blast furnaces in the U.S. injecting hydrocarbons, the results are consistently similar, i.e., a decrease in thermal efficiency and an increase in energy consumption per ton of pig iron produced. However, as the supplies of natural gas dwindle, more steelmaking concerns are attempting to utilize pulverized coal as the main injectant into the blast furnace at the substitutable rate of 0.78 lb. coke per lb. of coal up to 28% of the coke input.[1] Capital costs for the coal pulverizing equipment are assumed to be $7.00 ton.[2]

In summary, it should be pointed out that the scarcity of low sulphur bituminous coking coals has preempted the search for methods devised primarily to reduce total energy consumption in the blast furnace.

The blast furnace is quite versatile, being able to accept a variety of charges (mixes of scrap, sinter, pellets, lump ore) with little change in performance. Russell and Vaughan[3] specify a wide range of charges on several blast furnace types. In this model only three types of blast furnaces are included:

(a) those built prior to 1950 (amounting to 40 million tons capacity) which because of their limited ability to withstand either high temperatures or high pressures are allowed only one (low pressure and temperature) mode of operation. In addition, in order to reflect the possibility that coke

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[1]Ref. XVI, p. VII-4

[2]Ref. XVIII, p. 38,44

[3]Ref. XI

might replace hydrocarbon injectants in these old furnaces, the nominal input mix given in Ref. V, p. 69 was modified so that coke input replaced all injectants.

(b) those built after 1950 (80 million tons capacity) which have several options:

i) a choice of burden mix - full pellet, high pellet, high sinter, high ore

ii) a choice of BTU sources - high coke, hydrocarbon injection

iii) a high temperature option (requiring retrofit-relining at a cost of $5.00/ton)

iv) a bell-less top option (requiring retrofit-the top itself costing $18.00/ton)

v) powdered coal injection (requiring construction of a coal pulverizer at a cost of $7.00/ton)

vi) a low energy use mode of operation suggested by the International Iron and Steel Institute.

Not all combinations of (i) to (vi) are allowed - hence only 14 combinations appear in the model.

(c) the Jordan blast furnace, which is really a coal gasifier with by-produce iron produced during the operation, which costs $86/ton annual capacity. (Ref. XI)

Table 8 lists the options and the sources of the data utilized in modelling the Blast Furnace Activity; the following code explains the abbreviations given in Table 8.

Code for Table 8

LONM = Blast furnace with low lumped ore input. (.2 tons ore, .97 tons pellets, .46 tons sinter - approximates AISI 1976 figures)

MONM = Blast furnace with medium lumped ore input. (.41 tons ore, .76 pellets, .46 sinter - approximates AISI 1974 figures)

HONM = Blast furnace with high lumped ore input. (1.17 tons ore, .46 tons sinter)

50BF = 1950 Blast furnace. (use only MONM)

JORD = Jordan blast furnace

IISI = Int'l Iron and Steel Institute furnace. (1.16 tons pellets, .46 tons sinter)

LOHI = Blast furnace with low ore and hydrocarbon injectants. (coke charge reduced from .6 tons to .4 tons by injection of equivalent BTU value)

MOHI = Blast furnace with medium ore and hydrocarbon injectants

HOHI = Blast furnace with high ore and hydrocarbon injectants

LOHT = Blast furnace with low ore and high temperature. (hydrocarbon injection plus relining required)

MOHT = Blast furnace with medium ore and high temperature

HOHT = Blast furnace with high ore and high temperature

LOPC = Blast furnace with low ore and pulverized coal. (.78 lb coke reduction per 1 lb coal up to 28% of coke input)

MOPC = Blast furnace with medium ore and pulverized coal

HOPC = Blast furnace with high ore and pulverized coal

LOBT = Blast furnace with low ore and bell-less tops. (.02 ton coke reduction if retrofitted)

TABLE CHARBF **TABLE 8**

* THIS TABLE STORES DATA FOR BLAST FURNACE

				~~IISI (XII)~~
	INVESTMENT COST(NEW)	$	INVESTN	100,0000
	~~COKE~~	~~TONS~~	~~COKE~~	~~0,4000~~
	REFRACTORY	LBS	REF	5,0000
	~~SCRAP~~	~~TONS~~	~~SCR~~	~~0,0270~~
2620*	OXYGEN	E3 CU FT	OXY	0,6700
	~~LIMESTONE~~	~~TONS~~	~~LMS~~	~~0,2300~~
	ELECTRICITY	E3 KWH	ELE	0,1200
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~2,4900~~
	PELLETS	TONS	PELL	1,1600
	~~SINTERS~~	~~TONS~~	~~SINT~~	~~0,5000~~
	LABOR	MAN-HRS	LAB	0,3850
	~~OPER. + MAINT.~~	~~$~~	~~OAM~~	~~6,5400~~
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1,3800
	~~STEAM~~	~~E6 BTU~~	~~STM~~	~~1,5500~~
2630*	73 BF		BF73	1,0000
	~~COST~~	~~$~~	~~CST~~	~~10,0000~~
			~~COA~~	
			SORE	
				~~1950 (V)~~
	CAPACITY		CAP	72000,0000
	COKE	TONS	COKE	0,7400
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~5,0000~~
	SCRAP	TONS	SCR	0,0270
~~2640*~~	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~0,2100~~
	LIMESTONE	TONS	LMS	0,2300
	~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~0,0250~~
	ORE	TONS	SORE	0,4100

	PELLETS	TONS	PELL	0.7600
	SINTERS	TONS	SINT	0.4600
	LABOR	MAN-HRS	LAB	0.6080
	OPER. + MAINT.	$	OAM	0.0800
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	STEAM	E6 BTU	STM	1.5500
2650*	COST	$	CST	13.0000
			COA	
			PRH	
			BF73	
+			>	LCNM(1974 AISI)
	INVESTMENT COST(NEW)	$	INVESTN	100.0000
	COKE	TONS	COKE	0.6000
	REFRACTORY	LBS	REF	5.0000
	SCRAP	TONS	SCR	0.0270
2660*	OXYGEN	E3 CU FT	OXY	0.2100
	LIMESTONE	TONS	LMS	0.2300
	STEAM	E6 BTU	STM	1.5500
	ELECTRICITY	E3 KWH	ELE	0.0250
	RESIDUAL OIL	E6 BTU	PRH	1.0700
	ORE	TONS	SORE	0.200
	PELLETS	TONS	PELL	0.9700
	SINTERS	TONS	SINT	0.4600
	LABOR	MAN-HRS	LAB	0.3850
	OPER. + MAINT.	$	OAM	4.2300
2670*	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	73 BF		BF73	1.0000
	COST	$	CST	0.0000
			COA	
+			>	MCNM(1974 AISI)
	INVESTMENT COST(NEW)	$	INVESTN	100.0000
	COKE	TONS	COKE	0.6000
	REFRACTORY	LBS	REF	5.0000
	SCRAP	TONS	SCR	0.0270
	OXYGEN	E3 CU FT	OXY	0.2100
2680*	LIMESTONE	TONS	LMS	0.2300
	STEAM	E6 BTU	STM	1.5500
	ELECTRICITY	E3 KWH	ELE	0.0250
	RESIDUAL OIL	E6 BTU	PRH	1.0700
	ORE	TONS	SORE	0.4100
	SINTERS	TONS	SINT	0.4600
	LABOR	MAN-HRS	LAB	0.4520
	OPER. + MAINT.	$	OAM	4.2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	73 BF		BF73	1.0000

2690*	COST	$	CST	0.0000
			COA	
			PELL	0.76
+			>	LCAP
	INVESTMENT COST(NEW)	$	INVESTN	100.0000
	COKE	TONS	COKE	0.6000
	REFRACTORY	LBS	REF	5.0000
	SCRAP	TONS	SCR	0.0270
	OXYGEN	E3 CU FT	OXY	0.2100
	LIMESTONE	TONS	LMS	0.2300
2700*	STEAM	E6 BTU	STM	1.5500
	ELECTRICITY	E3 KWH	ELE	0.0250
	RESIDUAL OIL	E6 BTU	PRH	1.0700
	ORE	TONS	SORE	1.1700
	LABOR	MAN-HRS	LAB	0.6080
	OPER. + MAINT.	$	OAM	4.2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	73 BF		BF73	1.0000
	COST	$	CST	0.0000
			COA	
2710*			PELL	
			SINT	.46
+			>	LCHI
	INVESTMENT COST(NEW)	$	INVESTN	100.0000
	COKE	TONS	COKE	0.4000
	REFRACTORY	LBS	REF	5.0000
	SCRAP	TONS	SCR	0.0270
	OXYGEN	E3 CU FT	OXY	0.2100
	LIMESTONE	TONS	LMS	0.2300
	STEAM	E6 BTU	STM	1.5500
2720*	ELECTRICITY	E3 KWH	ELE	0.0250
	RESIDUAL OIL	E6 BTU	PRH	7.3000
	ORE	TONS	SORE	0.2000
	PELLETS	TONS	PELL	0.9700
	SINTERS	TONS	SINT	0.4600
	LABOR	MAN-HRS	LAB	0.4520
	OPER. + MAINT.	$	OAM	4.2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	73 BF		BF73	1.0000
	COST	$	CST	0.0000
2730*			COA	
+			>	MCHI
	INVESTMENT COST(NEW)	$	INVESTN	100.0000
	COKE	TONS	COKE	0.4000
	REFRACTORY	LBS	REF	5.0000
	SCRAP	TONS	SCR	0.0270

	OXYGEN	E3 CU FT	OXY	0,2100
	LIMESTONE	TONS	LMS	0,2300
	STEAM	E6 BTU	STM	1,5500
	ELECTRICITY	E3 KWH	ELE	0,0250
2740*	RESIDUAL OIL	E6 BTU	PRH	7,3000
	ORE	TONS	SORE	0,4100
	SINTERS	TONS	SINT	0,4600
	LABOR	MAN-HRS	LAB	0,4520
	OPER, + MAINT,	$	OAM	4,2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1,8400
	73 BF		BF73	1,0000
	COST	$	CST	0,0000
			COA	
			PELL	,76
2750* +		>		HCHI
	INVESTMENT COST(NEW)	$	INVESTN	100,0000
	COKE	TONS	COKE	0,4000
	REFRACTORY	LBS	REF	5,0000
	SCRAP	TONS	SCR	0,0270
	OXYGEN	E3 CU FT	OXY	0,2100
	LIMESTONE	TONS	LMS	0,2300
	STEAM	E6 BTU	STM	1,5500
	ELECTRICITY	E3 KWH	ELE	0,0250
	RESIDUAL OIL	E6 BTU	PRH	7,3000
2760*	ORE	TONS	SORE	1,1700
	LABOR	MAN-HRS	LAB	0,6080
	OPER, + MAINT,	$	OAM	4,2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1,8400
	73 BF		BF73	1,0000
	COST	$	CST	0,0000
			COA	
			PELL	
			SINT	,46
		>		UCRE (I)
2770*	CAPACITY		CAP	0,0000
	INVESTMENT COST(NEW)	$	INVESTN	66,0000
	COKE	TONS	COKE	0,3300
	REFRACTORY	LBS	REF	5,0000
	SCRAP	TONS	SCR	0,0270
	OXYGEN	E3 CU FT	OXY	11,4000
	LIMESTONE	TONS	LMS	0,2300
	ELECTRICITY	E3 KWH	ELE	0,0250
	COAL	TONS	COA	0,2200
	PELLETS	TONS	PELL	1,5000
2780*	LABOR	MAN-HRS	LAB	0,3850
	OPER, + MAINT,	$	OAM	4,2300

	COKE OVEN GAS		COG	6.7000
.....	NEW ROW			
	STEAM	E6 BTU	STM	1.5500
	~~COST~~	~~$~~	~~CST~~	~~0.0000~~
			~~PRH~~	
			SORE	
			~~SINT~~	
			BF73	
2790* +		→		~~LCET~~ (X)
	CAPACITY		CAP	0.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~108.0000~~
	COKE	TONS	COKE	0.5800
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~5.0000~~
	SCRAP	TONS	SCR	0.0270
	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~0.2100~~
	LIMESTONE	TONS	LMS	0.2300
	~~STEAM~~	~~E6 BTU~~	~~STM~~	~~1.5500~~
	RESIDUAL OIL	E6 BTU	PRH	1.0700
2800*	~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~0.0250~~
	ORE	TONS	SORE	0.4100
	~~PELLETS~~	~~TONS~~	~~PELL~~	~~0.7600~~
	SINTERS	TONS	SINT	0.4600
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0.3850~~
	OPER. + MAINT.	$	OAM	4.2300
	~~BLAST FURNACE OFFGAS~~	~~E6 BTU~~	~~BFG~~	~~1.8400~~
	73 BF		BF73	1.0000
	~~COST~~	~~$~~	~~CST~~	~~0.0000~~
	INVESTMENT COST(RETROFIT)	$	INVESTR	8.0000
				LCET (X)
	CAPACITY		CAP	0.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~105.0000~~
	COKE	TONS	COKE	0.5500
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~6.0000~~
	SCRAP	TONS	SCR	0.0270
	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~0.2100~~
	LIMESTONE	TONS	LMS	0.2300
	~~STEAM~~	~~E6 BTU~~	~~STM~~	~~1.5500~~

2820*	RESIDUAL OIL	E6 BTU	PRH	1.0700
	ELECTRICITY	E3 KWH	ELE	0.0250
	ORE	TONS	SORE	0.2000
	PELLETS	TONS	PELL	0.9700
	SINTERS	TONS	SINT	0.4600
	LABOR	MAN-HRS	LAB	0.4520
	OPER. + MAINT.	$	OAM	4.2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	COST	$	CST	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	5.0000
2830*			COA	
				HCHT(I)
	CAPACITY		CAP	0.0000
	INVESTMENT COST(NEW)	$	INVESTN	105.0000
	COKE	TONS	COKE	0.5500
	REFRACTORY	LBS	REF	6.0000
	SCRAP	TONS	SCR	0.0270
	OXYGEN	E3 CU FT	OXY	0.2100
	LIMESTONE	TONS	LMS	0.2300
	STEAM	E6 BTU	STM	1.5500
2840*	RESIDUAL OIL	E6 BTU	PRH	1.0700
	ELECTRICITY	E3 KWH	ELE	0.0250
	ORE	TONS	SORE	0.4100
	SINTERS	TONS	SINT	0.4600
	LABOR	MAN-HRS	LAB	0.4520
	OPER. + MAINT.	$	OAM	4.2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	COST	$	CST	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	5.0000
			COA	
2850*			PELL	.76
				HCHT(I)
	CAPACITY		CAP	0.0000
	INVESTMENT COST(NEW)	$	INVESTN	105.0000
	COKE	TONS	COKE	0.5500
	REFRACTORY	LBS	REF	6.0000
	SCRAP	TONS	SCR	0.0270
	OXYGEN	E3 CU FT	OXY	0.2100
	LIMESTONE	TONS	LMS	0.2300
	STEAM	E6 BTU	STM	1.5500
2860*	RESIDUAL OIL	E6 BTU	PRH	1.0700
	ELECTRICITY	E3 KWH	ELE	0.0250
	ORE	TONS	SORE	1.1700
	LABOR	MAN-HRS	LAB	0.6080
	OPER. + MAINT.	$	OAM	4.2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400

	COST	$	CST	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	5.0000
			COA	
			PELL	
2870*			SINT	.46
				LCPC(XVIII)
	CAPACITY		CAP	0.0000
	INVESTMENT COST(NEW)	$	INVESTN	106.5000
	COKE	TONS	COKE	0.4500
	REFRACTORY	LBS	REF	5.0000
	SCRAP	TONS	SCR	0.0270
	OXYGEN	E3 CU FT	OXY	0.2100
	LIMESTONE	TONS	LMS	0.2300
	STEAM	E6 BTU	STM	1.5500
2880*	RESIDUAL OIL	E6 BTU	PRH	1.0700
	ELECTRICITY	E3 KWH	ELE	0.0250
	COAL	TONS	COA	0.2000
	ORE	TONS	SORE	0.2000
	PELLETS	TONS	PELL	0.9700
	SINTERS	TONS	SINT	0.4600
	LABOR	MAN-HRS	LAB	0.4520
	OPER. + MAINT.	$	OAM	4.2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	COST	$	CST	0.0000
2890*	INVESTMENT COST(RETROFIT)	$	INVESTR	6.5000
				MCPC(XVIII)
	CAPACITY		CAP	0.0000
	INVESTMENT COST(NEW)	$	INVESTN	106.5000
	COKE	TONS	COKE	0.4500
	REFRACTORY	LBS	REF	5.0000
	SCRAP	TONS	SCR	0.0270
	OXYGEN	E3 CU FT	OXY	0.2100
	LIMESTONE	TONS	LMS	0.2300
	STEAM	E6 BTU	STM	1.5500
2900*	RESIDUAL OIL	E6 BTU	PRH	1.0700
	ELECTRICITY	E3 KWH	ELE	0.0250
	COAL	TONS	COA	0.2000
	ORE	TONS	SORE	0.4100
	SINTERS	TONS	SINT	0.4600
	LABOR	MAN-HRS	LAB	0.4520
	OPER. + MAINT.	$	OAM	4.2300
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	COST	$	CST	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	6.5000
2910*			PELL	.76

HOPG(XIII)

	CAPACITY		CAP	0.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~106.5000~~
	COKE	TONS	COKE	0.4500
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~5.0000~~
	SCRAP	TONS	SCR	0.0270
	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~0.2100~~
	LIMESTONE	TONS	LMS	0.2300
	~~STEAM~~	~~E6 BTU~~	~~STM~~	~~1.5500~~
2920*	RESIDUAL OIL	E6 BTU	PRH	1.0700
	~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~0.0250~~
	COAL	TONS	COA	0.2000
	~~ORE~~	~~TONS~~	~~SORE~~	~~1.1700~~
	LABOR	MAN-HRS	LAB	0.6080
	~~OPER. + MAINT.~~	~~$~~	~~OAM~~	~~4.2300~~
	BLAST FURNACE OFFGAS	E6 BTU	BFG	1.8400
	~~COST~~	~~$~~	~~CST~~	~~0.0000~~
	INVESTMENT COST(RETROFIT)	$	INVESTR	6.5000
			~~PELL~~	
2930*			SINT	.46

D. Direct Reduction

These are basically two types of direct reduction processes: gaseous direct reduction and solid direct reduction. In gaseous direct reduction the reductant for removing oxygen from iron is a gas, either hydrogen or carbon monoxide. In solid direct reduction processes the reductant is usually a solid carbon. An ideal iron ore for use in a direct reduction process would have an iron content of near 60 percent. Substantial amounts of this type of ore do exist and if a "run-of-the-mine" ore cannot be used, beneficiated ores can.

Both types of direct reduction processes are shown in Figure 1. The gaseous reductant process is the MIDREX PROCESS[1,2] named by the Midland-Ross Corporation. The solid reductant process is the SL/RN process, an acronymic name for the four companies which developed it. In both processes the product yielded is from 92 to 95% metallized.

Several advantages of directly reduced iron ore are:

1. chemical composition is known exactly;
2. chemical composition is uniform;
3. contains no undesirable metallic impurities;
4. easy to transport and handle;
5. increased steel furnace productivity;
6. direct reduction-electric furnace facilities can be constructed more quickly than coke oven-blast furnace-basic oxygen facilities.[3]

---

[1] Ref. XXVII

[2] Ref. XXVIII

[3] Ref. XXIX

Some studies[1,2] have shown that for small plants the economic advantages of the SL/RN electric furnace route are favored whereas for large plants (defined as greater than 2.5×10^6 tons per year) it is most economical to construct blast furnace-basic oxygen facilities. Of the two types of direct reduction processes, the SL/RN is favored in the U.S. since the solid reductant utilized is coal and gaseous reductants such as natural gas are becoming more scarce.

In the integrated mill, the Midrex Process is available, using pelletized ores of 60% Fe content to obtain a product of 92% metallization[3], thus requiring 1.53 tons of pellets/ton of sponge ore. Fuel consumption is estimated at 12.7×10^6 BTU/ton[3] for the process, at a cost of $92.30/ton of sponge ore produced.

The model allows sponge ore to be charged to any steel process -electric arc, open hearth, or BOF - even though worldwide practice is restricted to the electric arc or the blast furnace.[4]

In addition, the SL/RN solid reductant is available as an option in the mini-mill, using coal as the solid reductant: the inputs are based on the references cited, plus the cost breakdown in Reference XIX, p. 85.

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[1] Ref. XXX

[2] Ref. XXXI

[3] Ref. X, p. 5-6

[4] Ref. XIX, p. 61

Table 9 gives the data found for the direct reduction process in the matrix generator. Additional capacity over the 1.1 million tons[2] now in existence is assumed to cost $140/ton.[1]

E. Open Hearth Furnaces

Prior to the 1970's, the mainstay of the iron and steel industry was the open hearth furnace. Due to economic considerations and the energy crisis, a new workhorse, the basic oxygen furnace, has emerged. In 1973, 55% of the capacity was basic oxygen, 27% was open hearth, and 18% were electric arc furnaces. The fundamental process in all the steel furnaces is one of converting the major inputs of pig iron and scrap via oxidation into molten steel.

In the open hearth furnace which consists of a rectangular refractory hearth enclosed by refractory lined walls and roof, scrap is first charged accompanied by a small amount of limestone. After the fuel has been ignited and the melting of charge has begun, the proportioned amount of pig iron is charged. High purity oxygen is blown in. After various minor operations the molten steel is tapped for a total cycle time of from eight to twelve hours. The predominant characteristics of the open hearth process are:

1. ability to be charged with up to 100% scrap,
2. ability to be retrofitted by Q-basic oxygen process,
3. total tap to tap time of approximately eight hours and,
4. decreasing usefulness because of emergence of basic oxygen process (output decreased from 100×10^6 tons of raw steel in 1964 to 40×10^6 tons of raw steel in 1973).

---

[1] Ref. XIX, p. 85

[2] Ref. XVI, p. VII-31

TABLE PRCCDR- **TABLE 9**

* THIS TABLE STORES DATA FOR DIRECT REDUCTION

			>	INTG (X)
	~~CAPACITY~~		~~CAP~~	~~1400,0000~~
1890*	RESIDUAL OIL	E6 BTU	PRH	13,0000
	~~PELLETS~~	~~TONS~~	~~PELL~~	~~1,5200~~
	COST	$	CST	92,3000
			~~FLU~~	
			OXY	
			~~OAM~~	
			LAB	
			~~ELE~~	
			ETD	
			~~COA~~	
1900* +			>	MM(XIX)
	~~CAPACITY~~		~~CAP~~	~~2000,0000~~
	INVESTMENT COST(NEW)	$	INVESTN	28,0000
	PELLETS	TONS	PELL	1,5000
	~~FLUX~~	~~TONS~~	~~FLU~~	~~0,0600~~
	OXYGEN	E3 CU FT	OXY	0,1000
	~~OPER, + MAINT,~~	~~$~~	~~OAM~~	~~3,0000~~
	LABOR	MAN-HRS	LAB	0,5000
	~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~0,5100~~
	COAL	TONS	COA	0,6000
~~1910*~~			~~PRH~~	
			CST	

The model has three types of open hearth furnaces:

(a) the small relatively old vintages with 1 million tons of aggregate capacity

(b) small units built since 1945, amounting to 15 million tons capacity

(c) large units built since 1945, amounting to 34 million tons of yearly capacity

(These data were taken from Reference XV, exhibit A-5.) Energy and non-energy inputs are as reported in Reference V, p. 70, with the following exceptions. First, a high scrap option (.75 scrap, .38 pig iron) is available for all vintages as an alternative to the nominal mix in Reference V, (.51 scrap, .62 pig iron). When this option is chosen, an additional $.21 \times 10^6$ BTU is assumed necessary to heat the scrap. Second, oxygen injection is available only in the large units built since 1945, and the addition of 2×10^3 ft^3 per ton is assumed to reduce hydrocarbon inputs by 1.4 BTU^6/ton. Electricity inputs increase by .14 kWh^3/ton when this option is used. Third, nominal electricity, steam (net-use minus by-product steam output) by-product fuel (coke oven gas and tars) and natural gas and oil use per ton figures are as reported in Reference X, p. 4-7. Fourth, labor and maintenance costs are as reported in Reference XI, the Russell and Vaughan effort. Finally offgas, oxygen, and waste heat numbers are as reported in Reference VII. The terms in the objective function are to reflect the higher cost of operating the older, less efficient equipment.

Table 10 gives the portion of the matrix generator applying to the open hearth furnace with the data sources.

New investment in open hearths is allowed in the model at a capacity cost of $36/ton, given in Reference XX. Further, early and average open hearths

TABLE CHARCH - **TABLE 10**

* THIS TABLE STORES DATA FOR OPEN HEARTH FURNACE

				EAS
940*	REFRACTORY V	LBS	REF	40.0000
	~~FLUX V~~	~~TONS~~	~~FLU~~	~~0.0470~~
	LIME V	TONS	LIM	0.0130
	~~FERROALLOY V~~	~~TONS~~	~~FER~~	~~0.0100~~
	SCRAP V + variants	TONS	SCR	0.5100
	~~OXYGEN VII~~	~~E3 CU FT~~	~~OXY~~	~~1.2000~~
	STEAM X	E6 BTU	STM	-0.6100
	~~RESIDUAL OIL XI~~ + variants	~~E6 BTU~~	~~PRH~~	~~2.5~~
	ELECTRICITY X	E3 KWH	ELE	0.0140
	~~LABOR XI~~	~~MAN-HRS~~	~~LAB~~	~~0.6720~~
950*	OPER. + MAINT. XV	$	OAM	19.2600
	~~WASTE HEAT VII~~	~~E6 BTU~~	~~WHT~~	~~3.6000~~
	HOME SCRAP XXIII	TONS	HSC	0.0500
	~~STEEL FURNACE OFFGAS X~~	~~E6 BTU~~	~~SFG~~	~~0.0000~~
	COKE OVEN OFFGAS X	E6 BTU	COG	-0.7600
	~~PIG IRON V + variants~~	~~TONS~~	~~PIG~~	~~0.6200~~
	COST	$	CST	2.4900
				EHS
	REFRACTORY	LBS	REF	40.0000
	~~FLUX~~	~~TONS~~	~~FLU~~	~~0.0470~~
960*	LIME	TONS	LIM	0.0130
	~~FERROALLOY~~	~~TONS~~	~~FER~~	~~0.0100~~
	SCRAP	TONS	SCR	0.7500
	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~1.2000~~
	STEAM	E6 BTU	STM	-0.6100
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~2.7~~
	ELECTRICITY	E3 KWH	ELE	0.0140
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0.6720~~
	OPER. + MAINT.	$	OAM	19.2600
	~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~3.6000~~
970*	HOME SCRAP	TONS	HSC	0.0500
	~~STEEL FURNACE OFFGAS~~	~~E6 BTU~~	~~SFG~~	~~0.0000~~
	COKE OVEN OFFGAS	E6 BTU	COG	-0.7600
	~~PIG IRON~~	~~TONS~~	~~PIG~~	~~0.3800~~
	COST	$	CST	2.4900
				~~AAS~~
	REFRACTORY	LBS	REF	40.0000
	~~FLUX~~	~~TONS~~	~~FLU~~	~~0.0470~~
	LIME	TONS	LIM	0.0130
	~~FERROALLOY~~	~~TONS~~	~~FER~~	~~0.0100~~
980*	SCRAP	TONS	SCR	0.5100
	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~1.2000~~
	STEAM	E6 BTU	STM	-0.6100
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~2.5~~
	ELECTRICITY	E3 KWH	ELE	0.0140
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0.6720~~
	OPER. + MAINT.	$	OAM	19.2600
	~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~2.6000~~

	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.1000
990*	PIG IRON	TONS	PIG	0.6200
	COST	$	CST	1.4900
			COG	-.76
				ALS
	REFRACTORY	LBS	REF	40.0000
	FLUX	TONS	FLU	0.0470
	LIME	TONS	LIM	0.0130
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.7500
	OXYGEN	E3 CU FT	OXY	1.2000
1000*	STEAM	E6 BTU	STM	-0.6100
	RESIDUAL OIL	E6 BTU	PRH	2.7
	ELECTRICITY	E3 KWH	ELE	0.0140
	LABOR	MAN-HRS	LAB	0.6720
	OPER. + MAINT.	$	OAM	19.2600
	WASTE HEAT	E6 BTU	WHT	2.6000
	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.1000
	PIG IRON	TONS	PIG	0.3800
	COST	$	CST	1.4500
1010*			COG	-.76
				GAS
	INVESTMENT COST(NEW)	$	INVESTN	36.0000
	REFRACTORY	LBS	REF	40.0000
	FLUX	TONS	FLU	0.0470
	LIME	TONS	LIM	0.0130
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.5100
	OXYGEN	E3 CU FT	OXY	2.0000
	STEAM	E6 BTU	STM	-0.6100
1020*	RESIDUAL OIL	E6 BTU	PRH	1.1
	ELECTRICITY	E3 KWH	ELE	0.0280
	LABOR	MAN-HRS	LAB	0.6720
	OPER. + MAINT.	$	OAM	19.2600
	WASTE HEAT	E6 BTU	WHT	1.3000
	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.0000
	PIG IRON	TONS	PIG	0.6200
	COST	$	CST	0.0000
			COG	-.76

1030* +			>	BFS
	INVESTMENT COST(NEW)	$	INVESTN	36.0000
	REFRACTORY	LBS	REF	40.0000
	FLUX	TONS	FLU	0.0470
	LIME	TONS	LIM	0.0130
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.7500
	OXYGEN	E3 CU FT	OXY	2.0000
	STEAM	E6 BTU	STM	-0.6100
	RESIDUAL OIL	E6 BTU	PRH	1.3
1040*	ELECTRICITY	E3 KWH	ELE	0.0280
	LABOR	MAN-HRS	LAB	0.6720
	OPER. + MAINT.	$	OAM	19.2600
	WASTE HEAT	E6 BTU	WHT	1.3000
	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFO	0.0000
	PIG IRON	TONS	PIG	0.3800
	COST	$	CST	0.0000
			COG	-.76

can be converted to Q-BOP's at a cost of $12.50 per ton, given in Reference X, p. 5-29, assuming the cost of a BOF is as reported in Reference XX.

F. Q-BOP Steel Process

A new process called the Q-basic oxygen process had a worldwide capacity of 19 x 10^6 tons per year in 1973, of which nearly 10 million tons is in the United States.[1]

The difference between the QBO and the BO process is that oxygen is blown in at the tuyeres located at the bottom of the QBO furnace. Other notable differences are:

1. hot metal yield increase of 2% because of less spillage,
2. lowered capital costs as opposed to BO furnaces (lessened overhead structure requirements),
3. productivity increase of 10%, and
4. increased energy consumption per ton of raw steel (as compared to the basic oxygen furnace) due to the necessity of using an additional .168 BTU^6/ton of natural gas in the process.[2]

The input values in Table 11 reflect the above adjustments to the input figures for the BOP nominal operating values.

One energy conserving option - the installation of offgas recovery hoods is included in the model. It permits the reclamation of .42 BTU /ton offgas at a cost of $5.00/ton annual capacity.[3]

---

[1]Ref. X, p. 5-32

[2]Ref. X, p. 5-32

[3]Ref. X, p. 6-24, and Ref. XVII, p. 69-74

TABLE CHARGB **TABLE II**

===== ==========

* THIS TABLE STORES DATA FOR Q-BOF FURNACE

		>	NA
CAPACITY		CAP	4500.0000
INVESTMENT COST(NEW)	$	INVESTN	20.0000
REFRACTORY V	LBS	REF	13.0000
FLUX V	TONS	FLU	0.0130
LIME V	TONS	LIM	0.0750
FERROALLOY V	TONS	FER	0.0100
SCRAP V	TONS	SCR	0.3200
OXYGEN X	E3 CU FT	OXY	1.7000
NITROGEN V	10 CU FT	NIT	40.0000
STEAM V	E6 BTU	STM	0.0200
RESIDUAL OIL V	E6 BTU	PRH	0.3680
ELECTRICITY V	E3 KWH	ELE	0.0300
LABOR XI	MAN-HRS	LAB	0.2800
OPER. + MAINT. XI	$	OAM	3.5700
HOME SCRAP XXXIII	TONS	HSC	0.0500
WASTE HEAT	E6 BTU	WHT	0.7900
PIG IRON V	TONS	PIG	0.8000
COST	$	CST	0.0000
		SFG	

\+

		>	HC
CAPACITY		CAP	0.0000
INVESTMENT COST(NEW)	$	INVESTN	25.0000
REFRACTORY	LBS	REF	13.0000
FLUX	TONS	FLU	0.0130
LIME	TONS	LIM	0.0750
FERROALLOY	TONS	FER	0.0100
SCRAP	TONS	SCR	0.3200
OXYGEN	E3 CU FT	OXY	1.7000
NITROGEN	10 CU FT	NIT	40.0000
STEAM	E6 BTU	STM	0.0200
RESIDUAL OIL	E6 BTU	PRH	0.3680
ELECTRICITY	E3 KWH	ELE	0.0300
LABOR	MAN-HRS	LAB	0.2800
OPER. + MAINT.	$	OAM	3.5700
HOME SCRAP	TONS	HSC	0.0500
WASTE HEAT XIII	E6 BTU	WHT	0.3700
STEEL FURNACE OFFGAS XIII	E6 BTU	SFG	0.4200
PIG IRON	TONS	PIG	0.8000
COST	$	CST	0.0000

New Q-BOP capacity can be purchased at $20/ton, and old open hearth capacity can be retrofitted at $12.50/ton annual capacity, according to Reference X, p. 5-29.

Table 11 is the section in the matrix generator dealing with the process, and gives the references for all the contained data.

G. Basic Oxygen Process Furnace

The design of the basic oxygen furnace differs greatly from the open hearth furnace. The basic oxygen furnace is a pear shaped vessel which at the beginning of its cycle is tilted at a forty-five degree angle to firstly accommodate a scrap charge (up to 30% of charge), secondly to receive the molten pig iron charge. After the ladle is uprighted, high purity oxygen is injected by means of a water cooled lance located at the top of the vessel. Maintaining the melt at 2500-2900°F, chemical reactions take place after which the molten steel is poured into transfer cars for transporting either to an ingot pouring platform or to a continuous casting machine. The tremendous advantage of the basic oxygen furnace is its total cycle time which is approximately forty-five minutes; this results in total cost savings in the order of 12 to 15% over the open hearth, despite higher material costs.[1] With basic oxygen furnaces replacing open hearth at a rapid rate and with the limitations on the amount of scrap which can be charged into a BO furnace, integrated plants are relying upon the electric arc furnace to process the excess scrap. The prevailing characteristics of the basic oxygen furnace are as follows:

[1] Ref. XXVI, p. 7

1. increase in output from 17.5% of total steel production in 1965 to 55.5% in 1973 (causing a decrease from 3.2 to 2.3 x 10^6 BTU per ton of raw steel due to BTU's saved in the switch from OH's to BO's),
2. cycle time of 45 minutes which results in a significant increase of output per unit capital (as compared to an OH furnace), and
3. a better ability to have offgases captured with offgas hoods with savings of .75 x 10^6 BTU per ton of raw steel.

As in the case of other equipment, differing vintages of BOP's have differing characteristics. The model distinguishes between three vintages: (a) those small installations built prior to 1961; a million tons of capacity are still operating; (b) those built in the 1961-1968 period, amounting to 54 million tons capacity; (c) those built since 1968, totalling 15 million tons yearly capacity.[1]

Several energy saving options are available in the model.

BOF offgas hoods have long been recognized as a possible method of energy conservation. This offgas, whose quality is in the 250-300 BTU^6/cuf range, could be utilized by other processes. For an investment cost of $5.00/ton BOF capacity, an estimated .42 x 10^6 BTU's per year can be saved[2] with this option. Currently, 9.8 million tons of BOF capacity have such hoods installed[3], with an additional 5.8 by 1980.[3]

Next, the possibility of increasing the maximum scrap charge to the BOF by scrap preheaters has been explored as a method of utilizing the same BOF

[1] Ref. XXII

[2] Ref. XVII, p. 70

[3] Ref. XXII

offgases. This would then allow the integrated mills to retire the open hearths without the ncessity of building new electric arc furnaces to handle the home scrap. Such preheaters can increase BOF scrap charges from .32 tons/ton to .45 tons/ton of steel, using only the offgases saved by the recovery process just mentioned.[1] Estimated costs for this option are $2.50/ton.[2] No operating scrap preheat facilities exist in this country today. The retrofit of existing BOF facilities with those devices is limited in the model to those constructed since 1968. The model allows construction of new BOF facilities with these options: the cost of a new BOF is assumed to be $25/ton of annual capacity.[3]

Each BOF vintage has a differing set of operating options. Those built prior to 1961 have only one mode of operation to reflect the limited versatility of these early plants - that given in source V, p. 71 for the non-energy inputs, and source X, p. 4-6, for the energy inputs. The later two vintages have three options - a low scrap option (100% pig iron charge), a nominal scrap option (.32 tons/ton) and, with the scrap preheater installed, a high scrap option (.45 tons/ton). Further, the two vintages can be retrofitted with hoods to capture the offgases. If those facilities with scrap preheat installations are operated at nominal or low scrap charges, it is assumed that the $.42 \times 10^6$ BTU recovered for scrap preheat can be used elsewhere in the mill.

Table 12 gives the data sources and the appropriate section of the matrix generator.

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[1]Ref. X, p. 5-26

[2]Estimate

[3]Ref. XX

TABLE CHARBO - **TABLE 12**

150* * THIS TABLE STORES DATA FOR BASIC OXYGEN FURNACE

			~~ENNAS~~
CAPACITY		CAP	9000,0000
~~REFRACTORY~~ V	~~LBS~~	~~REF~~	~~13,0000~~
FLUX V	TONS	FLU	0,0130
~~LIME~~ V	~~TONS~~	~~LIM~~	~~0,0750~~
FERROALLOY V	TONS	FER	0,0100
~~SCRAP~~ V	~~TONS~~	~~SCR~~	~~0,3200~~
OXYGEN V	E3 CU FT	OXY	1,9000
~~NITROGEN~~ V	~~10 CU FT~~	~~NIT~~	~~40,0000~~
160* STEAM X	E6 BTU	STM	0,0400
~~RESIDUAL OIL~~ V	~~E6 BTU~~	~~PRH~~	~~0,2000~~
ELECTRICITY X	E3 KWH	ELE	0,0300
~~LABOR~~ XI	~~MAN-HRS~~	~~LAB~~	~~0,2800~~
OPER. + MAINT. XI	$	OAM	6,1300
~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~0,7500~~
HOME SCRAP XXXII	TONS	HSC	0,0500
~~STEEL FURNACE OFFGAS~~ X	~~E6 BTU~~	~~SFG~~	~~0,0000~~
PIG IRON V	TONS	PIG	0,8000
~~COST~~	~~$~~	~~CST~~	~~1,3300~~

+		>		APHHS
	CAPACITY		CAP	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	7.5000
.....	NEW ROW			
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.4500
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	5.1000
	WASTE HEAT	E6 BTU	WHT	0.3700
	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.0000
	PIG IRON	TONS	PIG	0.6700
	COST	$	CST	0.8000
+		>		APHAS
	CAPACITY		CAP	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	7.5000
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.3200
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	5.1000
	WASTE HEAT	E6 BTU	WHT	0.3700
	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.4200
	PIG IRON	TONS	PIG	0.6000
	COST	$	CST	0.8000
+		>		APHLS
	CAPACITY		CAP	0.0000

	INVESTMENT COST(RETROFIT)	$	INVESTR	7.5000
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~13.0000~~
	FLUX	TONS	FLU	0.0130
	~~LIME~~	~~TONS~~	~~LIM~~	~~0.0750~~
	FERROALLOY	TONS	FER	0.0100
	~~SCRAP~~	~~TONS~~	~~SCR~~	~~0.0000~~
	OXYGEN	E3 CU FT	OXY	1.9000
	~~NITROGEN~~	~~10 CU FT~~	~~NIT~~	~~40.0000~~
220*	STEAM	E6 BTU	STM	0.0400
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~0.2000~~
	ELECTRICITY	E3 KWH	ELE	0.0300
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0.2800~~
	OPER. + MAINT.	$	OAM	5.1000
	~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~0.3700~~
	HOME SCRAP	TONS	HSC	0.0500
	~~STEEL FURNACE OFFGAS~~	~~E6 BTU~~	~~SFG~~	~~0.4200~~
	PIG IRON	TONS	PIG	1.1200
	~~COST~~	~~$~~	~~CST~~	~~0.8000~~
230* +			>	ANNAS
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~13.0000~~
	FLUX	TONS	FLU	0.0130
	~~LIME~~	~~TONS~~	~~LIM~~	~~0.0750~~
	FERROALLOY	TONS	FER	0.0100
	~~SCRAP~~	~~TONS~~	~~SCR~~	~~0.3200~~
	OXYGEN	E3 CU FT	OXY	1.9000
	~~NITROGEN~~	~~10 CU FT~~	~~NIT~~	~~40.0000~~
	STEAM	E6 BTU	STM	0.0400
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~0.2000~~
240*	ELECTRICITY	E3 KWH	ELE	0.0300
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0.2800~~
	OPER. + MAINT.	$	OAM	5.1000
	~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~0.7900~~
	HOME SCRAP	TONS	HSC	0.0500
	~~PIG IRON~~	~~TONS~~	~~PIG~~	~~0.8000~~
	COST	$	CST	0.8000
			~~SFG~~	
+			>	ANNLS
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~13.0000~~
250*	FLUX	TONS	FLU	0.0130
	~~LIME~~	~~TONS~~	~~LIM~~	~~0.0750~~
	FERROALLOY	TONS	FER	0.0100
	~~SCRAP~~	~~TONS~~	~~SCR~~	~~0.0000~~
	OXYGEN	E3 CU FT	OXY	1.9000
	~~NITROGEN~~	~~10 CU FT~~	~~NIT~~	~~40.0000~~
	STEAM	E6 BTU	STM	0.0400
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~0.2000~~

	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	5.1000
	WASTE HEAT	E6 BTU	WHT	0.7900
	HOME SCRAP	TONS	HSC	0.0500
	PIG IRON	TONS	PIG	1.1200
	COST	$	CST	0.8000
			SFG	
+		>		BFHHS
	CAPACITY		CAP	0.0000
	INVESTMENT COST(NEW)	$	INVESTN	35.0000

..... NEW ROW

	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.4500
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	3.5700
	WASTE HEAT	E6 BTU	WHT	0.3700
	HOME SCRAP	TONS	HSC	0.0500
	PIG IRON	TONS	PIG	0.6700
	COST	$	CST	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	7.5000
			SFG	
+		>		BPHAS
	CAPACITY		CAP	0.0000
	INVESTMENT COST(NEW)	$	INVESTN	35.0000
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.3200
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
	ELECTRICITY	E3 KWH	ELE	0.0300

300*	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	3.5700
	WASTE HEAT	E6 BTU	WHT	0.3700
	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.4200
	PIG IRON	TONS	PIG	0.8000
	COST	$	CST	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	7.5000
+			>	BPHLS
	CAPACITY		CAP	0.0000
310*	INVESTMENT COST(NEW)	$	INVESTN	35.0000
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.0000
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
320*	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	3.5700
	WASTE HEAT	E6 BTU	WHT	0.3700
	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.4200
	PIG IRON	TONS	PIG	1.1200
	COST	$	CST	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	7.5000
+			>	BNNAS
330*	INVESTMENT COST(NEW)	$	INVESTN	25.0000
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.3200
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
340*	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	3.5700
	WASTE HEAT	E6 BTU	WHT	0.7500
	HOME SCRAP	TONS	HSC	0.0500
	PIG IRON	TONS	PIG	0.8000

	COST	$	CST	0.0000
			SFG	
+			>	ENNLS
	INVESTMENT COST(NEW)	$	INVESTN	25.0000
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.0000
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	3.5700
	WASTE HEAT	E6 BTU	WHT	0.7900
	HOME SCRAP	TONS	HSC	0.0500
	PIG IRON	TONS	PIG	1.1200
	COST	$	CST	0.0000
			SFG	
+			>	AHDAS
	INVESTMENT COST(RETROFIT)	$	INVESTR	5.0000
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.3200
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	5.1000
	WASTE HEAT	E6 BTU	WHT	0.3700
	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.4200
	PIG IRON	TONS	PIG	0.8000
	COST	$	CST	0.6000
+			>	AHDLS
	INVESTMENT COST(RETROFIT)	$	INVESTR	5.0000
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
	FERROALLOY	TONS	FER	0.0100

	SCRAP	TONS	SCR	0.0000
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2500
	OPER. + MAINT.	$	OAM	5.1000
400*	WASTE HEAT	E6 BTU	WHT	0.3700
	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.4200
	PIG IRON	TONS	PIG	1.1200
	COST	$	CST	0.8000
				EHCAS
	INVESTMENT COST(NEW)	$	INVESTN	30.0000
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
410*	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.3200
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	3.5700
	WASTE HEAT	E6 BTU	WHT	0.3700
420*	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.4200
	PIG IRON	TONS	PIG	0.8000
	COST	$	CST	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	5.0000
				BHDLS
	INVESTMENT COST(NEW)	$	INVESTN	30.0000
	REFRACTORY	LBS	REF	13.0000
	FLUX	TONS	FLU	0.0130
	LIME	TONS	LIM	0.0750
430*	FERROALLOY	TONS	FER	0.0100
	SCRAP	TONS	SCR	0.0000
	OXYGEN	E3 CU FT	OXY	1.9000
	NITROGEN	10 CU FT	NIT	40.0000
	STEAM	E6 BTU	STM	0.0400
	RESIDUAL OIL	E6 BTU	PRH	0.2000
	ELECTRICITY	E3 KWH	ELE	0.0300
	LABOR	MAN-HRS	LAB	0.2800
	OPER. + MAINT.	$	OAM	3.5700
	WASTE HEAT	E6 BTU	WHT	0.3700
440*	HOME SCRAP	TONS	HSC	0.0500
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.4200
	PIG IRON	TONS	PIG	1.1200
	COST	$	CST	0.0000
	INVESTMENT COST(RETROFIT)	$	INVESTR	5.0000

H. Electric Arcs

The treatment of electric arc operation in the model is relatively simple. Two vintages are identified - pre-1945 and post-1945.[1] The early vintages can produce both carbon and alloy steels, while the later vintage can produce carbon, alloy, and stainless steel. An option is available to use the sensible heat in the offgases to preheat the scrap charge for carbon steel only, thus reducing electricity consumption by 15%. This can be installed as a retrofit on post-1945 furnaces, and on all new furnaces; the cost is assumed to be $5.00/ton. New electric arc capacity is available in the model at a cost of $25.00/ton.[3]

Electricity consumption per ton in the model depends on both the vintage of the equipment, and the type of steel manufactured. Nominal electricity consumption, along with all other inputs, is as given in Reference V, p. 72; this consumption rate of 525 kWh/ton is achieved when pre-1945 vintage electric arcs are producing carbon steel. When steel alloys and stainless steel are produced, electricity consumption per ton increases to 740 kWh/ton[2] when produced on the same vintage furnaces. For the more recent furnaces, electricity consumption is assumed to be 10% lower than that obtainable in the early less efficient furnaces.

All of this data and sources are summarized in Table 13.

Since electric arcs are used in mini-mills, the capacity available in 1975 - approximately 28 million tons - must be allocated between the integrated

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[1]Ref. XV

[2]Ref. VII, p. 451

[3]Ref. XX

* THIS TABLE STORES DATA FOR ELECTRIC ARC FURNACE

			ANNC
INVESTMENT COST(NEW)	$	INVESTN	28,0000
~~REFRACTORY~~ V	~~LBS~~	~~REF~~	~~26,0000~~
FLUX V	TONS	FLU	0,0150
~~LIME~~ V	~~TONS~~	~~LIM~~	~~0,0300~~
FERROALLOY V	TONS	FER	0,0000
~~SCRAP~~ V	~~TONS~~	~~SCR~~	~~1,1000~~
OXYGEN V	E3 CU FT	OXY	0,2500
~~ELECTRODES~~ V	~~LBS~~	~~ETD~~	~~12,0000~~
RESIDUAL OIL V	E6 BTU	PRH	0,1000
~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	V ~~0,5250~~
LABOR XI	MAN-HRS	LAB	0,8100
~~OPER. + MAINT.~~ XX	~~$~~	~~OAM~~	~~18,4700~~
WASTE HEAT	E6 BTU	WHT	0,0500
~~HOME SCRAP~~ XX	~~TONS~~	~~HSC~~	~~0,0500~~
STEEL FURNACE OFFGAS V	E6 BTU	SFG	0,0000
~~COST~~	~~$~~	~~CST~~	~~1,2000~~
			BNNC
~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~28,0000~~
REFRACTORY	LBS	REF	26,0000
~~FLUX~~	~~TONS~~	~~FLU~~	~~0,0150~~
LIME	TONS	LIM	0,0300
~~FERROALLOY~~	~~TONS~~	~~FER~~	~~0,0000~~
SCRAP	TONS	SCR	1.1000
~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~0,2500~~
ELECTRODES	LBS	ETD	12,0000
~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~0,1000~~
ELECTRICITY	E3 KWH	ELE	XIII 0,4750
~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0,6400~~
OPER. + MAINT.	$	OAM	18,47
~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~0,0500~~
HOME SCRAP	TONS	HSC	0,0500
~~STEEL FURNACE OFFGAS~~	~~E6 BTU~~	~~SFG~~	~~0,0000~~
COST	$	CST	1.2000
			ANNA
INVESTMENT COST(NEW)	$	INVESTN	28,0000
~~REFRACTORY~~	~~LBS~~	~~REF~~	~~26,0000~~
FLUX	TONS	FLU	0.0150
~~LIME~~	~~TONS~~	~~LIM~~	~~0,0300~~
FERROALLOY	TONS	FER	0,0100
~~SCRAP~~	~~TONS~~	~~SCR~~	~~1,1000~~
OXYGEN	E3 CU FT	OXY	0,2500
~~ELECTRODES~~	~~LBS~~	~~ETD~~	~~12,0000~~
RESIDUAL OIL	E6 BTU	PRH	0,1000
~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	VII ~~0,7400~~
LABOR	MAN-HRS	LAB	0,8100
~~OPER. + MAINT.~~	~~$~~	~~OAM~~	~~18,4700~~
WASTE HEAT	E6 BTU	WHT	0,0500
~~HOME SCRAP~~	~~TONS~~	~~HSC~~	~~0,0500~~
STEEL FURNACE OFFGAS	E6 BTU	SFG	0,0000
~~COST~~	~~$~~	~~CST~~	~~1,2000~~
			BNNA
~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~28,0000~~
REFRACTORY	LBS	REF	26,0000
~~FLUX~~	~~TONS~~	~~FLU~~	~~0,0150~~

mills and the mini-mills. The only reference available as to mini-mill electric arc capacity is found in Reference X, p. 3-7 and 1-2, where a capacity of ~24 million tons is inferred. Thus, the model assumes only 4 million tons of electric arc capacity are available at the integrated mills; an arbitrary division of 1.8 million tons of pre-1945 vintage, 2 million post-1945, and .2 million post-1945 with hoods is assumed.

I. Casting, Forming, and Final Finishing

During the steel-making process, the various alloys are added to the steel: consequently, the model now must distinguish between three types of steel - carbon, alloy, and stainless. While all steel furnaces can manufacture carbon steel, it is assumed that only electric arc furnaces can produce stainless steel, while only the BOF's and electric arcs can produce alloys. (This does some violance to reality, since O.H.'s did produce about 1/7 of the total alloy production in 1976.)[1] First the treatment of carbon steel production is described, then the characterization of alloy and stainless production.

(i) Carbon Steel

After the hot metal leaves the steelmaking furnaces, two major processes remain - casting and forming, and final finishing.

Two options are available for the casting and forming stage in the integrated mill model:

(a) continuous casting, where the hot metal from the steel furnaces is cast directly into billets (CCCBI) or slabs (CCCSL) (bloom continuous casting is not now available as an option)

[1] AISI 1976 Report, p. 53

	LIME	TONS	LIM	0.0300	
	~~FERROALLOY~~	~~TONS~~	~~FER~~	~~0.0100~~	
730*	SCRAP	TONS	SCR	1.1000	
	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~0.2500~~	
	ELECTRODES	LBS	ETD	12.0000	
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~0.1000~~	
	ELECTRICITY	E3 KWH	ELE	0.6600	XIII
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0.6400~~	
	OPER. + MAINT.	$	OAM	18.47	
	~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~0.0500~~	
	HOME SCRAP	TONS	HSC	0.0500	
	~~STEEL FURNACE OFFGAS~~	~~E6 BTU~~	~~SFG~~	~~0.0000~~	
740*	COST	$	CST	0.0000	
+			>	~~BANS~~	
	INVESTMENT COST(NEW)	$	INVESTN	28.0000	
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~26.0000~~	
	FLUX	TONS	FLU	0.0150	
	~~LIME~~	~~TONS~~	~~LIM~~	~~0.0300~~	
	FERROALLOY	TONS	FER	0.0100	
	~~SCRAP~~	~~TONS~~	~~SCR~~	~~1.1000~~	
	OXYGEN	E3 CU FT	OXY	0.2500	
	~~ELECTRODES~~	~~LBS~~	~~ETD~~	~~12.0000~~	
750*	RESIDUAL OIL	E6 BTU	PRH	0.1000	
	~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~0.6600~~	XIII
	LABOR	MAN-HRS	LAB	0.6400	
	~~OPER. + MAINT.~~	~~$~~	~~OAM~~	~~18.47~~	
	WASTE HEAT	E6 BTU	WHT	0.0500	
	~~HOME SCRAP~~	~~TONS~~	~~HSC~~	~~0.0500~~	
	STEEL FURNACE OFFGAS	E6 BTU	SFG	0.0000	
	~~COST~~	~~$~~	~~CST~~	~~0.0000~~	
+			>	AHDC	
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~33.0000~~	
760*	REFRACTORY	LBS	REF	26.0000	
	~~FLUX~~	~~TONS~~	~~FLU~~	~~0.0150~~	
	LIME	TONS	LIM	0.0300	
	~~FERROALLOY~~	~~TONS~~	~~FER~~	~~0.0000~~	
	SCRAP	TONS	SCR	1.1000	
	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~0.2500~~	
	ELECTRODES	LBS	ETD	12.0000	
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~0.1000~~	
	ELECTRICITY	E3 KWH	ELE	.43	XIII
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0.8100~~	
770*	OPER. + MAINT.	$	OAM	18.47	
	~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~0.0200~~	
	HOME SCRAP	TONS	HSC	0.0500	
	~~STEEL FURNACE OFFGAS~~	~~E6 BTU~~	~~SFG~~	~~0.0300~~	

without loss of the sensable heat. Current capacity was 14 million tons in 1972.[1]

(b) ingot casting, (INGC), where the hot metal is allowed to cool, and then reheated in soaking pits (usually without recuperator)[2] (SPC) using offgases generated in prior stages of production before breaking into billets, blooms, and slabs suitable for final finishing. Current capacity is 185 million tons.[3]

Not all steel can utilize the continuous casting cycle (in particular, rimmed low carbon steels).[4] Current use represents only 7% (1974)[5] of domestic production, even though continuous casting capacity is much larger. It has been said that the technology exists now to continuously cast 50% of steel output (Reference XVI, p. VII-2). Nonetheless, for the time periods involved in the model, it is reasonable to assume that the technology will be developed to allow continuous casting of all forms of steel within the model's planning horizon. Costs of new capacity are 65 and 47 dollars a ton yearly capacity for billets/blooms and slabs respectively.[6]

[1] Ref. XV, p. A-5

[2] Ref. X, p. 4-17

[3] Ref. XVI, p. IX-3

[4] Ref. X, p. 5-35,36

[5] Ref. XV, p. A-24

[6] Ref. XX, exhibit 6

Table 14 gives the input coefficients for the operating and capacity expansion activities of the two alternative casting and forming processes; sources for the data are given in the footnotes.

Semi-finishing (primary hot rolling) is required for that portion of the steel production which is ingot cast and placed in the soaking pits; the steel which is continuously cast avoids this step. Table 15 gives the coefficients associated with this semi-finishing step for slabs (SFCSL), billets (SFCBI), and blooms (SFCBL).

Capacities of the semi-finishing processes are 31, 80, and 44 million tons respectively for billets, slabs, and blooms.[1] Costs of new yearly capacity are 48, 103, and 47 dollars a ton.[2]

The final finishing of steel is accomplished in two steps in the model; the reheat step, where the blooms, slabs, and billets are raised by burning natural gas or oil to 1500 K so they can be further rolled or milled into finished products, and the final finishing of the steel, where blooms are rolled and milled into heavy structural forms, rails, and pilings, slabs are rolled and milled into plates, sheets, strips, and welded pipes and tubes, and billets are rolled and milled into seamless pipes and tubes, wires, bars, and light structural shapes.

Two options are available for the reheating step:

(a) pusher-type reheat furnaces (PTCBI, PTCBL, PTCSL) equipped with recuperators to preheat the air to 1000°F.

[1] Ref. XV, vol. 1, p. A-5

[2] Ref. XX, vol. 2, exhibit 6

TABLE CHARCAST TABLE 14

* ===== ==========

* THIS TABLE STORES DATA FOR CASTING

			>	INGC
	CAPACITY		CAP	150630.0000
450*	CARBON HOT METAL	TONS	CARBN	1.0000
*			>	SPC
	INGOT CASTING	TONS	INGC XXIII	1.0200
	COKE OVEN OFFGAS	E6 BTU	COG	0.0000
	HOME SCRAP	TONS	HSC XXIII	0.0200
	RESIDUAL OIL	E6 BTU	PRH V	1.57
	DISTILLATE OIL/GAS	E6 BTU	HDG V	1.57
			SPITC	
			ELE	
470*			OXY	
			STM	
			LAB XX	.09
			OAM XX	1.91
			CARBN	
*			>	CCCSI
	CARBON HOT METAL	TONS	CARBN V	1.0400
	ELECTRICITY	E3 KWH	ELE V	0.0150
	HOME SCRAP	TONS	HSC V	0.0400
	DISTILLATE OIL/GAS	E6 BTU	HDG V	0.5100
480*	OXYGEN	E3 CU FT	OXY V	0.5600
	LABOR	MAN-HRS	LAB X	0.9900
	OPER. + MAINT.	$	OAM X	2.4700
	RESIDUAL OIL	E6 BTU	PRH V	0.5100
*			>	CCCSL
	CARBON HOT METAL	TONS	CARBN V	1.0400
510*	HOME SCRAP	TONS	HSC V	0.0400
	DISTILLATE OIL/GAS	E6 BTU	HDG V	0.6100
	ELECTRICITY	E3 KWH	ELE V	0.0250
	OXYGEN	E3 CU FT	OXY V	0.7500
	LABOR	MAN-HRS	LAB X	0.9900
	OPER. + MAINT.	$	OAM XX	22.2100
	RESIDUAL OIL	E6 BTU	PRH V	0.6100
			INGC	

1250* TABLE CHARSF *TABLE 15*

* THIS TABLE STORES DATA FOR SEMI-FINISHING

				SFCBL XX
	CAPACITY		CAP	31050.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~48.0000~~
	SOAKING PIT(CARBON)	TONS	SPITC	1.1600
	~~HOME SCRAP~~	~~TONS~~	~~HSC~~	~~0.1600~~
	ELECTRICITY	E3 KWH	ELE	0.0200
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~.38000~~
1260*	OPER. + MAINT.	$	OAM	4.3800
				SFCSL XX
	CAPACITY		CAP	80150.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~47.0000~~
	SOAKING PIT(CARBON)	TONS	SPITC	1.1600
	~~HOME SCRAP~~	~~TONS~~	~~HSC~~	~~0.1600~~
	ELECTRICITY	E3 KWH	ELE	0.0380
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~.31000~~
	OPER. + MAINT.	$	OAM	3.49000
				SFCEI XX
1270*	CAPACITY		CAP	44260.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~103.0000~~
	SOAKING PIT(CARBON)	TONS	SPITC	1.1600
	~~HOME SCRAP~~	~~TONS~~	~~HSC~~	~~0.1600~~
	ELECTRICITY	E3 KWH	ELE	0.0280
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~.83000~~
	OPER. + MAINT.	$	OAM	9.4000

(b) mono-beam furnaces (MBCBI, MBCSL, MBCBL), still under development, which can reduce fuel consumption by 10 to 15%.

Table 16 gives the data for the options; footnotes again give the data sources.

Current capacities (pusher plus walking beam) arc assumed to be 105, 50, and 45 million tons yearly capacity.[1] There are no production facilities in operation which utilize the mono-beam reheat furnace.

Capacity expansion costs in 1976 for the pusher type furnace are $9.42 per ton and $7.27 per ton for the monobeam.[2] Retrofit costs are substantially lower.[3]

The final finishing of steel is distinguished by high scrap losses for blooms, billets and slabs. Table 17 gives the data and sources: unless otherwise noted, all data are taken from Reference XX, exhibit 8-A.

Additional capacity is available at costs of $332, 194, and 127 dollars a ton for blooms, slabs, and billets, respectively.[4]

Some 30 million tons a year ($\sim$50% of slab production) of steel products are annealed, the vast majority cold rolled slab products.[5] When such products are annealed, they use about 1.5 M10^6 BTU per ton of product.[6] To reflect this use without further complicating the model with another step, it is

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[1] Ref. XVI, p. IX-3

[2] Ref. XVIII, p. 122

[3] Ref. XVI, p. IX-7

[4] Ref. XX, exhibit 6

[5] Ref. XVI, p. IX-22

[6] Ref. XVI, p. IX-22

TABLE CHARRH *TABLE 16*

* =====-==========

* THIS TABLE STORES DATA FOR REHEATING FURNACES

			->	~~MECEL~~ XXIII
	CAPACITY		CAP	0.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~6.1900~~
	SEMI-FINISHED CARBON	TONS	SFC	1.0200
	~~COKE OVEN OFFGAS~~	~~E6 BTU~~	~~COG~~	
1100*	HOME SCRAP	TONS	HSC	0.0200
	~~DISTILLATE OIL/GAS~~	~~E6 BTU~~	~~MDG~~	~~2.25~~
	ELECTRICITY	E3 KWH	ELE	0.0000
	~~STEAM~~	~~E6 BTU~~	~~STM~~ X	~~0.3000~~
	RESIDUAL OIL	E6 BTU	PRH	2.25
*			->	~~MECSL~~ XXIII
	CAPACITY		CAP	0.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~6.1900~~
	SEMI-FINISHED CARBON	TONS	SFC	1.0200
	~~COKE OVEN OFFGAS~~	~~E6 BTU~~	~~COG~~	
1110*	HOME SCRAP	TONS	HSC	0.0200
	~~DISTILLATE OIL/GAS~~	~~E6 BTU~~	~~MDG~~	~~2.25~~
	ELECTRICITY	E3 KWH	ELE	0.0000
	~~STEAM~~	~~E6 BTU~~	~~STM~~ X	~~0.3000~~
	RESIDUAL OIL	E6 BTU	PRH	2.25
*			->	~~MECEL~~ XXIII
	CAPACITY		CAP	0.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~6.1900~~
	SEMI-FINISHED CARBON	TONS	SFC	1.0200
	~~COKE OVEN OFFGAS~~	~~E6 BTU~~	~~COG~~	
1120*	HOME SCRAP	TONS	HSC	0.0200
	~~DISTILLATE OIL/GAS~~	~~E6 BTU~~	~~MDG~~	~~2.25~~
	ELECTRICITY	E3 KWH	ELE	0.0000
	~~STEAM~~	~~E6 BTU~~	~~STM~~ X	~~0.3000~~
	RESIDUAL OIL	E6 BTU	PRH	2.25
*			->	~~PTCEL~~ XXIII
	INVESTMENT COST(NEW)	$	INVESTN	6.1900
	~~SEMI-FINISHED CARBON~~	~~TONS~~	~~SFC~~	~~1.0200~~
1150*	HOME SCRAP	TONS	HSC	0.0200
	~~DISTILLATE OIL/GAS~~	~~E6 BTU~~	~~MDG~~	~~2.36~~
	RESIDUAL OIL	E6 BTU	PRH	2.36
	~~STEAM~~	~~E6 BTU~~	~~STM~~ X	~~0.3000~~
			COG	
			~~ELE~~	
*			>	PTCSL XXIII
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~6.1900~~
	SEMI-FINISHED CARBON	TONS	SFC	1.0200
	~~HOME SCRAP~~	~~TONS~~	~~HSC~~	~~0.0200~~
1160*	DISTILLATE OIL/GAS	E6 BTU	MDG	2.36
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~2.36~~
	STEAM	E6 BTU	STM X	0.3000
			~~COG~~	
			ELE	
*			->	~~PTCEL~~
	INVESTMENT COST(NEW)	$	INVESTN	6.1900
	~~SEMI-FINISHED CARBON~~	~~TONS~~	~~SFC~~	~~1.0200~~
	HOME SCRAP	TONS	HSC	0.0200
	~~DISTILLATE OIL/GAS~~	~~E6 BTU~~	~~MDG~~	~~2.36~~
1170*	RESIDUAL OIL	E6 BTU	PRH	2.36
	~~STEAM~~	~~E6 BTU~~	~~STM~~ X	~~0.3000~~
			COG	

TABLE CHARFF **TABLE 17**

* ===== ==========

* THIS TABLE STORES DATA FOR FINAL FINISHING

650*			>	FFCEI(XX)
	INVESTMENT COST(NEW)	$	INVESTN	194.0000
	REHEATED CARBON	TONS	FFC	1.13000
	HOME SCRAP	TONS	HSC	0.1300
	ELECTRICITY	E3 KWH	ELE	0.1200
	LABOR	MAN-HRS	LAB	2.0800
			OAM	27.14
	RESIDUAL OIL	E6 BTU	PRH	
	DISTILLATE OIL/GAS	E6 BTU	MDG	
	STEAM	E6 BTU	STM	1.1000
860*			FFA	
			FFS	
*			>	FFCSL(XX)
	INVESTMENT COST(NEW)	$	INVESTN	127.0000
	REHEATED CARBON	TONS	FFC	1.2800
	HOME SCRAP	TONS	HSC	0.2800
	ELECTRICITY	E3 KWH	ELE	0.2500
	LABOR	MAN-HRS	LAB	2.3600
			OAM	41.63
	RESIDUAL OIL	E6 BTU	PRH	.75
870*	DISTILLATE OIL/GAS	E6 BTU	MDG	.75
	STEAM	E6 BTU	STM	1.1000
			FFA	
			FFS	
*			>	FFCEL(XX)
	INVESTMENT COST(NEW)	$	INVESTN	332.0000
	REHEATED CARBON	TONS	FFC	1.200
	HOME SCRAP	TONS	HSC	0.200
	ELECTRICITY	E3 KWH	ELE	0.1700
	LABOR	MAN-HRS	LAB	.37000
880*			OAM	7.09
	RESIDUAL OIL	E6 BTU	PRH	
	DISTILLATE OIL/GAS	E6 BTU	MDG	
	STEAM	E6 BTU	STM	1.1000
			FFA	
			FFS	

assumed that all slabs are annealed at $.75 \times 10^6$ BTU/ton, rather than assuming 50% of the slabs are annealed at 1.5×10^6 BTU/ton.

(ii) Alloy and Stainless Steel

The model allows stainless and alloy steel billets to be continuously cast or to use the ingot/soaking pit cycle. The flows follow identical paths as in the case of carbon steel: hence, only a single table is presented which includes the ingot/soaking pit contintinuous casting, reheating, and final finishing steps. References are the same as in the case of carbon steels, and are not repeated.

Alloy

Table 18

	CCABI
ALLOY	1.04
HSC	.04
PRH	.51
MDG	.51
ELE	.015
OXY	.56
LAB	.99
OAM	2.47

	INGA	SPA	SFABI
ALLOY	1.00		
INGA		1.02	
SPITA			1.25
HSC		.02	.25
FRH	1.57	~~.97~~	
MDG	1.57	~~.97~~	
ELE			.028
LAB			1.10
CAM			3.70

	PTABI
SFA	1.02
OW	
SFS	
OW	
COG	
HSC	.02
PRH	2.43
MDG	2.43
ELE	
STM	.5

	MBABI
	1.02
	~~1.8~~
HSC	.02
PRH	2.35
HDG	2.25
ELE	.04
	.3

	FFSBI
	1.20
STM	1.1
HSC	.20
ELE	.028
LAB	8.24

STAINLESS

Table 19

CCSBI

STAIN	1.04
HSC	.04
PBH	.51
HDG	.51
ELE	.015
OXY	.56
LAB	.99
OAM	2.47

	INGSSPS	SFSBI
STAIN	1.00	
INGS		1.02
SPITS		1.~~25~~
HSC	.02	~~.25~~
PRH	1.57 ~~.97~~	
MDG	1.57 ~~.97~~	
ELE		.028
LAB		1.10
OAM		3.70

PTSBI

	1.02
HSC	.02
PBH	2.43
HDG	2.43
STM	.3

MBSBI

	1.02
~~STAIN~~	
HSC	.02
PBH	~~1.48~~ 2.25
HDG	~~1.48~~ 2.25
ELE	.04
STM	~~1.05~~ .3

FFABI

	1.20
STM	1.1
HSC	.20
ELE	.028
LAB	8.24

III. THE MINI-MILL INDUSTRY MODEL

Non-integrated mills or mini-mills utilize steel scrap or directly reduced ore as a feedstock material although, in the latter case, the scarcity of high iron content ores has kept directly reduced ore mini-mills from flourishing. With mini-mills accounting for approximately 17%[1] of U.S. capacity, the ratio of mini-mills to integrated mills seems to be growing. The reasons for the increase are mainly due to improved technologies in utilization, preparation, and smelting of steel scrap along with a constantly improving technology for directly reduced ore. A major result of a shift from integrated to mini-mills is that large amounts of fuel may be conserved by processing waste scrap as opposed to processing iron ore. Specifically, about half the fuel is required to produce a ton of steel from steel scrap than from iron ores.

The model allows two types of steel - carbon and alloy - to be produced at mini-mills; only one product type - billets - is produced. The first phase of mini-mill steel-making - the electric arc furnace - has two options: (a) a 100% scrap charge, whose characteristics are identical to those found in the average arcs in integrated mills; (b) a charge of 30% directly reduced iron ore and 70% scrap.[2] The direct reduction of ore for the mini-mill (the SL/RN process) plus the 2 charge options for the electric arc are given in Table 20.

Next, the model allows the carbon or alloy hot metal to be either continuously cast, or to be cast into ingots, put in a soaking pit, and semi-finished. The ingot/soaking pit/semi-finish alternative is as in Table 21.

---

[1]Ref. X, p. 1-2

[2]Estimate based on Fe content equivalent

TABLE 20 - MINI MILL ELECTRIC ARC

	COST	$	CST	1.2000
				~~MCCC~~
	INVESTMENT COST(NEW)	$	INVESTN	28.0000
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~26.0000~~
	FLUX	TONS	FLU	0.0150
	~~LIME~~	~~TONS~~	~~LIM~~	~~0.0300~~
780*	SCRAP	TONS	SCR	1.1000
	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~0.2500~~
	ELECTRODES	LBS	ETD	12.0000
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~0.1000~~
	ELECTRICITY	E3 KWH	ELE	.525
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0.6400~~
	OPER. + MAINT.	$	OAM	18.47
	~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~0.8600~~
	HOME SCRAP	TONS	HSC	0.0500
	~~STEAM~~	~~E6 BTU~~	~~STM~~	~~1.0000~~
.....	~~NEW ROW~~			
~~790*~~	~~COST~~	~~$~~	~~CST~~	~~0.0000~~
			DRED	
.....	NEW ROW			
			FER	
				~~MCCA~~
	INVESTMENT COST(NEW)	$	INVESTN	28.0000
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~26.0000~~
	FLUX	TONS	FLU	0.0150
	~~LIME~~	~~TONS~~	~~LIM~~	~~0.0300~~
	FERROALLOY	TONS	FER	0.0100
	~~SCRAP~~	~~TONS~~	~~SCR~~	~~1.1000~~
800*	OXYGEN	E3 CU FT	OXY	0.2500
	~~ELECTRODES~~	~~LBS~~	~~ETD~~	~~12.0000~~
	RESIDUAL OIL	E6 BTU	PRH	0.1000
	~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~.74~~
	LABOR	MAN-HRS	LAB	0.64000
	~~OPER. + MAINT.~~	~~$~~	~~OAM~~	~~18.47~~
	WASTE HEAT	E6 BTU	WHT	0.8600
	~~HOME SCRAP~~	~~TONS~~	~~HSC~~	~~0.0500~~
	STEAM	E6 BTU	STM	1.0000
	~~COST~~	~~$~~	~~CST~~	~~0.0000~~
810*			DRED	

				MDRC
	INVESTMENT COST(NEW)	$	INVESTN	28.0000
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~28.6000~~
	FLUX	TONS	FLU	0.0150
	~~LIME~~	~~TONS~~	~~LIM~~	~~0.0400~~
	SCRAP	TONS	SCR	0.7700
	~~OXYGEN~~	~~E3 CU FT~~	~~OXY~~	~~0.2500~~
	ELECTRODES	LBS	ETD	11.0000
	~~RESIDUAL OIL~~	~~E6 BTU~~	~~PRH~~	~~0.1000~~
820*	ELECTRICITY	E3 KWH	ELE	.525
	~~LABOR~~	~~MAN-HRS~~	~~LAB~~	~~0.6400~~
	OPER. + MAINT.	$	OAM	18.47
	~~WASTE HEAT~~	~~E6 BTU~~	~~WHT~~	~~0.8600~~
	HOME SCRAP	TONS	HSC	0.0500
	~~STEAM~~	~~E6 BTU~~	~~STM~~	~~1.0000~~
	DIRECT REDUCTION ORE	TONS	DRED	0.3300
	~~COST~~	~~$~~	~~CST~~	~~0.0000~~
			FER	

				~~MCRA~~
830*	INVESTMENT COST(NEW)	$	INVESTN	28.0000
	~~REFRACTORY~~	~~LBS~~	~~REF~~	~~28.6000~~
	FLUX	TONS	FLU	0.0150
	~~LIME~~	~~TONS~~	~~LIM~~	~~0.0400~~
	FERROALLOY	TONS	FER	0.0100
	~~SCRAP~~	~~TONS~~	~~SCR~~	~~0.7700~~
	OXYGEN	E3 CU FT	OXY	0.2500
	~~ELECTRODES~~	~~LBS~~	~~ETD~~	~~11.0000~~
	RESIDUAL OIL	E6 BTU	PRH	0.1000
	~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~.74~~
840*	LABOR	MAN-HRS	LAB	0.6400
	~~OPER. + MAINT.~~	~~$~~	~~OAM~~	~~18.47~~
	WASTE HEAT	E6 BTU	WHT	0.8600
	~~HOME SCRAP~~	~~TONS~~	~~HSC~~	~~0.0500~~
	STEAM	E6 BTU	STM	1.0000
	~~DIRECT REDUCTION ORE~~	~~TONS~~	~~DRED~~	~~0.3300~~
	COST	$	CST	0.0000

	MINGC	MSPC	MSFCBI	MSFASI	MSPA	MINGA
CARBN	1.00					
INGC		1.02				
SPITC			1.25			
SPITA				1.25		
COG						
HSC		.02	.25	.25	.02	
PRH		1.57			1.57	
MDG		1.57			.157	
ELE			.028	.028		
LAB			1.1	1.1		
OAM			3.7	3.7		
ALLOY						1.00
INGA					1.02	

TABLE 21 - MINI MILL SEMIFINISHING

480*

	MCCCBI	MCCABI
CARBN	1.04	
ALLOY		1.04
HSC	.04	.04
ELE	.015	.015
OXY	.56	.56
LAB	.99	.99
OAM	2.47	2.47
PRH	.51	.51
MDG	.51	.51

TABLE 22 - MINIMILL CONTINUOUS CASTING

Data sources are identical to those described in the integrated section.

The continuous casting option is as in Table 22. Again, references are described in the integrated section.

Next, the mini-mill can either pass the semi-finished steel through pusher type or mono-beam reheat furnaces in preparation for final finishing, as described in Table 23, and then through final finishing in Table 24.

As was mentioned in the integrated mill write-up, the initial capacity of the mini-mills is hard to determine. Reference X, p. 1-2, implies that mini-mill electric arc capacity is about 24 million tons, the number used in this study; since this is only an estimate, it should be used cautiously. Mini-mill direct reduction capacity is estimated at 2 million tons, and the remaining capacities are set to satisfy the output of the electric arc furnaces. New capacity for the mini-mill can be obtained at costs identical to those for the integrated mills.

	MFTABI	MFTCBI
SFA	1.02	
SFC		1.02
CARBN		
ALLOY		
HSC	.02	.02
ELE		
OXY		
LAB		
CAM		
PRH	2.36	2.36
MDG	2.36	2.36
STM	.30	.30

PUSHER

	MMBCBI	MMBABI
HSC	.02	.02
ELE	.04	.04
STM		
PRH	2.25	2.25
MDG	2.25	2.25
LAB		

MONOBEAM

TABLE 23 - MINI MILL REHEAT

	MFFCBI	MFFABI
SFC		
FFA		1.20
FFC	1.20	
HSC	.2	.2
ELE	.028	.028
STM		
~~PRH~~		
~~MDG~~		
LAB	8.24	8.24

TABLE 24 MINIMILL FINAL FINISHING

IV. ELECTRICITY AND STEAM GENERATION

The model provides 15 steam and electricity co-generation options: electricity and steam are provided by using as fuels;

(a) coal assisted blast furnace gas (CCBFG)

(b) coal assisted coke oven gas (CCCOG)

(c) oil/gas assisted blast furnace gas (OOBFG)

(d) oil/gas assisted coke oven gas (OOCOG)

(e) blast furnace and coke oven gas (OWBFG)

(f) coal assisted blast furnace gas in new boilers (NCBFG)

(g) coal assisted coke oven gas in new boilers (NCCOG)

(h) oil/gas assisted blast furnace gas in new boilers (NOBFG)

(i) oil/gas assisted coke oven gas in new boilers (NOCOG)

(j) blast furnace and coke oven gas in new boilers (NWBFG)

(k) gas turbine using distillate or gas (GTO)

(l) gas turbine using coke oven gas (GTW)

(m) mini-mill steam production from gas turbine (MGT)

(n) mini-mill steam production from oil fired boiler (MBLO)

(o) mini-mill steam production from coal fired boiler (MBLC)

mini-milloptions

The input requirements for each are given in Table 25, along with the sources used to construct the options.

* THIS TABLE STORES DATA FOR BOILER COGENERATION SYSTEMS

			~~OCEFG~~
STEAM	E6 BTU	STM	-1,0000
~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~-0,0325~~
COAL	TONS	COA	0,0346
~~OPER, + MAINT,~~	~~$~~	~~OAM~~	~~0,0405~~
BLAST FURNACE OFFGAS	E6 BTU	BFG	-1,0000
		~~PRH~~	
		COG	
			~~OCCCG~~
STEAM	E6 BTU	STM	-1,0000
~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~-0,0325~~
COAL	TONS	COA	0,0346
~~OPER, + MAINT,~~	~~$~~	~~OAM~~	~~0,0405~~
COKE OVEN OFFGAS	E6 BTU	COG	-0,7760
		~~PRH~~	
		BFG	
			~~OCBFG~~
STEAM	E6 BTU	STM	-1,0000
~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~-0,0325~~
OPER, + MAINT,	$	OAM	0,0405
~~BLAST FURNACE OFFGAS~~	~~E6 BTU~~	~~BFG~~	~~-1,0000~~
RESIDUAL OIL	E6 BTU	PRH	0,9000
		~~COG~~	
		COA	
			~~OCCCG~~
STEAM	E6 BTU	STM	-1,0000
~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~-0,0325~~
OPER, + MAINT,	$	OAM	0,0405
~~COKE OVEN OFFGAS~~	~~E6 BTU~~	~~COG~~	~~-0,7760~~
RESIDUAL OIL	E6 BTU	PRH	0,9000
		~~COA~~	
		BFG	
			~~OWEFG~~
CAPACITY		CAP	0,0000

..... NEW ROW

STEAM	E6 BTU	STM	-1,0000

40*	ELECTRICITY	E3 KWH	ELE	-0.0325
	OPER. + MAINT.	$	OAM	0.0405
	BLAST FURNACE OFFGAS	E6 BTU	BFG	-1.0000
	COKE OVEN OFFGAS	E6 BTU	COG	-1.0000
			PRH	
			COA	
+			>	NCEFG
	CAPACITY		CAP	0.0000
	INVESTMENT COST(NEW)	$	INVESTN	5.2500

..... NEW ROW

	STEAM	E6 BTU	STM	-1.0000
50*	ELECTRICITY	E3 KWH	ELE	-0.0420
	COAL	TONS	COA	0.0346
	OPER. + MAINT.	$	OAM	0.0630
	BLAST FURNACE OFFGAS	E6 BTU	BFG	-1.0000
			PRH	
			COG	
+			>	NCCGG
	CAPACITY		CAP	0.0000
	INVESTMENT COST(NEW)	$	INVESTN	5.2500
	STEAM	E6 BTU	STM	-1.0000
60*	ELECTRICITY	E3 KWH	ELE	-0.0420
	COAL	TONS	COA	0.0346
	OPER. + MAINT.	$	OAM	0.0630
	COKE OVEN OFFGAS	E6 BTU	COG	-0.7780
			PRH	
			BFG	
+			>	NCBFG
	CAPACITY		CAP	0.0000
	INVESTMENT COST(NEW)	$	INVESTN	2.9650
	STEAM	E6 BTU	STM	-1.0000
70*	ELECTRICITY	E3 KWH	ELE	-0.0420
	OPER. + MAINT.	$	OAM	0.0630
	BLAST FURNACE OFFGAS	E6 BTU	BFG	-1.0000
	RESIDUAL OIL	E6 BTU	PRH	0.9000
			MDG	

..... NEW ROW

			COA	
			COG	
+			>	NCCCG

```
            CAPACITY                                     CAP       0.0000
            INVESTMENT COST(NEW)          $              INVESTN   2.9650
  80*       STEAM                         E6 BTU         STM      -1.0000
            ELECTRICITY                   E3 KWH         ELE      -0.0420
            OPER. + MAINT.                $              OAM       0.0630
            COKE OVEN OFFGAS              E6 BTU         COG      -0.7760
            RESIDUAL OIL                  E6 BTU         PRH       0.9000
                                                         MDG
                                                         COA
                                                         BFG
       +                                               >           NWEFG
            CAPACITY                                     CAP       0.0000
  90*       INVESTMENT COST(NEW)          $              INVESTN   2.9650
            STEAM                         E6 BTU         STM      -1.0000
            ELECTRICITY                   E3 KWH         ELE      -0.0420
            OPER. + MAINT.                $              OAM       0.0630
            BLAST FURNACE OFFGAS          E6 BTU         BFG      -1.0000
            COKE OVEN OFFGAS              E6 BTU         COG      -1.0000
                                                         PRH
                                                         MDG
                                                         COA
       +                                               >           GTC
 100*       CAPACITY                                     CAP       0.0000
            INVESTMENT COST(NEW)          $              INVESTN   6.5470
            STEAM                         E6 BTU         STM      -1.0000
            DISTILLATE OIL/GAS            E6 BTU         MDG       2.2500
            ELECTRICITY                   E3 KWH         ELE      -0.2200
            OPER. + MAINT.                $              OAM       0.4400
            RESIDUAL OIL                  E6 BTU         PRH       2.2500
                                                         COA
                                                         BFG
                                                         COG
 110*  +                                               >           GTW
            CAPACITY                                     CAP       0.0000
            INVESTMENT COST(NEW)          $              INVESTN   6.5470
            STEAM                         E6 BTU         STM      -1.0000
            ELECTRICITY                   E3 KWH         ELE      -0.1500
            OPER. + MAINT.                $              OAM       0.4400
            COKE OVEN OFFGAS              E6 BTU         COG      -2.0000
                                                         PRH
                                                         MDG
                                                         COA
 120*                                                    BFG
       +                                               >           MGT
            CAPACITY                                     CAP       30000.0000
            INVESTMENT COST(NEW)          $              INVESTN   6.5470
```

	STEAM	E6 BTU	STM	-1.0000
	~~DISTILLATE OIL/GAS~~	~~E6 BTU~~	~~MDG~~	~~2.2500~~
	ELECTRICITY	E3 KWH	ELE	-0.2200
	~~OPER. + MAINT.~~	~~$~~	~~OAM~~	~~0.4400~~
	RESIDUAL OIL	E6 BTU	PRH	2.2500
			~~COA~~	
130* +		>		MELC
	~~CAPACITY~~		~~CAP~~	~~1000.0000~~
	INVESTMENT COST(NEW)	$	INVESTN	2.9650
	~~STEAM~~	~~E6 BTU~~	~~STM~~	~~-1.0000~~
	ELECTRICITY	E3 KWH	ELE	-0.0420
	~~OPER. + MAINT.~~	~~$~~	~~OAM~~	~~0.0630~~
	RESIDUAL OIL	E6 BTU	PRH	1.5300
			~~MDG~~	
			COA	
+		>		~~MELC~~
140*	CAPACITY		CAP	17000.0000
	~~INVESTMENT COST(NEW)~~	~~$~~	~~INVESTN~~	~~5.2500~~
	STEAM	E6 BTU	STM	-1.0000
	~~ELECTRICITY~~	~~E3 KWH~~	~~ELE~~	~~-0.0420~~
	COAL	TONS	COA	0.0617
	~~OPER. + MAINT.~~	~~$~~	~~OAM~~	~~0.0630~~
			PRH	
			~~MDG~~	

V. ECONOMIC ASSUMPTIONS

A. Cost of Materials - Non-Energy

Table 26 lists the costs of non-energy materials purchased for the first period (1975) of the model. Sources of the prices are given in the footnotes.

(i) Limits on Material Availability

An upper limit of 570 x 10 BTU's per year (1975 actual purchases) of natural gas is assumed to reflect the increasing scarcity of this fuel to the industry.

B. Cost of Materials - Energy

Table 27 gives the assumptions relating to energy prices over the 5 periods (25 years in total) now in the model. They are taken from base case projections made by DOE based on 1975 actual prices.[1] They assume energy prices approximately double (relative to other prices) by 1995.

C. Initial Capacity

Even though the assumptions and sources corresponding to the initial capacities have been discussed in previous sections of the report, they are summarized again in Table 28. Sources are found in the individual sections.

D. Capacity Expansion Costs

Table 29 summarizes the costs for expanding each of the activities represented in the model for both new and retrofit.

---

[1] Source: 1975. Census of Manufacturers - SIC 3312

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TABLE COSTMAT TABLE 26

2390* * THIS TABLE STORES DATA FOR COST OF MATERIALS PURCHASED

	COST
REF	0,0580
~~FLU~~	~~83,~~
OXY	2,5300
~~LIM~~	~~27,050~~
FER	440,00
~~SSCR~~	~~0,0000~~
NIT	0,0900
~~ETD~~	~~0,3300~~
LMS	4,4500
~~STM~~	~~11,5400~~
LAB	10,5900
~~OAM~~	~~1,0000~~
PELL	7,34
~~IMPELL~~	~~34,46~~
SINGCSL	576,9000
~~IMCBL~~	~~961,5400~~
IMCBI	961,5400
~~IMCSL~~	~~961,5400~~
IMALLOY	1153,3000
~~MREF~~	~~0,0580~~
MFLU	83,00
~~MOXY~~	~~2,5300~~
MOAM	1,0000
~~MLAB~~	~~10,5900~~
METD	0,3300
~~MLIM~~	~~27,0500~~
MSTM	11,5400
~~MPELL~~	~~34,6200~~
MFER	440,00
~~IMSORE~~	~~23,86~~

2400*

2410*

2420*

GAS	0,9600
DSL	2,3600
RSL	2,0200
ELE	18,05000
CCO	44,210000
SELE	-15,0000
MGAS	0,9600
MDSL	2,3600
MRSL	2,0200
MELE	18,05000
MCOA	29,500000
COA	29,500
>	2
GAS	1,67000
DSL	2,9200
RSL	2,4200
ELE	20,6300
CCO	48,42000
SELE	-15,0000
MGAS	1,67000
MDSL	2,9200
MRSL	2,4200
MELE	20,6300
MCOA	33,71000
COA	33,71
>	3
GAS	2,3700
DSL	3,4800
RSL	2,8300
ELE	23,2100
CCO	52,6300
SELE	-15,0000
MGAS	2,3700
MDSL	3,4800
MRSL	2,8300
MELE	23,2100
MCOA	37,9300
COA	37,93
>	4
GAS	3,0800
DSL	4,0400
RSL	3,2300
ELE	25,7800
CCO	56,85000
SELE	-15,0000
MGAS	3,0800
MDSL	4,0400
MRSL	3,2300
MELE	25,7800
MCOA	42,14000
COA	42,14
>	5
GAS	3,7900
DSL	4,6100
RSL	3,6400
ELE	28,3600
CCO	61,07
SELE	-15,0000
MGAS	3,7900
MDSL	4,6100
MRSL	3,6400
MELE	28,3600
MCOA	46,360000
COA	46,360

TABLE 27 - COST OF FUELS

TABLE RESCAP

* THIS TABLE STORES DATA FOR INITIAL CAPACITY

TABLE 28

	RES
DCOKE	0.0000
WCOKE	60000.0000
PELL	70000.0000
SINT	47000.0000
DRED	1100.
BF73	47900.0000
BFBT	0.0000
BFPC	0.0000
BFHT	0.0000
1950	72000.0000
JORD	0.0000
EBONN	9000.0000
ABONN	54000.0000
BBONN	15000.0000
ABOPH	0.0000
BBOPH	0.0000
ABOHD	4500.0000
BBOHD	4500.0000
QBNN	10000.
OBHD	0.0000
EOH	1000.0000
AOH	15000.
BOH	34000.
AEANN	1800.0000
BEANN	2000.0000
AEAHD	200.0000
ING	170000.
CCBL	0.0000
CCBI	2400.0000
CCSL	1200.0000
SFBL	31050.0000
SFSL	80150.0000
SFBI	44260.0000
PTBL	45000.
PTSL	105000.
PTBI	50000.
MBBL	0.0000
MBSL	0.0000
MBBI	0.0000
FFBL	15360.0000
FFSL	110000.0000
FFBI	47000.0000
OBLC	100000.0000
OBLO	320000.0000
OBLW	0.0000
NBLC	0.0000
NBLO	0.0000
NBLW	0.0000
GT	0.0000
MEA	24000.
MGT	30000.0000
MBLO	1000.0000
MBLC	17000.0000
MDRED	2000.0000
MCCBI	21700.0000
MFFBI	24000.
MPTBI	24000.
MMBBI	0.0000
MING	15000.0000

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TABLE NEWCAP *TABLE 29*

* THIS TABLE STORES DATA FOR NEW CAPACITY FINANCIAL CHARAC*

		TOTALINV
1460*	DCOKE	138.
	WCOKE	123.0000
	PELL	75.0000
	BF73	46.0000
	JORD	46.0000
	BBONN	25.0000
	BBOHD	26.7000
	BBOPH	32.5
	QBNN	20.0000
	QBHD	25.0000
1470*	BOH	36.0000
	AEAHD	30.0
	BEANN	25.
	ING	30.9500
	CCBL	999.0000
	CCBI	65.0000
	CCSL	47.0000
	SFBL	48.0000
	SFSL	47.0000
	SFBI	103.0000
1480*	PTBL	9.42
	PTSL	9.42
	PTBI	9.42
	MBBL	7.27
	MBSL	7.27
	MBBI	7.27
	FFBL	332.0000
	FFSL	127.0000
	FFBI	194.0000
	NBLC	5.2500
1490*	NBLO	2.9650
	NBLW	2.9650
	GT	6.5470
	MGT	6.5470
	MBLO	2.9650
	MBLC	5.2500
	MEA	28.0000
	MDRED	140.
	MPTBI	9.42
	MMBBI	7.27
1500*	MFFBI	194.0000
	MCGBI	65.0000

E. Demand Data

Table 30 gives the demand for steel assumed in the model. The initial period's demand is 1975 actual demand for finished steel products taken with minor adjustments from Reference III.

A 1.5% yearly rate of growth was assumed in the base case to drive the model; the mix of steel products was assumed to remain constant over the planning horizon.

F. The Scrap Supply Curve

One important consideration in the model is price and availability of scrap material to the steelmaking industry. Left unconstrained at current prices, the model would choose to purchase more scrap than is actually available. Market steel scrap is composed of obsolete scrap and prompt scrap. Obsolete scrap is generated from discarded steel-bearing material and its availability is primarily dependent on past steel production. On the other hand, the source of prompt scrap is steel fabrication losses and its supply is primarily determined by the amount of current steel production.

The report "Purchased Ferrous Scrap: United States Demand and Supply Outlook" by W.T. Hogan and F.T. Koeble (Reference XXIII) describes the present and projected supply of purchased scrap by the U.S. Steel industry. Using this reference, as well as several conversations with one of the authors, a predictive equation for price-insensitive purchased scrap was developed:

$$\text{Tons of steel industry purchased scrap}(t) = 9658(1,053)^{t-1975} + .0667D(t)$$

where

t = year

$D(t)$ = tons of demand for steel products in year t.

```
           TABLE DEMAND   TABLE 30
    *      ===== ==========
    * THIS TABLE STORES DATA FOR    FINAL DEMAND-STEEL PRODUCTION
                                          >         1
                                            SBI     757,
                                            ABI     8436,
                                            CBL     7086,
                                            CSL     45804,
                                            CBI     17674,
    +                                     >         2
                                            SBI     844.0000
                                            ABI     9405.0000
                                            CBL     7900.0000
                                            CSL     51065.0000
                                            CBI     19926.0000
    +                                     >         3
                                            SBI     931.0000
                                            ABI     10374.0000
                                            CBL     8714.0000
                                            CSL     56326.0000
                                            CBI     21980.0000
    +                                     >         4
                                            SBI     1018.0000
                                            ABI     11343.0000
                                            CBL     9527.0000
                                            CSL     61586.0000
                                            CBI     24033.0000
    +                                     >         5
                                            SBI     1105.0000
                                            ABI     12312.0000
                                            CBL     10341.0000
                                            CSL     66487.0000
                                            CBI     26086.0000
```

Because the prompt scrap component of the relation depends on current steel production, the purchased scrap supply is a function of steel demand. In general, scenarios are energy price and steel demand driven. Therefore, the price-insensitive purchased scrap is also scenario-dependent and the above equation should be used to maintain consistency.

A scrap supply curve can be generated by combining the price-insensitive relation above with the reported supply price elasticity. To accomplish this, we make the following assumptions:

1. The supply equation given above is the availability at the current real price of scrap.
2. The long-term price elasticity of scrap supply is 1.12 from R.C. Anderson and R.D. Spiegelman, "Tas Policy and Secondary Material Use," Journal of Environmental Economics and Management, 4, p. 68-72, 1977.
3. The ultimate scrap limit is 60% above the Hogan relation.
4. A step-wise linear supply curve using the point elasticity of 1.12 is an adequate representation of the scrap supply curve.

Four supply "bins" are used in the model to describe the scrap supply curve. The first allows the price-incentive supply availability from Hogan to be purchased at the 1975 real cost of scrap. The other three bins increase supply availability by 20% for an 18% increase in price. (The 1.12 elasticity results in a 20% increase in supply for an 18% price increase.)

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