# ENERGY AND MATERIALS SAVINGS FROM GASES AND SOLID WASTE RECOVERY IN THE IRON AND STEEL INDUSTRY IN BRAZIL: AN INDUSTRIAL ECOLOGY APPROACH

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## ABSTRACT

This paper attempts to investigate, from an entropic point of view, the role of selected technologies in the production, transformation, consumption and release of energy and materials in the Iron and Steel Industry in Brazil. In a quantitative analysis, the potential for energy and materials savings with recovery of heat, gases and tar are evaluated for the Iron and Steel Industry in Brazil. The technologies for heat recovery of gases include Coke Dry Quenching (CDQ), applied only in one of the five Brazilian coke integrated steel plants, Top Gas Pressure Recovery Turbines (TPRT), recovery of Coke Oven Gas (COG), recovery of Blast Furnace Gas (BFG), recovery of BOF gas, recovery of tar, and thermal plant.

Results indicate that, in a technical scenario, some 5.1 TWh of electricity can be generated if these technologies are applied to recover these remaining secondary fuels in the Iron and Steel Industry in Brazil, which is equivalent to some 45% of current total electricity consumption in the integrated plants in the country.

Finally, solid waste control technologies, including options available for collection and treatment, are discussed. Estimates using the best practice methodology show that solid waste generation in the Iron and Steel Industry in Brazil reached approximatelly 18 million metric tons in 1994, of which 28% can be recirculated if the best practice available in the country is applied thoroughly.

## INTRODUCTION

Large quantities of normally considered unwanted products, such as gases and solid wastes, which are only partially used in industrial plants and other economic activities, are produced in the Iron and Steel Industry. Some technologies currently available, but not widely disseminated, can improve the efficiency of energy and materials use in this industry, by recovering part of the production gases and solid wastes that are inherent to the processes. Therefore, the potential for improving the overall efficiency of the Iron and Steel Industry is far from being entirely tapped. A technical reorganization of processes within the plants, aiming at maximizing gases and heat recovery, as well as solid wastes, may be introduced, which will greatly reduce entropy production by the iron and steel making process. Within an ecological perspective, try to save low entropy should be a legitimate objective of economic activities.[1]

Using an Industrial Ecology approach, it is suggested that processes integration in iron and steel production systems can and should evolve to recycling of materials and reutilization of low entropy energy still available as secondary fuels. In this study, we selected available technologies of gases, heat, tar and solid waste recovery to estimate potential energy and materials savings in the Iron and Steel Industry in Brazil.

## INDUSTRIAL ECOLOGY

The reconciliation of Economics with its biophysical basis seems to be facilitated by the entropic analysis of economic systems. The identification of economic systems and life forms with open systems far from equilibrium is a first good reason for this reconciliation. The continuous flow of low entropy (high quality) inputs through the systems does not constitute a sufficient condition for evolution and mantainance of those complex structures. The periodic release of high entropy (low quality) outputs to the environment is also necessary. Energy is dissipated in the form of waste heat and some materials are released as waste products (pollutants). Dissipative processes allow the economic and ecological systems to evolve and maintain their complex structures in far from equilibrium states.[2, 3, 4, 5, 6]

A second good reason is related to the approach of "Industrial Ecology," which deals, specifically, with the interconnections between the various parts of a system (much in the same way biological ecosystems function and prosperate), with exchanges of energy and materials and with the reuse of much of the wastes from one production unit as inputs to another production unit.

The study of industrial systems from the perspective of materials transformations, mass and energy flows is a recent field of research. The environmental issues that emerge from this approach are various, and comprehend the relationships between industrial systems and global changes, including, but not limited to, impacts on soil, water and air.

The expression "industrial metabolism"[7] has been used to designate studies on materials flows of the international industrial system, focusing, in particular, on the routes of toxic substances on the global environment. The expression "industrial ecology," on the other hand, suggests that industrial activity can be thought of, and approached in, much the same way as a biological ecosystem.

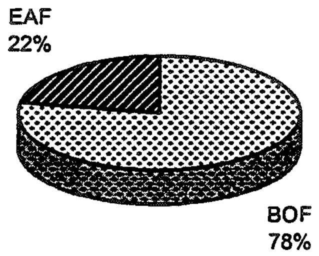
Industrial ecology is a metaphor to the analysis of industrial systems and their environment. It is an intelectual descendant of energy analysis, which, during the past two decades, has provided new ways of seeing the organization and functioning of specific activities or even entire economies.[8] The principles of Industrial Ecology point towards the evolution of industrial activities as ecologically sustainable processes, meaning a technological and organizational reestructuring of processes that can comply with new environmental standards.

One of the basic orientations of Industrial Ecology is the search for the optimization of the full cycle of materials, from raw materials to finished products and wastes. Factors to be optimized include materials, energy and capital resources. But there seems to be an additional basic orientation derived from the analogy with biological ecology. Similarly to biological ecosystems, industrial ecosystems can also be seen as interconnected parts of an even larger system, with wastes from one industrial system becoming resources to another.[9] The objective of complete cyclization of production though, reducing wastes to zero, will never be achieved. In any case, the search for improving energy and materials efficiency mandatorily includes recycling and minimization of wastes. There is no extra room left for a model of industrial ecosystem based on infinite resources and no constraints on waste production.

## THE BRAZILIAN IRON AND STEEL INDUSTRY

The Brazilian Iron and Steel Industry comprises twenty six companies producing a wide range of products, from slabs to galvanized sheets. In 1994, total production of crude steel reached 25.7 million metric tons. The share of different production processes on total production (Figure 1) shows that BOF (Basic Oxigen Furnace) is the major route, responsible for 78% of total production, while EAC (Electric Arc Furnace) route accounts for the remaining 22%. The technical configuration of steelworks indicates that, in 1994, five coke integrated companies produced 17.7 million tons of crude steel, six charcoal integrated companies produced 4.9 million tons and thirteen semi-integrated companies produced 3.1 million tons. The share of different technologies on total crude steel production is shown in Figure 2.

**Figure 1 - Crude Steel Production by Steelmaking Process, 1994[10]**



In 1994, 59% of crude steel production in Brazil was produced by continuous casting. This follows an increasing tendency in the country over time. Although in recent years the production mix has become more diversified, with higher value added products, the Brazilian Iron and Steel Industry keeps on producing mainly common steel flat products (see Table 1). Two of the main features in the production mix are the relatively low proportion of special steels and the relatively high proportion of semi-finished products like slabs, blooms and billets, with these latter products almost entirely devoted to exports.

**Figure 2 - Share of Different Technical Configurations of Steelworks on Total Crude Steel Production, 1994[10]**

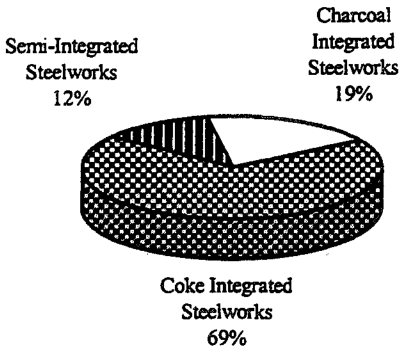


**Table 1 - Production of Rolled and Semi-finished Products for Sale, 1994[10] (Mt)**

| | | |
|---|---|---|
| Rolled Products | Common Steel Flat Products | 10,217 |
| | Common Steel Long Products | 5,528 |
| | Special Steels | 1,575 |
| Semi-finished Products | Slabs | 4,035 |
| | Blooms and Billets | 2,181 |
| | Ingots | 5 |

**Table 2 - Final Energy Consumption in Iron and Steel Industry in Brazil, 1994[11] (PJ)**

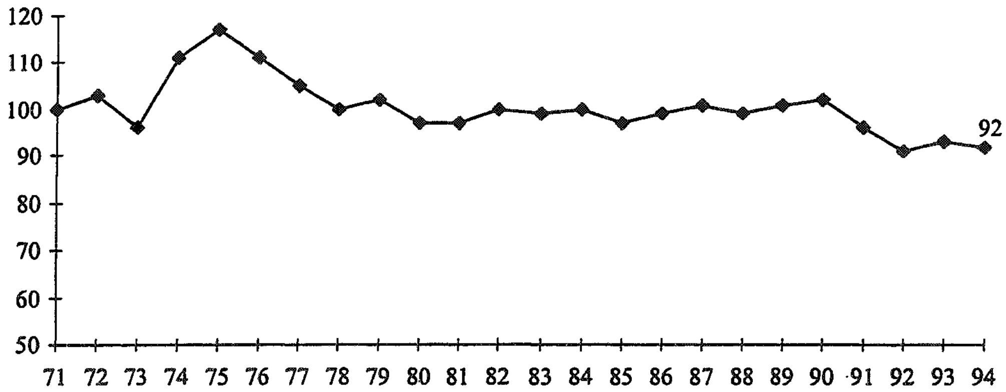
| | | |
|---|---|---|
| Coke and Coal | 276 | 48.3% |
| Charcoal | 158 | 27.7% |
| Electricity[a] | 48 | 8.4% |
| Oil | 19 | 3.3% |
| Natural Gas | 18 | 3.2% |
| Coke Oven Gas | 40 | 7.0% |
| Others | 12 | 2.1% |
| Total | 571 | 100.0% |

Note: [a] Considering 1 kWh = 860 kcal

Charcoal plants are a peculiarity of the Brazilian Iron and Steel Industry. Two different kinds of plants use charcoal in Brazil: pig iron and integrated plants. Charcoal plants present important advantages over coke plants, like very low sulphur emissions and low slag generation per ton of steel produced. On the other hand, charcoal plants are facing a series of problems related to the relatively small fraction of charcoal made from sustainable forests as compared to charcoal made from nonsustainable forests, as well as poor labor conditions.

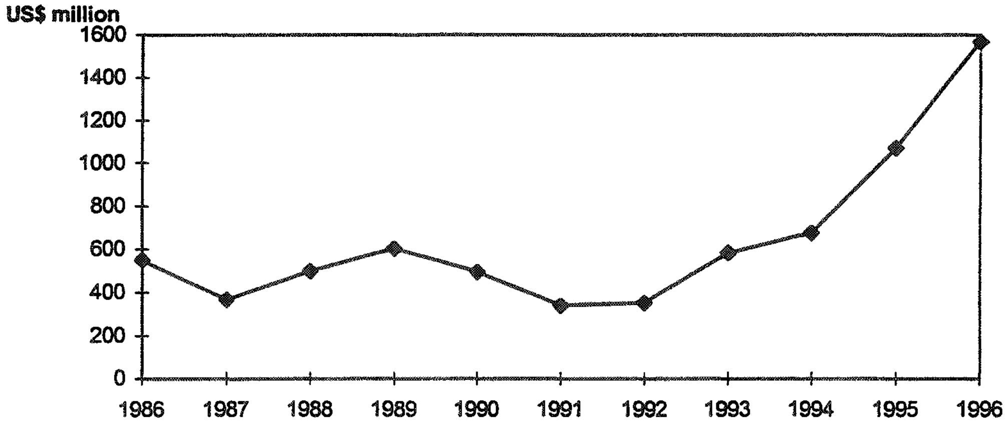
Specific Energy Consumption (SEC) for the Brazilian Industry as a whole has not changed much since 1971 (Figure 3). In spite of the increase in the energy efficiency of specific processes, the mix of products within the industry has changed, which explains the relatively flat behavior of the industry's SEC over time. However, since 1990 the industry's SEC has been showing a downward trend that is very likely to continue.

**Figure 3 - Specific Energy Consumption in the Brazilian Iron and Steel Industry (index numbers)**[10, 11]



As indicated in Figure 4, investments have increased substancially since 1993, reaching almost US$ 1.6 billion in 1996. Most of these investments have been directed to technological modernization, environmental protection, automation and product development.

**Figure 4 - Total Investments in the Brazilian Iron and Steel Industry, 1986-96** [10]



## PROCESS INTEGRATION IN THE IRON AND STEEL INDUSTRY

Iron and steelmaking is a batch process consisting, basically, of unit operations settled in series. One of the remarkable features of the process is the generation of huge amounts of by-products that can be recycled in the industry itself or even in other industries. This includes energy carriers like gases, steam or tar, as well as several kinds of materials released as powder, sludge and slag.

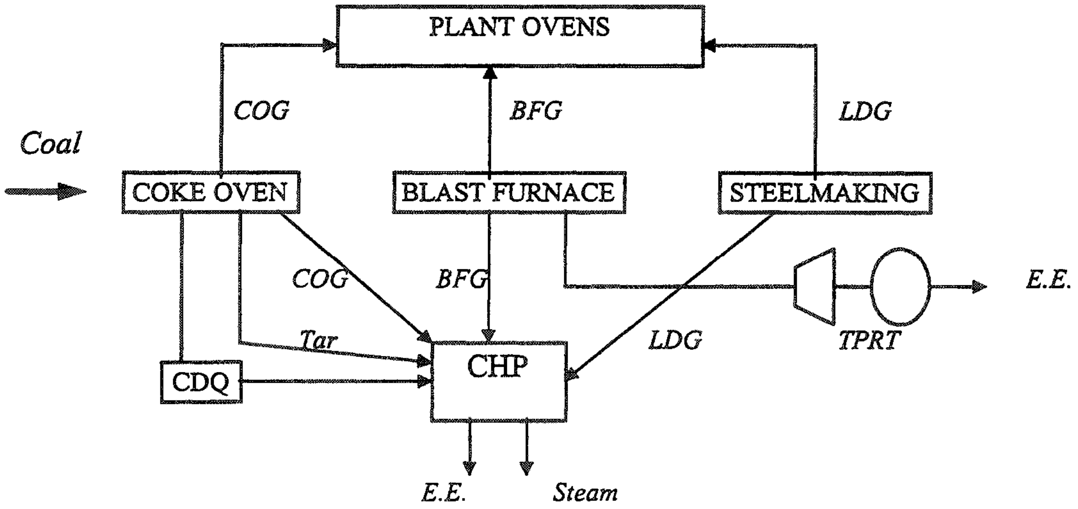
Process integration goals can be reached with the careful exam of the production methods. Fuel requirements can be greatly reduced with the optimization of heat exchanges, for example, or with the utilization of well known cogeneration technologies. Second Law Analysis provides not only a method for determining where available energy is wasted in a given process, but also for identifying associated and irreducible losses of fuels and materials.[12] New paradigms of production can be stimulated with the exam of these irreducible losses, so as to help the selection of information activities that can promote morphological changes in steel production processes.[13]

In this paper we are interested in exploring the possibilities for the reorientation of energy and materials flows based on by-products recycling. None of the new production methods, like Smelting-reduction or Thin Strip Casting, are dealed with here. Although the options examined here may, in some cases, demand large investments, all of them are technically and commercially established. Some exceptions do exist though. The recycling of materials by-products, for example, still requires additional research and development. Even so, some iron and steel companies in Brazil already present outstanding results in terms of solid waste recycling.[14]

**Gases and Tar Recovery** - In a coke integrated plant, the availability of gases suggests that it is technically possible to establish a "primary fuel plant," i.e., steel production in a coke integrated plant can utilize coal as the only energy carrier to supply its energy demand.[15] If this model proves not to be economically feasible, it can, at least, be partially adopted in order to reduce part of the oil consumption and electricity purchases. The model proposed depicted in Figure 5 requires the following premises:

1. The steam required in the industrial process is produced by cogeneration in a Combined Heat and Power Plant (CHP);
2. The pressure and temperature of the steam generated in Coke Dry Quenching (CDQ) should be increased in such a way as to make possible their utilization in CHP turbines;
3. The Top Pressure Recovery Turbine (TPRT) utilizes the high pressure of gases on the top of the Blast Furnace; and
4. The tar from Coke Oven is consumed in CHP turbines.

**Figure 5 - Squematic Representation of a Possible Distribution of By-Product Gases and Tar in a Coke Integrated Plant[16]**



By-Product Gases:

*COG - Coke Oven Gas*

COG losses are very small due to their extensive utilization in different parts of the plant, including Blast Furnace and Steelmaking (not indicated in Figure 5 for simplicity).

*BFG - Blast Furnace Gas*

BFG is consumed in the Blast Furnace and in the production ovens. The remainder volume goes to a Thermal Plant (CHP) to produce electricity and steam.

*LDG - Steelmaking Gas*

LDG is consumed in production ovens and burned in the CHP Plant to produce electricity and steam.

Selected Technologies:

*CDQ - Coke Dry Quenching*

Heat Recovery of Coke Oven Gases to generate high pressure steam to be used in the CHP Plant.

*TPRT - Top Gas Pressure Recovery Turbine*
Utilizes the high pressure of Blast Furnace Gases to generate electricity.

*CHP - Combined Heat and Power Plant*
Consumption of Tar and COG from the Coke Oven, BFG from the Blast Furnace and LDG from the Steelmaking to generate electricity and steam. Also utilizes the high pressure steam from CDQ.

**Solid Waste Recovery** - Each one of the several operation units in a steel plant generates a certain amount of solid wastes. Blast Furnace and Steelmaking slags constitute the major fraction of total volume generated. Powder, sludges and scurfs, although in small quantities, are extremelly important too, specially if we consider the contamination hazard of each kind of solid waste. In this paper we focus only on volume issues. In general, it is possible to consider the distribution of generated and recycled solid wastes by operation unit, as shown in Table 3.

**Table 3 - Generation and Recycling of Solid Wastes by Operation Units**

| OPERATION UNIT | GENERATION | REUTILIZATION |
|---|---|---|
| **Coke Oven** | Powders, Sludges and Tar | Sludges and Tar |
| **Sintering** | Powders and Thin Particles | Powders, Sludges and Scurfs |
| **Blast Furnace** | Powders, Sludges and Slag | Tar and Briquets |
| **Calcination** | Limestone Powder | - |
| **Steelmaking** | Powder, Sludges, Slag and Refractories | Slag, Scurfs, Briquets and Scrap |
| **Rolling Mills** | Sludges, Scurfs and Scrap | |
| **CHP Plant** | - | Tar |

Solid wastes recovery can be obtained by recycling products in the plants themselves (Table 3) or by selling them to other economic sectors; for example, slags that can be sold to the cement industry, agriculture and road construction companies as an additive for the asphalt layer of roads.

## ENERGY AND MATERIALS SAVINGS FROM GASES AND SOLID WASTES RECOVERY

**Gases and Tar** - Based on the model described in the previous section, the available energy from by-products gases and tar (Table 4) are calculated in order to estimate the potential for energy savings from the use of by-products from the processes. In addition, the available energy that can be obtained from the two selected technologies (CDQ and TPRT) applied to Coke Ovens and Blast Furnace are also determined (Table 5).

Final results are conservative in a sense that we have not considered the full set of steel production companies in Brazil, disconsidering, for example, those ones that produce steel from scrap. The 35% efficiency for the CHP Plant and for the TPRT generator are also conservative having in mind modern cogeneration plants. Not to mention various other options for increasing the efficiency of energy use with extra heat cascading and recovery. Taking the process as a whole, available heat still exists at Sinter Plant, Pellet Plant, Refining Plant, Hot and Cold Rolling Mills and Finishing.[17]

Table 4 - **Total Production, Consumption and Available By-Products Gases and Tar in the Iron and Steel Industry in Brazil, 1994[18]**

| | **FUELS (Tcal)** | | | |
|---|---|---|---|---|
| | **COG[a]** | **BFG[b]** | **LDG[b]** | **Tar[a]** |
| **Production** | 15,605 | 33,625 | 3,080 | 3,317 |
| **Consumption** | 15,501 | 29,321 | 627 | 1,025 |
| **Available** | 104 | 4,304 | 2,453 | 2,292 |

Notes: [a] Considering data from the five coke integrated companies in the country. [b] Considering data from the five coke integrated companies and from two charcoal integrated companies in the country; for the other four charcoal integrated companies data were obtained by a conservative estimation based on the first two.

**Table 5 - Available Energy Obtained from the Application of Selected Technologies in Coke Ovens and Blast Furnaces, 1994**

| | CDQ[a]<br>(Coke Dry Quenching) | TPRT[b]<br>(Top Gas Pressure Recovery Turbine) |
|---|---|---|
| Available Energy (Tcal) | 2,100 | 1,292 |

Notes: [a] 3.1 Mt of steam per year. Considering the five coke integrated companies. [b] Considering the five coke integrated companies, and generating some 60 MW with 35% efficiency.

It is important to mention that neither of the available secondary fuels nor technologies refered to semi-integrated plants. It must also be noted that TPRT technology is considered to be applied only in the five coke integrated companies. For the six charcoal integrated companies, data are not available. As these latter account for 19% of total steel production, if TPRT were applied in those companies too the contribution from this technology would be even higher.

The sum of the six items from Tables 4 and 5 gives rise to a total of 12,545 Tcal of available energy from by-product gases, tar and heat. In 1994, the total consumption of energy in the Brazilian Iron and Steel Industry reached 136,355 Tcal. In other words, the calculated available energy is 9.2% of this total. In the case of transforming 12,545 Tcal in electricity, considering a thermal efficiency of 35%, there exists an additional untapped potential for electricity production in the country of some 5.1 TWh per year, which is equivalent to some 833 MW of power, assuming a 0.7 capacity factor, typical for thermal plants in Brazil.

As a whole, the Iron and Steel Industry in Brazil consumed 14.5 TWh of electricity in 1994, with a consequent potencial for electricity production equivalent to 35% of that. Considering only the set of integrated plants (total consumption of 11.4 TWh), the percentual goes up to 45% (Table 6). That is a very significant result because of the increasing importance thermoelectricity will have in Brazil in the near future.

**Table 6 - Available Energy from Waste Heat Recovery in Integrated Plants and Electricity Consumption and Demand**

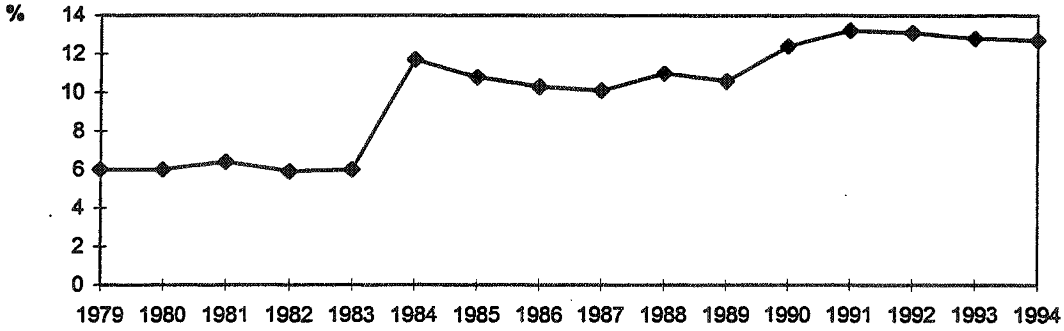
| | |
|---|---|
| Available Energy | 12,545 Tcal |
| Equivalent Electricity | 5.1 TWh |
| % of Total Electricity Consumption | 35% |
| % of Electricity Consumption of Integrated Plants | 45% |
| Equivalent Capacity (0.7 Capacity factor) | 833 MW |
| % of Total Installed Thermal Power in Brazil | 12% |

These results present a technical potential for utilizing waste gases and heat from the process. Our main task is to try to estimate the remaining availability of energy in the Iron and Steel Industry by-products. We have made the strong assumption that all available energy provided by waste gases and heat could be transformed in electricity. Technically speaking, there is no reason not to recover and reutilize this energy. But possibly real operational conditions may limit this balance between electricity production and plant ovens energy requirements.

Due to economic barriers, such as low electricity prices and long maturation periods for the installed equipments, some of these investments may not be of high priority. For example, for CDQ, the payback period is high, considering energy savings only. For example, with the sole exception of Companhia Siderúrgica de Tubarão (CST), which already operates CDQ equipments since 1983, no other coke integrated company in Brazil intends to invest in CDQ equipments in the foreseeable future. In the case of TPRT technology, two of the largest companies in Brazil included this technology in their investments programs for the medium term. BFG, LDG and Tar recovering depends on thermal plants investments, which are already been made, as described below.

Figure 6 shows the evolution of electricity self-generation in the Brazilian Iron and Steel Industry, including coke and charcoal integrated plants and semi-integrated plants. Short-term trends seem to indicate that electricity self-generation levels as a whole will increase in the country due the construction of a 230 MW thermal plant by Companhia Siderúrgica Nacional (CSN), the largest company in volume of crude steel production in Brazil (4.5 million tons in 1994). This plant will be comprised of two 115 MW units each, and will be fueled with BFG, COG and natural gas. With estimated costs of US$ 235 million and payback time of 2.5 years, the thermal plant will increase CSN electricity self-generation from 4 to 55% of its needs, reducing its annual costs by some US$ 60 million.[19] Considering this thermal plant alone, electricity self-generation levels in Brazilian Iron and Steel Industry will grow from 13 to 23%, a 77% increase compared to 1994 levels.

**Figure 6 - Evolution of Electricity Self-Generation in Brazilian Iron and Steel Industry[18]**



**Solid Wastes** - In 1994, the Brazilian Iron and Steel Industry generated 18.0 million tons of solid wastes (700 kg/ton of crude steel). While 3.1 million tons were recycled within the plants, 8.1 million tons were sold and 6.8 million tons were disposed of in deposits (Table 7).

From an Industrial Ecology point of view, the final disposal of wastes should be reduced to a minimum. The task must be focused in decreasing the deposits amount. Solid wastes may be recycled in steel plants or utilized in other industries. From the firms' point of view, the recycling and selling of wastes may constitute an important source of extra revenues.

For the quantitative analysis of solid waste recovery, the "best practice" methodology is used to evaluate the remaining potential for materials savings achieved with pollution control technologies. A coke integrated plant that presents the highest level of solid waste recovery in Brazil is choosen as a case study. CST produces steel slabs mainly for exports. In 1994, production reached 3.15 million tons of slabs, meaning that the company is the larger producer of slabs for sale in the world, with a 20% share of the international market.

In 1994, CST generated 2.1 million tons of solid wastes (570 kg/ton of crude steel), of which 0.78 million were recycled, 1.11 million were sold and 0.21 million tons were disposed of in deposits (Table 8). Comparing the different percentages indicated in Tables 6 and 7, we noticed that the share of Recycling plus Sales in CST (90%) is considerably higher than the figure for the Brazilian Iron and Steel Industry as a whole (62%). Table 8 also shows the equivalent revenues obtained with solid waste recycling and sales. The total sum of US$ 26 million represented 3.5% of total company sales (from products and services) in 1994.

**Table 7 - Solid Waste Generation and Final Destination in the Brazilian Iron and Steel Industry, 1994[20]**

| | Mt | % |
|---|---|---|
| Recycling in plants | 3.1 | 17 |
| Sales | 8.1 | 45 |
| Final disposal | 6.8 | 38 |
| Total Generation | 18.0 | 100 |

If the whole Iron and Steel Industry in Brazil had the same pattern of solid waste final destination as the "best practice" in the country, some 90% of the total solid waste generated, 16.2 million tons, would be recycled or sold, which would mean an additional reutilization of 5 million tons per year of solid waste compared to the present situation. Considering the same volume of solid waste produced (18.0 million tons), and the same level of revenues, in dollars per ton of solid waste, obtained by CST, the equivalent additional revenues, for the whole sector, can be estimated in US$ 68 million per year (Table 9). If the generation of solid waste per ton of crude steel is reduced to the same levels performed by CST (from 700 to 570 kg/t), the results change as shown in Table 9.

**Table 8 - Solid Waste Generation and Final Destination in the CST Coke Integrated Plant, 1994** [21]

| | Mt | % | Revenues/year (US$ million) |
|---|---|---|---|
| Recycling in plants | 0.78 | 37 | 11 |
| Sales | 1.11 | 53 | 15 |
| Final disposal | 0.21 | 10 | - |
| Total Generation/Revenues | 2.10 | 100 | 26 |

Among the solid wastes produced by the Iron and Steel Industry, slags comprise almost 50% in weight. Cement Industry utilizes Blast Furnace Slags as a substitute for clinker, the main cement component. In Brazil, clinker/cement ratio is 80% and clinker energy consumption reaches 800 Mcal per ton of clinker. Considering 12% as the fraction of Blast Furnace Slags in an overall cement production of 25.23 million tons, it is possible to assign savings of 2,422 Tcal for the Cement Industry as a whole, which means 13% of total energy consumption (18,565 Tcal) in the sector in 1994.

**Table 9 - Solid Waste Final Destination in the Brazilian Iron and Steel Industry Assuming a Best Practice Methodology**

| Generation | Average | Best Practice |
|---|---|---|
| Generation per ton of crude steel | 700 kg/t | 570 kg/t |
| Total Generation | 18.0 Mt | 14.6 Mt |
| Recycling | 6.7 Mt | 5.4 Mt |
| Sales | 9.5 Mt | 7.7 Mt |
| Final disposal | 1.8 Mt | 1.5 Mt |
| Equivalent Additional Revenues per year | US$ 68 million | US$ 56 million |

Notes: Using a total production base of 25.7 million tons of crude steel (1994). Assuming an average revenue of US$ 13.8 per ton of solid waste reused or sold.

## FINAL CONSIDERATIONS

The Brazilian Iron and Steel Industry presents a large potential for increasing energy and materials use efficiency. As such, there also exists a huge potential for reducing environmental impacts associated with its activities.

The recovery of by-products from the processes is another area that also deserves further attention, including the use of secondary fuels such as waste gases and tar. If this additional potential is also explored, the need for oil use and purchased electricity could be greatly reduced as well.

Coke integrated companies in the Iron and Steel Industry in Brazil can/should explore this potential and try to become net producers of electricity to the grid if the economics of the extra investments needed to adapt the plants prove this to be advantageous to the sector. Recent investments made in Brazil by some companies to build their own thermal generating facilities in order to have their own supply of electricity and sell the excess capacity to the grid may indicate a williness, within the sector, to seriously consider the possibility of optimizing the plants in the direction indicated here.

The solid waste recovery analysis presented here pointed out a large potential for reducing solid waste generation and for recycling and selling of most of the wastes in the Iron and Steel Industry. The results are meaningful if we consider that high levels of solid waste recovery have already been achieved by one coke integrated plant in the country (CST), used in this work as our model of "best practice plant."

If efforts are made in this direction, large benefits for the Industry itself and for the Economy as a whole, understood here in its broader sense, can be expected. This includes increase in energy and materials use efficiency in steel plants and other industries as well; air, water and soil pollution reduction; and even the possibility of the development of new products. And we hopefully will strenghten the reconciliation of Economics with its biophysical basis, helped by Industrial Ecology.

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