POLITECNICO DI MILANO

Scuola di Ingegneria dei Sistemi

POLO TERRITORIALE DI COMO

Master of Science in

Management, Economics and Industrial Engineering

IMPROVING ENERGY EFFICIENCY IN THE STEEL INDUSTRY THROUGH SCRAP RECYCLING

Supervisor: Prof. Marco Taisch
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Master Graduation Thesis by: AMAEFULE KELECHI CHINEDU
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ABSTRACT

Energy efficiency in manufacturing industries has become an issue of concern in the world today. This has become paramount to adopt efficient practices due to scarcity and unsecured energy supply, rising price of energy, awareness of "green" customer, environmental concern and above all, the need to manufacture products that are competitive. Considering the process industry, a lot of processes have been adopted to enhance energy efficiency ranging from more efficient technological innovations, better management and better operational practices. As a means to further exploring energy efficient practices in iron and steel industries, this study aims at investigating the energy consumption in producing steel through scrap recycling route and the energy savings that could be accrued it compared to other steel production routes. Once the difference in energy consumption of these different process routes are considered and evaluated scrap recycling could be proposed as an alternative route to producing steel in Nigerian context. This approach will help the country (as it lacks the availability of quality iron ore and coking coal) to produce steel internally thereby reducing it's over dependence in imported steel, creates employment and also produce semi-finished steel at a competitive price.

DEDICATION

This thesis is dedicated to the memory of my beloved father;
Nze Ernest Onuohaegbu Amaefule.

ACKNOWLEDGEMENTS

I would like to express my appreciation to all those who have provided assistance and encouragement to me throughout the period of this research work. My special thanks to my supervisor Professor Marco Taisch for his dedicated attention and support. I also would like to acknowledge my assistant supervisor Dr. Alessandro Cannata for his tolerance, assistance and commitment to always give a helping hand towards the successful completion of this thesis work.

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Finally, I would like to express my sincere gratitude for my family who have given support to my study and prayed for my life.

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Chapter one

INTRODUCTION

1.1 Background

The term energy efficiency has become a central focus of energy policies as well as for industrial company's [1]. It is the aim of efforts to reduce the amount of energy required to produce goods and services and to make it competitive in the market. Giving the rising price of energy, global warming, awareness of green houses gases, scares resources and so on, it has awaken the consciousness on efficient innovative technology, efficient manufacturing/operation practices and better management. Because of this, the improvement in energy efficiency has become very fundamental, and yet a significant way of addressing energy security and environmental concerns [1].

Sitting European Union for instance (as an advanced industrialized economy) the ratio of energy consumption in different sectors are as follows: 33% in manufacturing, 29% in households, 26% in transportation, 9% in service sector and 4% in others while total direct and indirect carbon dioxide emission are distributed as follows: 38% in manufacturing, 21% in households, 12% in service sector, 25% in transport and 4% others [1]. This statistics shows that manufacturing sector is the main consumer of energy and emitter of carbon dioxide. Among the manufacturing sector, the energy intensive industries are the cement industry, chemical industry, iron and steel, pulp & paper and refining .Because of the significant and indispensible role of iron and steel as regards to its use in automotive industries, construction, bridges, machinery, tools, railways, container, buildings, household appliances and many more, it has become imperative to device means of producing it in more efficient manner .This will serve as a competitive factor, for customers ask not for only efficient product but also for efficient production process.

Identifying recycling as one of the efficient ways of producing steel, obsolete iron and steel products and ferrous scraps generated in steel mill and steel-product manufacturing plants are collected because they are economically advantageous to recycle by re-melting and recasting them into semi finished form for use in the manufacture of new steel products. The steel scrap market is mature and highly efficient [14]. Iron and steel scrap is more than just economically beneficial to steelmakers; ferrous scrap recycling is part of wise management of iron resources. Recovery of one metric tone of steel from scrap conserves an estimate of 1,030kg of iron ore, 580kg of coal and 50 kg of limestone [4]. Each year ,steel recycling saves the energy equivalent required to electrically power about one-fifth of the households in the united states(about 18million homes) for one year [4][14].

Faced with low awareness of energy efficiency by developing countries, Nigeria is consuming 0.2 % out of the total world energy consumption and this is not to say that the total demand is being met. Of this 0.2%; 10% is consumed in the manufacturing sector, 68% in transportation, 3% in residential, 12% in communication and public service and 8% others[2]. Be that as it may, Nigeria is a developing economy and as such the iron and steel industry is intensifying effort to ensure efficiency in its operations, that is why this research work is focused on evaluating steel production through recycling of scrap in other to ensure energy saving and make their product competitive.

1.2 Problem definition

This study attempts to answer the following questions:

1. What is the amount of energy that could be saved from producing steel from scrap through recycling rather than producing from iron ore?
2. What are the benefits of recycling compared to production from iron ore?
3. How this process could be sustained in the Nigerian context in terms of making available the feedstock (steel scrap).

1.3 Objective

The objective of this research work is to investigate the energy efficiency (saving) of producing steel from scrap (recycling) compare to its production from virgin material (ore). Literature has shown that considerable amount of energy could be saved from recycling of steel scrap. Sitting Nigeria iron and steel industry which forms the bases for this study, our iron and steel industry has been non functional because of the problem of un-coke-able coal and also low quality iron ore. But with the much availability of steel scrap, this can serve as an alternative mean of local production of steel. This will go a along way to reduce cost, time to market and reduction on carbon emission. Nigeria as a developing country where there is high demand for steel for huge number of construction work going on day by day. It has a total projected annual demand of

10.4 million tons as such, there is a great need for steel production locally; in other to boost its local content and reduce it's over dependence on steel importation [3].

Chapter two

LITERATURE REVIEW

2.1 Steel making Background

Steel is an alloy of iron usually containing less than 1% carbon [5]. It is used most frequently in the automotive and construction industries. Steel can be casted into bars, strips, sheets, nails, spikes, wire, rods or pipes depending on the need of the intended user.

The process of steelmaking has undergone many changes in the 20th century based on the political, social and technological evolution [6]. In the 1950s and 1960s, demand for high quantity steel encouraged the steelmaking industry to produce large quantities. Large, integrated steel mills with high capital costs and limited flexibility were built in the U.S. [21]. Integrated steel plants produce steel by refining iron ore in several steps and produce very high quality steel with well controlled chemical compositions to meet all product quality requirements.

The energy crisis of the 1970s made thermal efficiency in steel mills a priority [21]. The furnaces used in integrated plants were very efficient; however, the common production practices needed to be improved. The large integrated plants of the 1950s and 1960s tend to produce steel in batches where iron ore was taken from start to finish. This causes some equipment to be idle while other equipment was in use and a lot of heat losses. To help reduce energy used-up during the idle time, continuous casting methods were developed. By keeping blast furnaces continually feed with iron ore, in this way heat is used more efficiently.

As environmental concerns have gained importance in the 1980s and 1990s coupled with scare resources and high cost of energy, regulations have become more stringent, and also changes to green manufacturing. This also aroused other changes in the steelmaking industry. Competition has also increased during this period do to decreasing markets and increasing foreign steel production plants. The competition has forced steelmaking facilities to reduce expenses by maximising value from minimum spent resources in other to be competitive.

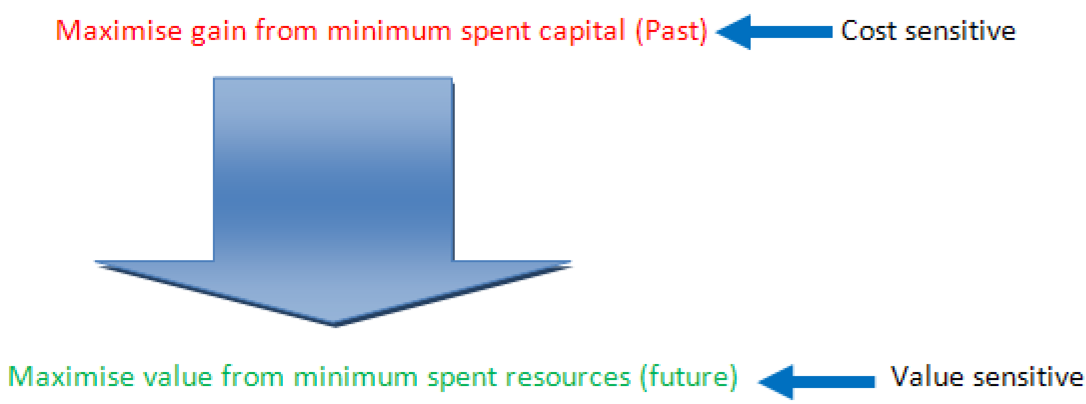

Figure 2-1 Change in the business paradigm

To meet these changing needs, automation of processes, ICT and just-in-time technology has become more prominent and integrated steel plants are being replaced with smaller plants, called mini-mills, which rely on steel scrap as a base material rather than iron ore. But mini-mills will never completely replace integrated steel plants. This is because they cannot maintain the tight control over chemical composition and more especially the possibility to fulfil the market demand.

2.2 Process route of manufacturing steel

Steel making is a complicated process involving many stages and yielding thousands of by-products (see appendix 2). Steel can be produced either from scrap or iron ore .The process used for the manufacturing of iron and steel determines to a great extent on the cost of its production (energy consumption and emission) and the quality of the steel produced. Worldwide steel is manufactured through two main routes namely; primary route and the secondary route. Also there is the intermediate route called direct reduction route which uses the combination of direct reduced iron and feed into the Electric Arc Furnace for onward steel production as detailed in figure 2.2 below.

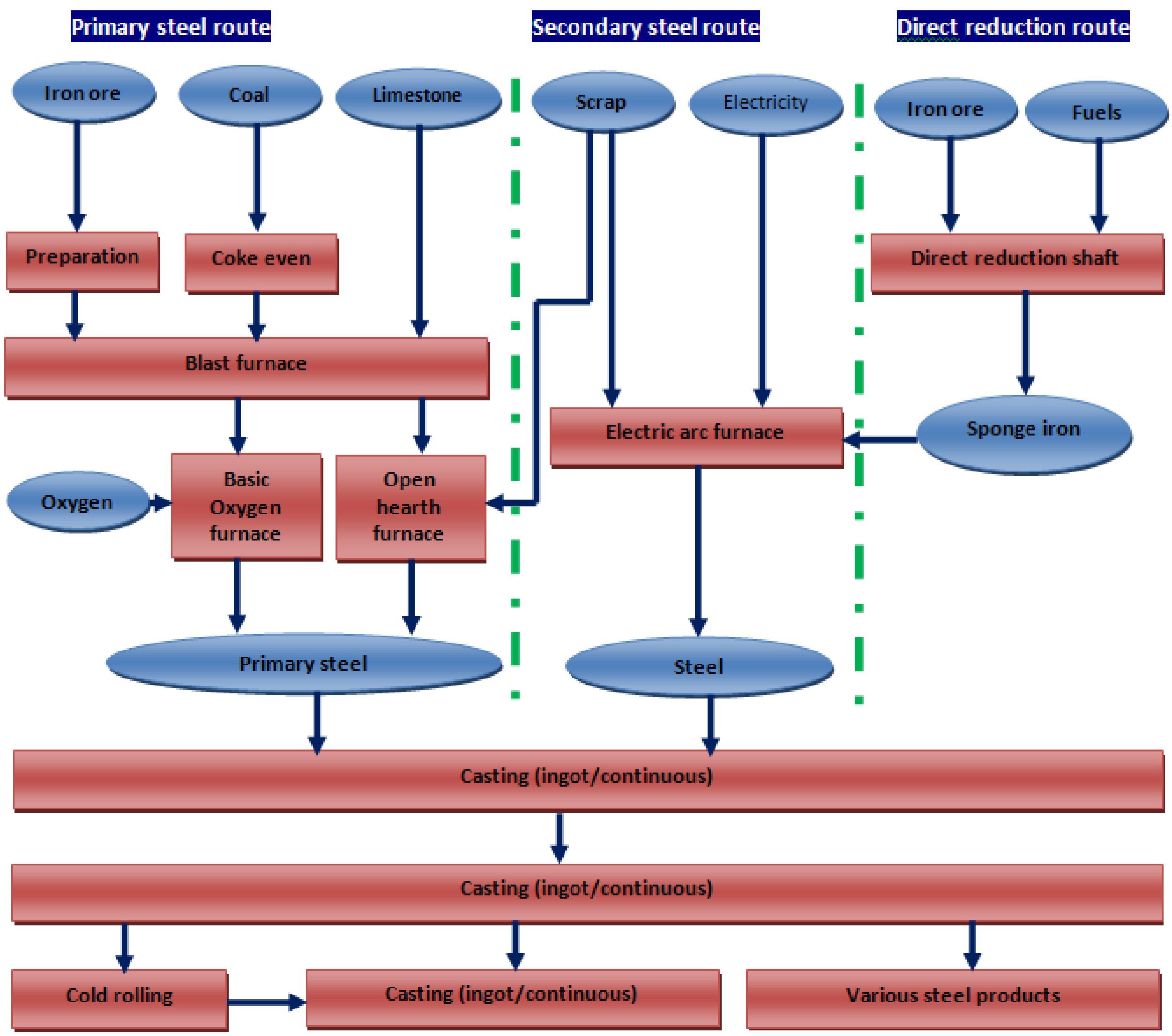

Figure 2-2 Process route in the Iron and steel industry [7]

2.2.1 The primary route

The primary route uses the blast furnace/ basic oxygen furnace (BF/BOF) for steel making, which is a traditional route. It is also generally called the integrated route. Iron ore and coke is the main raw material in this process. This leads to high carbon emission into the environment. Steel produced by primary route accounts for about 70% of the global production (Iron and steel report 2005).

The Steel production through this integrated steel plant involves three basic steps. First, the heat source used to melt iron ore is produced. Secondly, the iron ore is melted in a furnace. Thirdly, the molten iron is processed for crude steel production in the Basic Oxygen Furnace. These three steps can be done at one facility; however, the fuel source is often purchased from off-site producers.

2.2.1.1 Coke making

Coke is a solid carbon fuel and carbon source used to melt and reduce iron ore. Coke production begins with pulverized, bituminous coal. The coal is fed into a coke oven (figure 2.2 above) which is sealed and heated to very high temperatures for 14 to 36 hours [7]. Coke is produced in batch processes, with multiple coke ovens operating simultaneously. In the coke making process, heat is frequently transferred from one oven to another to reduce energy requirements. After the coking is finished, it is moved to a quenching tower where it is cooled with water spray. Once cooled, the coke is moved directly to an iron melting furnace (Blast Furnace) or into storage for future use.

2.2.1.2 Iron-making

During iron-making, iron ore, coke, heated air and limestone or other fluxes are fed into the blast furnace. The heated air causes the coke combustion, which provides the heat and carbon sources for iron production. Limestone or other fluxes may be added to react with and remove the acidic impurities, called slag, from the molten iron. The limestone-impurities mixtures float on the top of the molten iron and are skimmed off, after melting is completed.

Sintering products may also be added to the furnace. Sintering is a process in which solid wastes are combined into a porous mass that can then be added to the blast furnace. These wastes include iron ore fines, pollution control dust, coke breeze, water treatment plant sludge, and flux. Sintering plants help reduce solid waste by combusting waste products and capturing traces of iron present in the mixture. Sintering plants are not used at all steel production facilities.

2.2.1.3 Steelmaking (in BOF)

Molten iron from the blast furnace is sent to a basic oxygen furnace, which is used for the final refinement of the iron into steel. This process can also use up to 25-30% scrap as feed stock for cooling the melt [7]. High purity oxygen is blown into the furnace and combusts carbon and silicon in the molten iron. The basic oxygen furnace is fed with fluxes to remove any final impurities. Alloy materials may be added to enhance the characteristics of the steel depending on the customer's orders and/or specification. The resulting steel is most often cast into slabs, beams or billets. Further shaping of the metal may be done at steel foundries, which re-melt the steel and pour it into moulds, or at rolling facilities, depending on the desired final shape known as continuous casting. The entire energy consumption of this process as recorded by the world best practice (ranging from iron raw material processing to thin slab casting) is 14.8GJ/t [18]

2.2.2 The secondary route

In this route, the initial process of coke-making, sintering and iron making is omitted. The raw material to this process is 100% scrap which is feed into the Electric Arc Furnace (EAF) as the raw material [7].

Steelmaking from scrap metals involves melting scrap metal, removing impurities and casting it into the desired shapes. Electric arc furnaces (EAF) are often used. The Electric Arc Furnace melts the scrap metal in the presence of electric energy and oxygen. The process does not require the three step refinement as needed to produce steel from ore as stated above. Production of steel from scrap can also be economical on a much smaller scale.

Frequently mills producing steel with Electric Arc Furnace technology are called mini-mills. While Electric Arc Furnaces are sometimes small, some are large enough to produce 400 tons of steel at a time. The growth of Electric Arc Furnace has been driven by the technology's smaller initial capital investment and lower operating costs and better energy efficient processes.

Moreover, scrap metal is found in all parts of the country, so Electric Arc Furnace process route are not tied to closeness to raw material deposits as are in the case of integrated mills (primary route) and thus can be placed closer to customers. For instance Electric Arc Furnaces now account for well over half of American steel production and their share is expected to continue to grow in coming years [13]. The energy consumption of this process as a world best practice (ranging from steel production to thin slab casting) is 2.6GJ/ T [18]

2.2.3 The direct Reduced Iron (DRI)

The Direct Reduced Iron is another alternative route of producing Iron. It can be called "intermediate process route" because it uses the iron ore as the raw material to produce the sponge iron which is later feed into the secondary route (Electric Arc Furnace) for onward production of steel. The Direct Reduction process produces iron (sponge iron) by the reduction of iron ore at a temperature of 1000^0 which is below the melting point of iron (1530^0). Figure 2.3 show the standard chemical equation for the reduction of iron ore through the direct reduction process. The product of this process is direct reduced iron (DRI). This reduction process which uses a combination of iron ore lumps, pellet or fines depending on the processing technology normally require high grade(>90%) of iron ore and low impurity level in this ferrous raw material than other iron-making producers. As such, this tends to limit the iron ore sources that can be used for this process. Direct reduction grade iron ore normally sell at premium price compared to regular blast furnace grade ore reflecting higher quality and limited supply. The direct reduction process can use gas, uses fine ores and involves a lower capital investment. The downside is that a relatively high grade of iron ore is required as the process retains the impurities and even some unconverted iron oxide. This process can also use steel scrap as a combination when feed (sponge iron) into the Electric Arc Furnace for steel making process. It can consume about 20% of steel scrap as combination with the sponge iron in the steelmaking process [7].The energy consumption of this process as recorded by world best practice from the sponge iron making to the steel making and finally thin slab casting is 16.9GJ/t [18]

REDUCTION

$$Fe_3O_4 + CO > 3FeO + CO_2$$

$$Fe_3O_4 + H_2 > 3FeO + H_2O$$

$$FeO + CO > Fe + CO_2$$

$$FeO + H_2 > Fe + H_2O$$

REFORMING

$$CH_4 + CO_2 > 2CO + 2H_2$$

$$CH_4 + H_2O > CO + 3H_2$$

Figure 2-3 Standard Chemical equation showing the reduction process of Iron ore through the Direct Reduction process (DRI) and the reform of the carbon doixide to produced carbon monoxide

2.3 Recycling

Recycling involves processing of used materials (scrap) into new product to prevent waste of potentially useful materials. It reduces the consumption of fresh materials, reduce energy usage, reduce water pollution and landfill. It also reduces air pollution from incineration by reducing the need for “conventional” waste disposal, and lower greenhouse gas emission as compared to production from virgin material. It is the key component of modern waste reduction and is the third component of the “reduce”, “reuse” and “recycle” in the waste hierarchy [13].

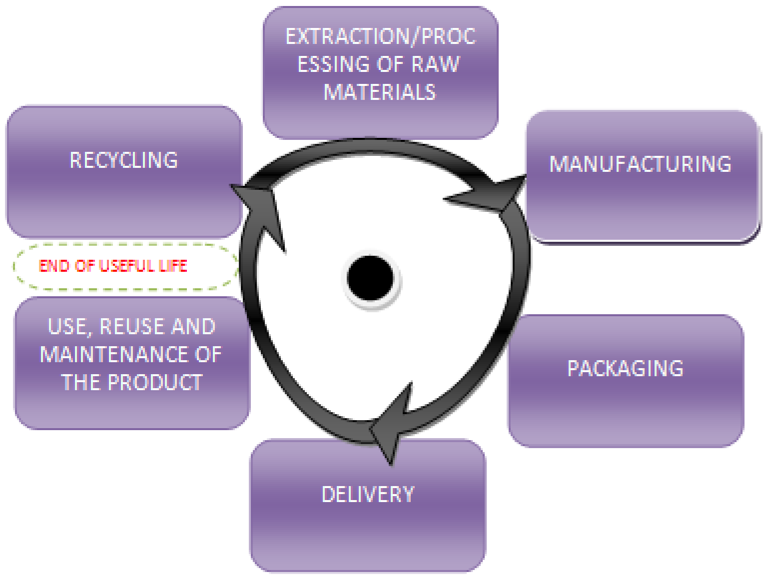

Figure 2-4 cyclic flow routes of steel scrap material [8]

With the increasing need for environmental concern in terms of carbon emission coupled with scares resources and high cost of energy this has made recycling of steel to gain much awareness as such changed the image from “rust coloured “to “green material”. Figure 2.4 above details the cyclic flow of steel materials from its production to its use and reuse before the end of its useful life. Then recycling process starts at this end of the useful life of the first steel produced. This continues cyclic process shows the endless recycling potential of steel. The figure 2.4 above is a modified version from the original source. The endless recycling of steel products has also transformed steel recycling from merely an environmental goal into a genuine business. For instance, according to a recent study released by steel recycling institute , automobiles are recycling more than any other product with nearly 100% of vehicle recycled today for there iron and steel content .

Figure 2-5 A crane loading auto bodies to be recycled from collection center(source: institute of scrap recycling industries

2.3.1 Overview of steel recycling

Recycling of steel has been a common practice in human history, with recorded advocates as far back as Plato in 400BC [22]. During that period when resources were scare, archaeological studies of ancient waste dumps shows less household waste such as ash, broken tools and pottery. This implies that more waste was being recycled in the absence of new materials. In the pre-industrial times, there is evidence of scrap bronze and other metals being collected in Europe and melted down for perpetual reuse [22]. In Britain, dust ash from wood and coal fires was collected by dustmen and down cycled as a base material used in brick making .The driver for this type of recycling was the economic advantage of obtaining recycled feedstock instead of acquiring virgin material as well as lack of public waste removal in ever more dense populated areas.

The properties of metal compared to other materials provide a unique benefit and advantage for their recycling. Unlike other recycled materials, such as paper and plastic, glasses etc, steel can be repeatedly recycled without degradation of their properties. Steel from secondary source are just as good as steel from primary source.

As practiced since ancient times, iron and steel recycling embodies the spirit of sustainable development .This is a development which meets the requirements of the present without compromising the ability of future generation to fulfil their own needs as defined by world commission on environment and development .Recycling widens the efficient use of metals and minerals, reduce pressure on landfill and incinerators which result in significant major energy saving compared to primary production.

Steel is one of the world's most recycled products. In fact it is 100% recyclable, which means its life cycle is potentially continuous .Steel scrap is a necessary component in the production of new steel. With the growing awareness of the benefit of recycling, the industry has made even stronger moves to reuse as much steel as possible.

2.3.2 Types of iron and steel scraps

Scraps which are the main source of Electric Arc Furnace (EAF) steelmaking feedstock consist of three main types: home scrap, prompt scrap, and obsolete scrap. The forth type is know as dormant scrap which are the unrecovered scrap.

2.3.2.1 Home scrap

These are scraps generated within the steel mills which are left-over pieces from steel making and defective or rejected products. They are collected and recycled into new steel right there at the mill. Home scrap never leaves the plant. Technological advancement has really reduced the generation of home scrap through the use of efficient processes.

2.3.2.2 Prompt scrap (purchased scrap)

These are off-cut generated from product manufacturing companies, such as car companies, home appliance manufacturers, and other similar companies. Off-specification products are also returned as prompt scrap. They are created during the production of steel products. Prompt scrap can also be called industrial scrap.

2.3.2.3 Obsolete scrap (post consumed scrap)

These are steel locked up in items that have come to the end of their useful lives. The quality of obsolete scrap varies considerably, depending on the use and how the steel was manufactured in the past. Often the quality of many small pieces cannot be economically determined.

2.3.2.4 Dormant scrap

These are that portion of iron and steel scrap units which is not, as yet, recycled back into the steel-making process. It is made up of two distinct categories:

One: Oxides (dust, sludge, slag, etc.) that go into special landfills, usually on or near the steel plant site. Two: Metallic parts that are no longer useful product but which cannot be economically recovered as obsolete scrap.

Table 2-1 The main source of steel scrap [12]

Source	Percentage
vehicles	25
Manufacturing off-cuts	14
Consumer durables and landfill	22
Industrial machinery	11
Demolition	18
cans	5
rails	5

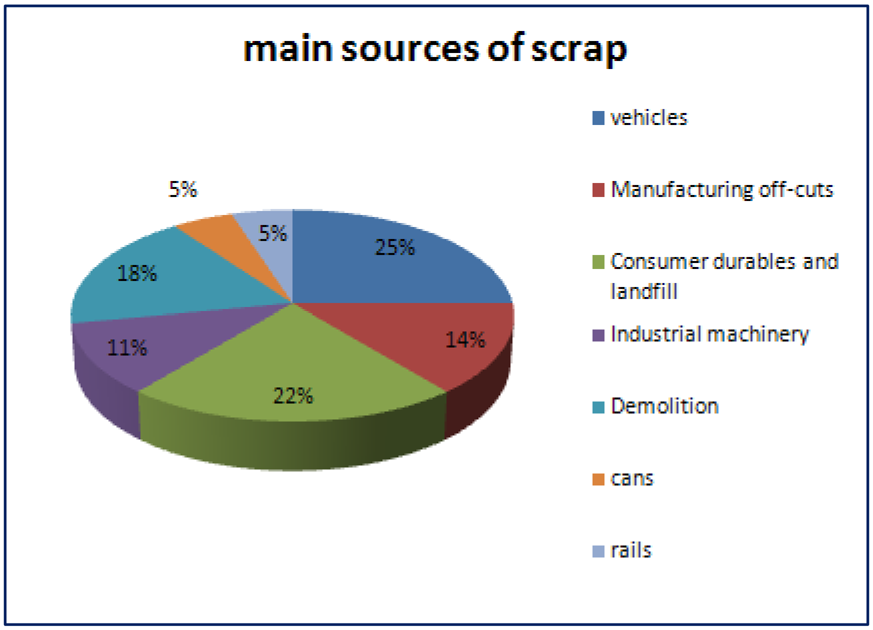

Figure 2-6 Graphical representation of sources of steel scrap [12]

2.3.3 Sources of steel scrap

There are different channels in which steel scrap can be generated. Scrap can be generated from vehicles that have come to the end of its useful life or those that are damaged through accident which are normally sent for demolition. Examples of such vehicles are shown in figure 2.5 above. Other channels include steel cans, damaged rails, industrial machineries etc. Details are shown in table 2.1 and there corresponding percentages (figure 2.6) of availability. Most of these steel scraps are generated from steel that has come to the end of their useful life. Table 2.2 shows the average life span of steel in their application areas. The steel scraps when collected are prepared as feedstock for the electric arc furnace by passing through the processing steps to make them ready to be feed into the furnace. Samples of prepared steel scraps are shown in figure 2.7.

Table 2-2 The showing the average life of items made maily from steel [12]

Item manufactured from steel	Average year
Buildings	20-60
Major industrial and power plants	40
Heavy industrial machinery	30
rails	25
Consumer durables	7-15
Cars –all types	5-15
Steel cans	<1

Figure 2-7 Sample of mini mill prepared steel scrap.

2.4 Brief History of Nigeria steel industry

Figure 2-8 Map of Nigeria showing the major commercial cities

The Plan to set up Nigerian Steel Industry started as early as 1958. At this time, many international organizations and consulting firms had been commissioned at various levels to study the feasibility of steel plants to be built in Nigeria under the umbrella of the Federal Ministry of Industries. Parallel efforts were made to identify and analyze the principal raw materials needed for the steel industry. In 1971 an extra-ministerial agency was established to stream line efforts required to actualize a steel plant in Nigeria. That Agency was called “Nigerian Steel Development Authority”. Under this agency, efforts were intensified in market survey of the feasibility of steel market in Nigeria. They searched for the appropriate local inputs (iron ore and coal), of which the quality of the iron ore found will determined the particular technologies that would be adopted. In the quest of this search, Iron ore was found to be located at Agbaja, Itakpe and Udi. Also suitable deposit of Limestone was found at Jakura, Mfamosin and other parts of the country. Coal deposits were always found at Enugu while potential coke-able coal was struck at Lafia.

Market surveys were commissioned and the construction of the Kainji Hydro-electric Dam promised an abundant source of electrical energy. Between 1961 and 1965 many firms from the industrialized nations of the world submitted proposals for the construction of an integrated Steel Plant in Nigeria. Though, it was anticipated that the available raw materials could not be used in conventional Iron and Steel making technologies. As such the "Strategic Udy Process", a direct reduction (DR) process still in the pilot plant stage in the USA, was then considered by Nigeria. The idea was accepted by the joint venture company. Then the Nigerian Steel Associates was formed with Westinghouse and Koppers as the foreign Partners. Unfortunately, this program failed because it did not prove capable of meeting commercial scale requirements.

Again In 1967 a UNIDO survey identified Nigeria as a potential steel Market. This led to the signing of a bilateral agreement between the defunct Soviet Union and Nigeria, and, the arrival of Soviet steel experts in Nigeria to conduct a feasibility study. The experts recommended the Blast Furnace/Basic Oxygen Furnace (BF/BOF) process. They also confirmed the availability of raw materials and recommended further geological surveys. In 1970 a contract was awarded to TiajProm Export (TPE) of defunct USSR to conduct a study to identify sources of feedstock, quality and quantity of materials for the proposed integrated iron and steel plant. By this time the second National Development Plan had envisaged the construction of 750,000 tons per year capacity Plant.

With the source of Iron Ore confirmed it was proposed that coking coal would be imported and blended appropriately with local coals. A three-phased development program (1st phase to produce 1.3 million tons, which will be expanded to 2.6 million tons incorporating the flat sheet production in the 2nd phase, and the third phase to increase capacity to 5.2 million tons) was accepted.

The initial product mix proposal suggested 50% long products and 50% flat products. This was based on the product demand profile revealed by market surveys. The Government decided that Ajaokuta Steel Plant should produce only long products in the first stage of 1.3 million tons per year, and flat products in the 2.6 million tons expansion which was planned to dove-tail the first phase completion and this is to be followed by a third phase of 5.2 million tons per annum. This decision was advised by the need to take advantage of economy of scale since flat-product mills of capacity below 1 million tons were considered uneconomical. An additional consideration was to use the relatively simpler technology of long-products rolling to rain up an otherwise virgin and inexperienced Nigerian Workforce of the time.

The National Steel Development Authority was dissolved by the federal Government in 1979 and this metamorphosed into forming several organizations, namely: Ajaokuta Steel Project, Ajaokuta, The Delta Steel Company, Ovwian – Aladja, Jos Steel Rolling Company, Jos, Katsina Steel Rolling Company, Katsina, Oshogbo Steel Rolling Company, Oshogbo, National Iron Ore Mining Company, Itakpe, National Steel Raw Materials Exploration Agency, Kaduna, National Metallurgical Development Center, Jos, Metallurgical Training Institute, Onitsha. With the dissolution of the National Steel Development Authority (NSDA) the above mentioned bodies were formed and other public and private companies with there various proposed product line and production capacity as stated in the table2.3 below.

Table 2-3 List of public and private sector companies showing their product line and production capacities [19]

S/No	Plant Location	Type of Plant	Iron-making Process and capacity (per year)	Casting Process	Rolling Capacity (per year)	Product Mix
1	Ajaokuta Steel Co. Ltd. Ajaokuta	Inter-grated (Public)	Blast furnace, capacity 1.35m.ton	3 no. 4-strand for blooms	540,000 tons long products	Bars, rods, light sections
2	Alliance Steel Co., Ibadan	Rolling mill	-	-	20,000 tons long products	Bars
3	Allied Steel Co., Onitsha	Rolling mill	-	-	20,000 tons long products	Bars
4	Asiastic Manarin Ind., Ikeja	Rolling mill	-	-	60,000 tons long products	Bars; sections
5	Continental Iron & Steel Co., Ikeja	Mini mill	-	-	150,000 tons long products	Bars; sections
6	Delta Steel Co., Ovwien/Aladja,	Inter-grated (Public)	2 Midrex 600 series Direct Reduction furnaces; capacity1.02 m.t	3no. 6-strand for billets	320,000 tons long products	Bars; rods; sections
7	Federated Steel Industry, Otta	Mini mill	-	-	140,000 tons long products	Bars; sections
8	General Steel Mill, Asaba	Mini-mill	-	-	50,000 tons long products	Bars
9	Jos Steel Rolling Company, Jos	Rolling mill (Public)	-	-	210,000 tons long products	Bars, rods
10	Katsina Steel Rolling Co. Katsina	Rolling mill (Public)	-	-	210,000 tons long products	Bars, rods
11	Kew Metal Industries, Ikorodu	Mini-mill	-	-	20,000 tons long products	Bars; sections
12	Kwara Commercial, Metal and Chemical	Rolling mill	-	-	40,000 tons long products	Bars

	Industries, Ilorin					
13	Mayor Eng. Co., Ikorodu	Rolling mill	-	-	220,000 tons long products	Bars. sections
14	Metcombe Steel Co., Owerri	Rolling mill	-	-	10,000 tons long products	Bars; sections
15	Nigerian Spanish Eng. Co., Kano	Mini mill	-	-	100,000 tons long products	Bars
16	Nigersteel Co., Enugu	Mini mill	-	-	40,000 tons long products	Bars; sections
17.	Oshogbo Steel Co., Oshogbo	Rolling mill (Public)	-	-	210,000 tons long products	Bars; rods
18	Qua Steel Products, Eket	Rolling mill	-	-	60,000 tons long products	Bars, sections
19	Selsametal, Otta	Rolling mill	-	-	100,000 tons long products	Bars
20	Union Steel Co., Ilorin	Rolling mill	-	-	20,000 tons long products	Bars
21	Universal Steel Co., Ikeja	Mini mill	-	-	80,000 tons long products	Bars, sections
22	Baoyao Futurelex, Abuja	Rolling mill	-	-	20,000 tons long	Bars

But it is very unfortunate that these steel companies have remained un-operational after the commissioning stage of most of them while some are still under construction till date due to poor funding from the Government. The unavailability of adequate raw material and coke-able coal has also been a very great impediment. These has made the steel companies not to produce steel from iron ore and are left with the only alternative of importing semi finished steel products which they use as their feedstock.

Chapter three

METHODOLOGY AND DATA ANALYSIS

As the objective of this research work is to investigate the energy saving in steel production through the use of scrap to produce new steel. The data used for this analysis was collected from a steel company in Nigeria which was revitalized after the privatization exercise and it stated operation less than six months ago.

3.1 Profile of the company

This company in view was among the nine steel company and institutes established in Nigeria in 1980 after the dissolution of the Nigerian Steel Development Authority.

The company's project started as a turnkey project with an Austro-German Loan. What the concept of turn-key project means, is that the Austro-German Consortium of Seven Companies, completed the plant, commissioned it and hand over the key (commissioning) to the Federal Government of Nigeria for continuing operation.

The Consortium completed the plant according to the terms of the contract as stated in the project charter and did bring in commissioning raw materials like Iron Ore from Liberia and Brazil, Graphite electrodes, ferro-alloys, scraps and so on. They also brought in some spares (called commissioning spares). After the commissioning raw materials were exhausted, it then became necessary that the Federal Government should provide adequate working capital, so that the plant could attempt proving itself to design capacity, which was one million tons of liquid steel. But it was unfortunate that adequate working capital was not made available. This led to the non production of the company after commissioning because of insufficient fund to import raw material (iron ore) to run the company.

The company had a new life after the privatization exercise undergone by the Federal Government of Nigeria under the bureau of public Enterprise BPE, which led to the purchase of the company.

The business type of the company is manufacturing of iron and steel from Midrex Direct Reduced Iron (DRI) and scrap recycling. The products and services are steel production, billets, roll products etc. It has a total of 1000 employees. The trade and market areas are Eastern Europe and Southern Asia and the main market are Africa, Eastern Asia and Western Europe. The company is located in the southern part of Nigeria and it has a factory size of 100,000square meters. It has management certification of ISO 9001:2000 and ISO 14001:2004.

3.2 Model for the analysis

3.2.1 Porter's Generic value chain model

This model helps us to better understand the activities through which a firm develops competitive advantage and creates shareholders value .The model separate the business system into a series of value generating activities (primary and support activities) which are referred to as the value chain.

The goal of these activities is to offer the customer a level of value that exceeds the cost of the activities thereby resulting in a profit margin.

In this way, the profit of the company will be attributed to the effective performance of these activity chains more especially in the operation activity through the use of steel scrap in the production of new steel. This is intended to reduce the energy consumption and also carbon emission as such reducing the cost of energy purchased. Through this effective performance, the amount the customer will be willing to pay for the end steel product will exceed the cost of the activities in the value chain.

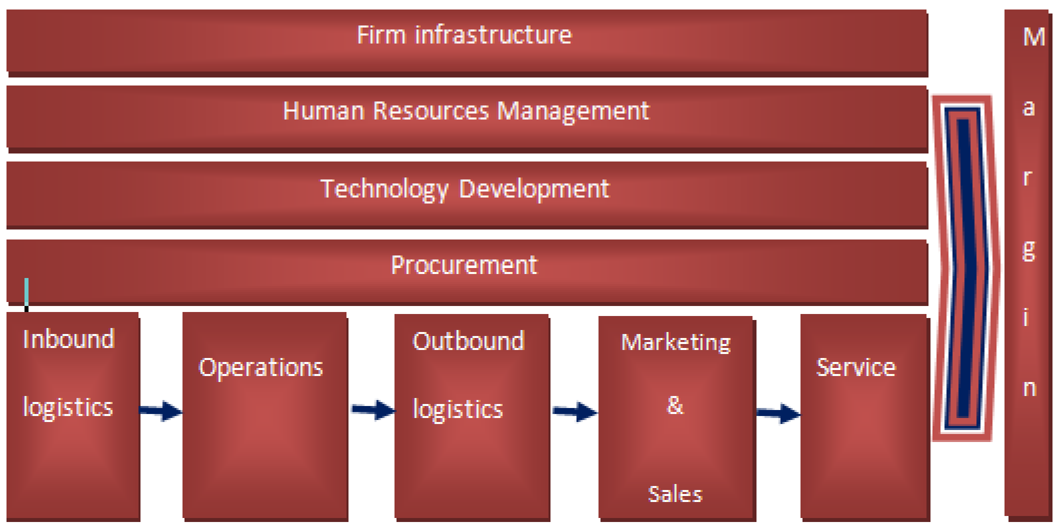

Figure 3-1 Diagram of the porter's value chain generic model [20]

Inbound logistics (primary activity): The semi-finished steel manufacturing companies receives the delivery of their raw materials and warehouses them. For this Company in quote, they receive the imported iron ore from Bulgaria or Brazil. They are cleared at the sea-port and are transported to the company for warehousing. The steel scrap is sourced locally from local supplier's .These supplier's source for the scrap from homes, foundry and fabrication shops and so on. They purchase and gather these scraps for onwards supply to the company. At times the company uses direct sourcing. By this I mean that they send some of their own agents who go out to the cities at strategic places to purchase steel scrap from there owners and finally transport them to the company for warehousing.

Operation (primary activity): This activity forms the basis of this research work. At this stage the input raw materials which are the steel scrap and iron ore are processed and transformed into the semi-finish product (steel). The scrap passes through some preparation stages which include: sorting, cutting, sizing and weighing before being charged into the electric Arc furnace.

When charged into the electric arc furnace (EAF) the scrap is heated-up till it reaches its melting point. This point marks the energy saving compared to amount of energy used to melt iron ore and produce steel when producing through the direct reduction process. The data in table 3.1 and 3.2 shows the calculation of energy consumption for producing semi-finished steel through Electric Arc Furnace route and iron ore through the Direct Reduction/EAF Route.

3.3 Data collection and its source

The data for the amount of raw material input (iron ore in tons) used for the Direct Reduction Route and the steel Scrap (in tons) for the recycling route (EAF only) are collected from the steel company in Nigeria that started operation few months ago. The data includes:

- The amount of input iron ore per day (in tons) for the Direct Reduction process Route
- The amount of input steel scrap per day (in tons) for the Recycling route
- Energy consumed to process the input ore in other to produce semi-finished steel (in MWH) for the Direct Reduction Route.

- ❖ Energy consumed to process the input steel scrap in other to produce semi-finished steel (in MWH) for the recycling route.
- ❖ The corresponding tap weight of semi-finished steel for the Direct Reduction Route and that of Recycling Route.
- ❖ The furnace temperature for the two process routes.

These data were collected in agreement with this company for the purpose of this work, for a period of one month (thirty one days). The data was limited for one month because it was the time the company ran full production from the Direct Reduction Route and Recycling Route (EAF) concurrently. This data reflect the whole amount of input iron ore and the steel scrap used (in tons) and the energy consumed for each of the routes. The data for tap weight will be used to calculate the yield and the energy consumed for one ton of semi-finished steel produced for each of the process route as done in table 3.1 and 3.2 below. The production process runs for twenty four hours, three shifts per day for a period of thirty one days.

3.4 Calculation of the energy consumption

As stated earlier, the data for this analysis was collected for a period of one month when the company ran full production for the direct reduction route and the scrap recycling (EAF) route. The amount of input raw materials in tons, energy consumed and the tap weight for the two routes are recorded for each day for a period of thirty one days. The following steps was adopted in the calculation and analysis

1. The amount of the raw material was calculated and recorded to represent the input iron ore for the direct reduction route and steel scrap for recycling route.

2. The energy consumption was calculated and recorded to represent the energy consumption for the direct reduction process (DRI+EAF) and that of the recycling process (EAF only) respectively.
3. Using the input iron ore data and scrap input data and the corresponding tap weight for each of them respectively. The yield of semi-finished steel was calculated for each of the process routes as follows: Yield rate=output semi-finished steel divided by input iron ore or steel scrap respectively.
4. Summation of the output semi-finished steel for direct reduction route for the thirty one days
5. Summation of the output semi-finished steel for the recycling route for the thirty one days
6. Summation of the energy consumption for each of the direct reduction route and the recycling route respectively for a period of thirty one days.
7. Finally the energy consumed for one ton of semi-finished steel produced was calculated by dividing the total consumed energy by the total output steel for each of the two process routes(table 3.1 and 3.2) using the formula below

A weighted average approach was used to calculate the amount of energy consumed and the output semi-finished steel produced for the period of thirty one days in each of the process routes. The yield rate for each of the two process route was also computed by dividing the output semi-finished steel by the input iron ore or scrap as applicable.

Energy consumed to produce one ton of semi-finished steel = $\frac{\text{Total energy consumed (MWH)}}{\text{Total Quantity of semi-finished Steel produced (Tons)}}$

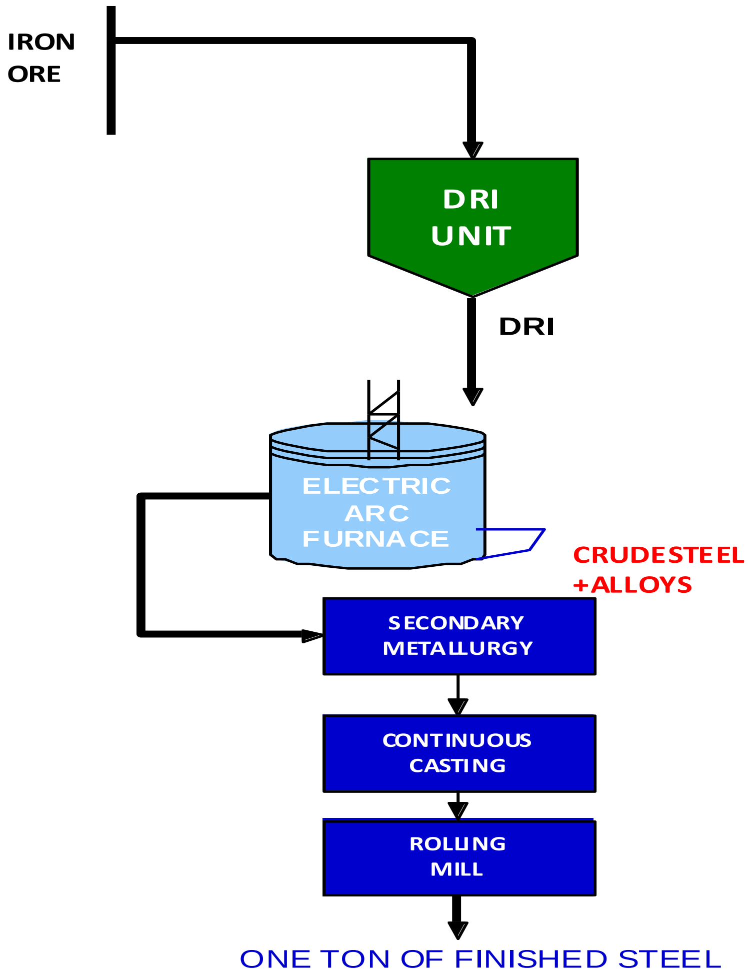

Figure 3-2 Schematic flow for DRI/EAF process route [10]

The diagram in figure 3.2 above shows the process flow for steel production through the direct reduction process. First the sponge iron need to be produced in the DRI unit and later fed into the electric arc furnace for semi-finished steel production. This means that in the direct reduction route, two major process are involve(1)sponge iron making in the DRI unit (2) semi-finished steel making in the electric arc furnace. And it is in this two process more especially in the DRI unit that marks the differential energy consumption.

Table 3-1 Data calculation for steel production through the DRI+EAF Route

DATA ANALYSIS FOR STEEL PRODUCTION FROM DRI(DRI+EAF ROUTE)						
Day	ORE INPUT(TONS)	ENERGY CONSUMED (MWH)	TAP WEIGHT(TONS)	YIELD	YIELD (%)	FURNACE TEMP (^{O}C)
1	38.12	157.16	32.614	0.855561	85.55614	1733
2	39.52	153.43	32.874	0.831832	83.1832	1730
3	41.02	156.9	34.723	0.84649	84.64895	1733
4	46.92	153.98	41.014	0.874126	87.41262	1739
5	59.62	149.69	51.391	0.861976	86.19758	1730
6	55.12	156.73	48.853	0.886303	88.63026	1730
7	47.79	154.37	40.748	0.852647	85.2647	1730
8	53.62	145.4	44.388	0.827825	82.78254	1735
9	39.12	153.16	33.587	0.858563	85.85634	1742
10	21.12	154.9	18.982	0.898769	89.87689	1730
11	43.62	149.08	36.143	0.828588	82.85878	1728
12	39.12	151.41	33.77	0.863241	86.32413	1730
13	46.12	132.53	33.996	0.737121	73.71206	1730
14	43.62	153.32	36.566	0.838285	83.82852	1665
15	37.52	139.89	29.133	0.776466	77.64659	1730
16	44.12	170.39	36.631	0.830258	83.02584	1740
17	36.12	148.42	30.476	0.843743	84.37431	1730
18	31.12	156.32	28.083	0.90241	90.241	1670
19	21.12	162.73	17.093	0.809328	80.93277	1740
20	23.45	138.42	20.958	0.893731	89.37313	1730
21	27.37	145.99	23.071	0.84293	84.29302	1730
22	25.14	151.81	21.592	0.85887	85.88703	1730
23	31.12	153.53	24.331	0.781844	78.18445	1735
24	32.72	149.93	29.143	0.890678	89.06785	1730
25	39.87	158.1	34.072	0.854577	85.45774	1730
26	34.92	153.17	28.638	0.820103	82.01031	1730
27	43.82	154.63	36.528	0.833592	83.3592	1730
28	45.36	146.79	35.114	0.774118	77.41182	1730
29	38.62	144.89	32	0.828586	82.85862	1730
30	26.12	138.86	22.467	0.860145	86.01455	1669
31	36.12	143.91	30.16	0.834994	83.49945	1730
Total	1189.08	4679.84	999.139	26.0977	2609.77	53499
AVERAGE	38.35742	150.9626	32.23029	0.841861	84.18614	1725.77419
ENERGY CONSUMED TO PRODUCE ONE TON OF STEEL=150.9626/32.23029=4.6839MWH/TON						

Energy consumed per ton produced from the DRI+EAF route=4.68MWH

Table 3-2 Data calculation for steel production through the recycling route(EAF only)

DATA ANALYSIS FOR STEEL PRODUCTION FROM SCRAP(EAF ROUTE)						
DAYS	SCRAP INPUT(TONS)	ENERGYCONSUMED (MWH)	TAP WEIGHT (tons)	YIELD	YIELD (%)	FURNACE TEMP.^{0}c
1	105.06	62.1	93.83	0.8931087	89.31086998	1733
2	101.34	62.35	88.174	0.870080916	87.00809157	1730
3	100.16	61.76	88.887	0.88745008	88.74500799	1733
4	87.13	70.25	80.103	0.919350396	91.9350396	1739
5	76.75	64.85	70.177	0.914358306	91.43583062	1730
6	76.71	71.35	71.744	0.935262678	93.52626776	1730
7	91.29	64.88	82.008	0.898324022	89.83240223	1730
8	91.12	60.95	79.829	0.876086479	87.60864794	1735
9	98.86	60.36	88.778	0.898017398	89.80173983	1742
10	116.92	56.46	107.905	0.922895997	92.28959973	1730
11	116.79	58.35	101.428	0.868464766	86.84647658	1728
12	117.41	67.45	105.762	0.900792096	90.07920961	1730
13	116.51	61.06	90.431	0.776165136	77.6165136	1730
14	113.9	68.65	99.96	0.87761194	87.76119403	1665
15	100.7	67.55	81.653	0.810854022	81.08540218	1730
16	102.69	69.55	89.635	0.872869802	87.28698023	1740
17	90.05	66.65	86.298	0.958334259	95.83342587	1730
18	117.7	64.58	112.573	0.956440102	95.6440102	1670
19	133.02	57.45	107.358	0.807081642	80.70816419	1740
20	120.01	58.26	109.983	0.916448629	91.64486293	1730
21	117.97	60.55	102.528	0.869102314	86.91023141	1730
22	115.25	59.59	101.571	0.881310195	88.13101952	1730
23	107.6	62.58	86.861	0.807258364	80.72583643	1735
24	104.15	65.6	96.016	0.921901104	92.19011042	1730
25	103.8	67.45	92.899	0.894980732	89.49807322	1730
26	91.87	66.14	78.686	0.85649287	85.64928704	1730
27	106.06	68.57	92.799	0.874967	87.49669998	1730
28	110.66	69.8	90.538	0.818163745	81.81637448	1730
29	101.02	68.23	88.291	0.873995248	87.39952485	1730
30	113.1	62.57	102.569	0.90688771	90.688771	1669
31	118.17	67.73	102.6	0.86824067	86.82406702	1730
TOTAL	3263.77	1993.67	2871.874	27.33329732	2733.329732	53499
AVERAGE	105.2829032	64.31193548	92.64109677	0.881719268	88.17192684	1725.774194
ENERGYCONSUMED TO PRODUCE ONE TON OF STEEL=64.31193548/92.64109677=0.69420MWH/TON						

Energy consumed per ton produced from the recycling (EAF) route=0.69420MWH

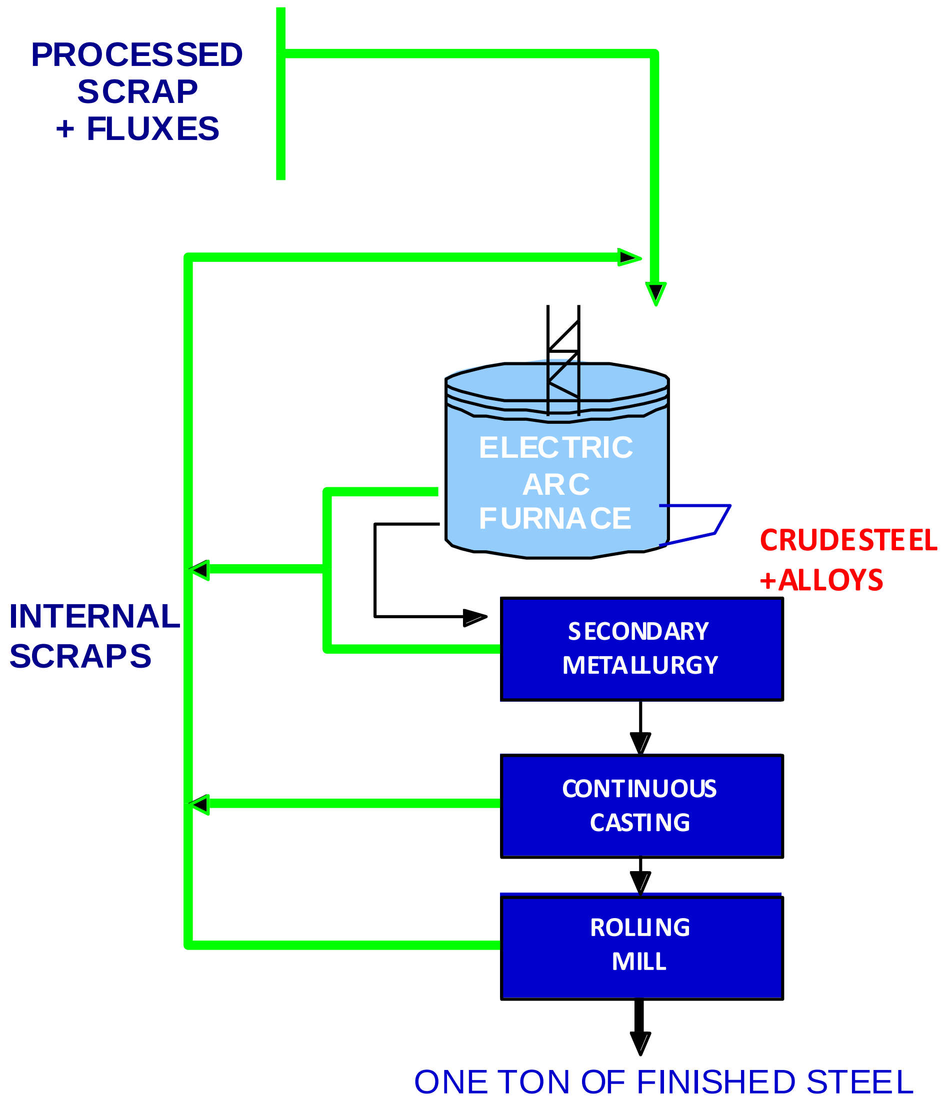

Figure 3-3 Schematic of recycling (EAF) process flow [10]

In figure 3.3 above it shows the process flow for the recycling process route. The steel scrap is fed into the electric arc furnace which is heated up till its melting point. Fluxes and other purifying agents are also added in other to remove impurities and further increase the quality of the semi-finished steel to be produced. The recycling process is easier and requires a very short step to produce the semi-finished steel. The figure also show how home scraps generated within the plant yard could also be fed into the electric arc furnace again.

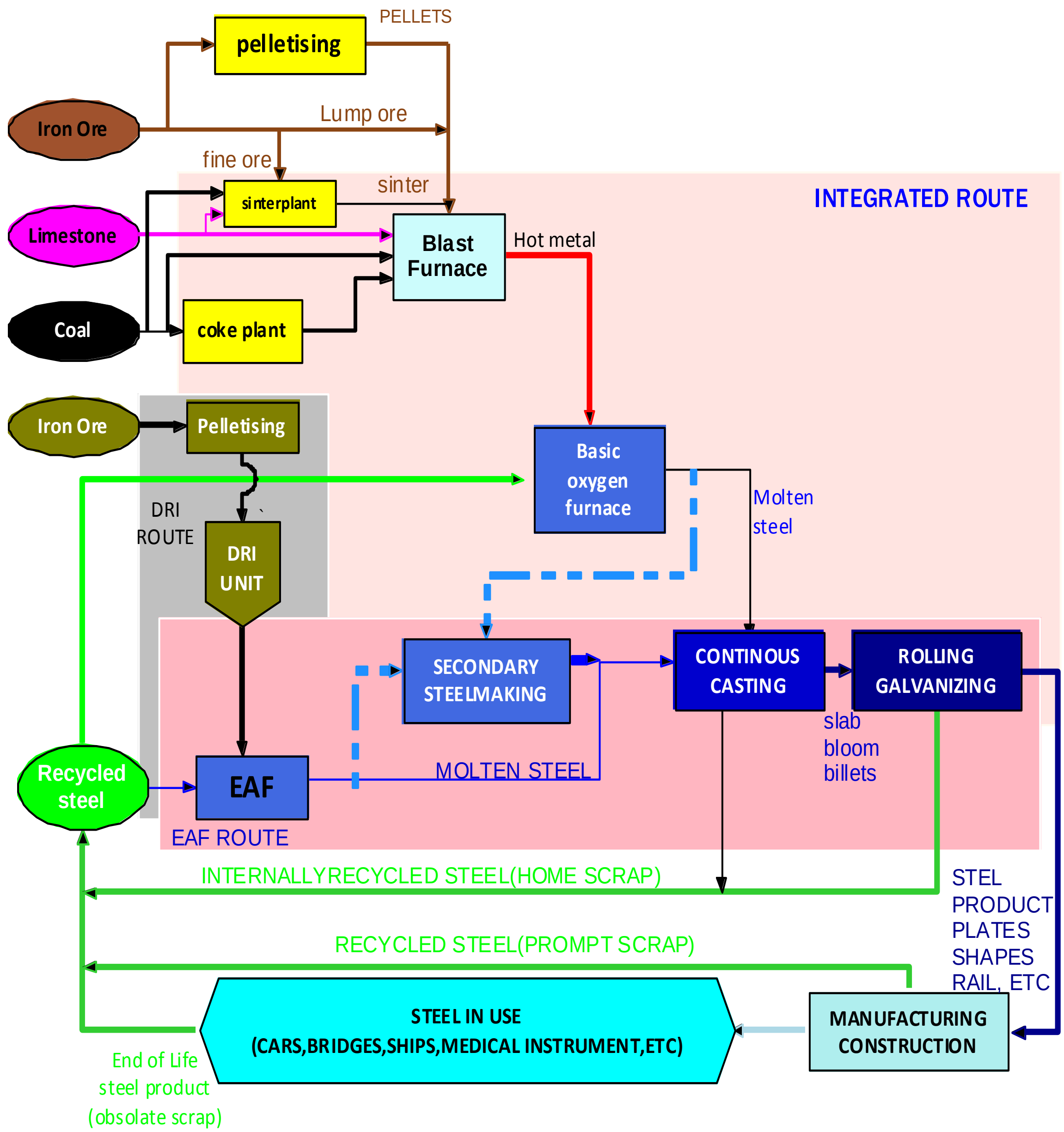

Figure 3-4 Steel making routes:Integratedroute,EAF(recycling) route and DRI+EAF route [13]

In figure 3.4 above it diagramtically details the three process routes of steel production. It also show the steps of flow of each of the routes. For the recycling route, the diagram details all the channels in which steel scrap could be generated and how they are fed back into the electric arc furnace for new steel production. This diagram is a modified version incorpurating the direct reduction route into the original source of the diagram.

3.5 Analysis of the result

From the computations in table 3.1 and 3.2 above, the energy consumption to produce one ton of semi-finished steel from the direct reduction process and the scrap recycling process has been calculated. The analysis of the result based on the calculation for steel production from recycling route and the direct reduction route are analyzed below under the following key indicators.

ENERGY CONSUMPTION AND SAVING: From the calculation , it showed that the energy consumed to produce one ton of semi-finished steel through the secondary route using steel scrap recycling (EAF) **is 0.6942MWH/T** while the energy consumed for producing one ton of semi-finished steel through the direct reduction process route (DRI+EAF) is **4.6839MWH/T**. This implies that a total of **3.9897MWH/T** (4.6839 minus 0.6942) of energy could be saved by producing semi-finished steel from the secondary route (steel scrap recycling).

COST: Also calculating this savings in monetary term, taking the cost of energy to be 5.45cents per KWH, It is calculated that the cost of energy for producing one ton of semi-finished steel from the direct reduction process (DRI+EAF) will be $255.27/T (4.6839*1000*5.45) while the cost for producing through the recycling route (EAF) will be $37.83/T (0.6942*1000*5.45).This also shows a savings of $217.44/T for each ton of semi-finished steel produced from the recycling route.

YIELD RATE: In terms of yield, the result of the calculation also proves further advantage of producing steel through the recycling process. In this analysis as shown in table 3.3 below, semi-finished steel produced from the recycling process has a yield rate of 88.17% as against the direct reduction process (DRI+ EAF) (table 3.2) that has a yield rate of 84.18%. Information from literature also indicates that steel produced from recycling can have a yield rate as high as 93.85% if a very high grade scrap is used in the production process (charlotte, NC, US, 2002). Table 3.3 show the summary of the difference in energy consumption and the yield rate for the two process route. The final energy consumption to produce one ton of semi-finished steel for each of the process routes is converted to GJ/T to further show the visibility of the result

Table 3-3 Table showing the analysis of energy consumption for steel production through scrap recycling(EAF) and production through direct reduction (DRI+EAF) and the savings achieved

PRODUCTION ROUTE	ENERGY INTENSITY (MWH)/T	ENERGY INTENSITY(GJ)/T	YIELD (%)	COST OF ENERGY(DOLLARS)
DRI+EAF	4.6839	16.86	84.18	$255.27/T
SCRAP(EAF)	0.6942	2.50	88.17	$37.83/T
SAVINGS	3.9897	14.33	3.99	$217.44/T

NB: 1GJ=0.2778MWH and 1MWH=1000KWH
Assume cost of energy to be 5.45cent/KWH

CARBON DIOXIDE EMISSION: Carbon dioxide emission was also reduced, that is the lesser the energy consumed the lesser the carbon dioxide discharged to the atmosphere and lesser the green house houses. More so, energy is the single largest source of carbon dioxide emission in the iron and steel sector which contributes to global environmental problems. Therefore, reducing energy intensity is not only beneficial to saving scares resources and input cost, but also in reducing carbon emission and thus integrating global climate change. Above all, the entire process of producing steel through the recycling route showed cost advantage and definitely make the final product competitive.

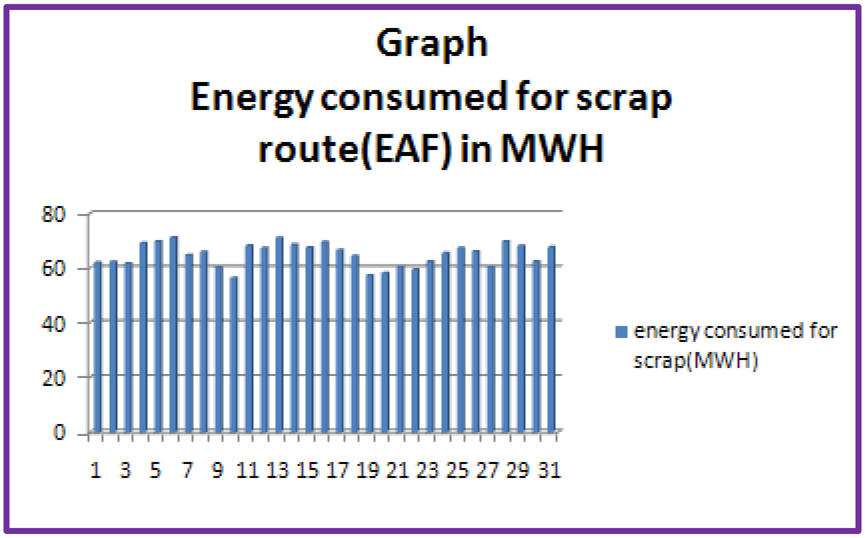

Figure 3-5 Graph showing the daily energy consumption for steel production through scrap recycling(EAF) route

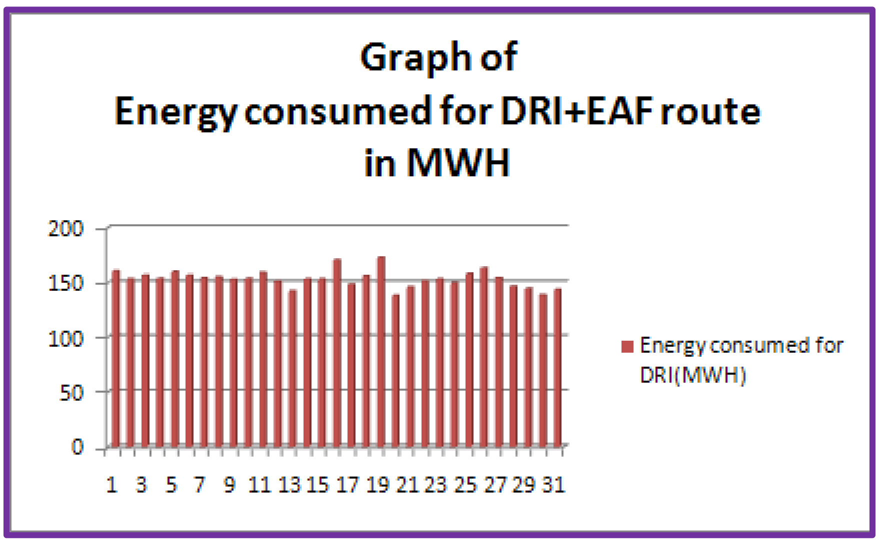

Figure 3-6 Graph showing the daily energy consumption for steel production from iron ore through DRI+EAF process route

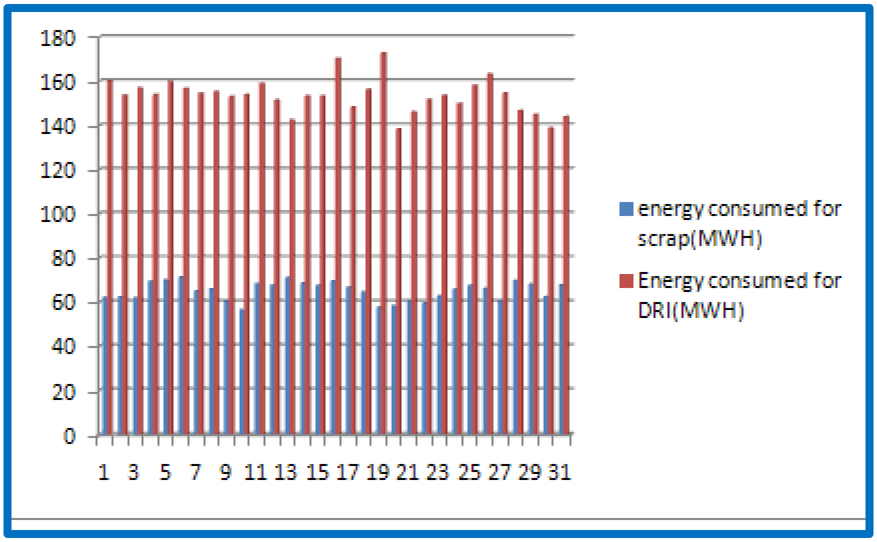

Figure 3-7 Graph for comparing the energy consumed for daily steel production through the DRI+EAF route and recycling (EAFonly) routes

Also comparing the results of the analysis above with the world best practices (table 3.4) for steel production, the energy consumed by my own analysis for recycling process route was lesser (2.5GJ/T) while that of the world best practice was 2.6GJ/T. Though in the world best practice data, the energy for producing thin slab casting was included and from literature it takes between 0.6 to 0.9GJ/T for each thin slab casted [15]. Analyzing the world best practice data, producing steel from scrap has a savings of 14.3GJ/T (16.9 minus 2.6) when compared with the direct reduction plus electric arc furnace process (DRI+EAF).Also an energy savings of 12.2GJ/T (14.8 minus 2.6) will be achieved when compared to producing steel from the blast furnace/basic oxygen furnace route and the recycling route.

Figure 3.5 and 3.6 shows the graph for daily energy consumption of the recycling route and the direct reduction route respectively. While the comparison of the two graphs when plotted together is shown in figure 3.7.

Table 3-4 Table showing the data for world best practice final energy intensity for steel production through the three process route inclusive of energy consumed per ton of thin slab casting [18]

S/NO	Technology process	unit	Energy intensity(GJ/t)
1	BF>BOF>Thin slab casting	steel	14.8
2	DRI>EAF>Thin slab casting	steel	16.9
3	Scrap>EAF>Thin slab casting	steel	2.6

Outbound Logistics: At this stage of the value generation, the steel product is casted into semi finished product such as bloom, thin slab, etc. some of the semi finished products might be taken to the rolling mill where they are rolled into rods, wires and other product based on customer's order and/or specification. These products are finally, taken to the warehouse for sorting and packaging according to customer order and final distribution. This is a continuous process because customers make there orders in advance. It is only on rare cases that semi-finished steel manufacturing companies take delivery to their customers because the customers come to the company to carry their ordered semi finished products.

Marketing and sales: The customers to semi-finished steel manufacturing companies are more of manufacturing companies also who uses these semi-finished steel products to manufacture the final product. The marketing activity is more of business-to-business (B2B). With the good image name of a company and better quality of their products, this will make any company to retain good number of their customers. This is achieved through effective customer relationship management and always making sure that the customer's orders and the required specification are met at any point in time.

Service: Companies should try as much as possible to attend to the need of their teeming customer chain. They should not stop at selling their semi- finished steel product to their customers but also try as much as possible to find out from their customers about the performance of their product at the manufacturing shops floor. They should take the customers complains and make sure that they are attended to as quickly as possible without any delay.

Support activities: In every organization, the primary and support activities work hand in hand to ensure effective performance of the company .This is really the case for effective growth of any company. The procurement team tries as much as possible to make sure that the raw materials are purchased from the best supplier at the best competitive price and the best quality. The technology applied should also be modern. This will help the company in being very efficient in their operation. The workers should also be well trained and the human resources department makes sure that the best workers are employed at any point in time. There should also be a constant training of staff to ensure their development which will finally transcend to better performance. Finally with better infrastructure on ground all these put together will make any company to be the best steel company.

Chapter four

BENEFITS OF RECYCLING

Steel scrap has become the steel industry's single largest source of raw material because it is economically advantageous to recycle old steel into new steel. In light of this, steelmaking furnaces have been designed to consume steel scrap. Apart from the huge amount of energy that could be saved through steel recycling, a lot of other benefits are also derived. On this note, the benefits of producing steel through recycling as compared to producing from Iron ore (direct reduction route and blast furnace/ basic oxygen furnace route) are itemized below.

4.1 Conservation of Resources

Steel scrap recycling has been identified as an effective means of conserving natural resources. It is more than economically beneficial for steelmakers and also a part of wise management of iron ore resources. It reduces the consumption of valuable minerals like iron ore, coal, limestone and water. For every metric ton of recycled steel scrap, 1.5tons of iron ore, 0.5ton of coal, 0.054ton (120 pound) of limestone and 40%of water normally used in the production from virgin material is conserved [4]. Through this recycling process, not only the resources that are conserved, the natural habitat is also protected for the future.

4.2 Energy saving

Using steel scrap in the manufacturing of new steel uses considerably lesser energy than that required for producing new steel from virgin raw materials (iron ore, coal, limestone). Not only that, there is also extra energy savings because more energy is required to extract, refine, transport and process raw materials ready for industry use compared with providing steel scrap which are ready materials to be charged into the Electric Arc Furnace for easy and faster steel production. Producing one ton of steel from recycling steel scrap saves a total of 14.3 GJ of energy as show in my analysis (table 3.3). This amount of energy saving from my analysis is affirmed from data in world best practices energy consumption data in table 3.4 above

4.3 Environment protection (Air pollution and water pollution)

Manufacturing steel from virgin ore involves the emission of greenhouse gases, which contribute to global warming. Using recycled steel srcap generates 85 percent fewer emissions [21]

Recycling reduces the need for extracting (mining, quarrying and logging), refining and processing raw materials all of which create substantial air and water pollution.

As recycling saves energy it also reduces greenhouse gas emissions, which helps to tackle climate change. Currently, UK recycling is estimated to save more than 18 million tons of carbon dioxide a year – the equivalent to taking 5 million cars off the road (steel recycling institute)

4.4 Reduced landfill

Recycling steel scrap helps in saving landfill space by diverting steel scrap from the waste stream. When we recycle, steel scrap materials are reprocessed into new products, and as a result of this, the amounts of scraps sent to landfill sites are substantially reduced. Figure 4.1 below shows a picture of scraps that are reclaimed from landfill.

Figure 4-1 Reclaimed steel scrap from landfill(source: Institute of scrap recycling industries)

4.5 Making Money

Recycling metal provides many benefits for everyone, such as a cleaner environment and fewer greenhouse gas emissions. But a huge sum of money can also made by selling scrap metal to scrap-metal recycling company. In this case steel materials which are generated from homes or cars that are discarded can be sold by the owner to scrap collecting centres or even agent that move from house to house to buy steel scrap(obsolete scrap) from the owners. Through this the owners can generate some revenue from their steel properties that are no longer useful to them.

4.6 Production Plant can be sited close to the market

Unlike the primary steel production route, the mini mills can be sited in a location that is closer to the market. This is because the location of the plant is not tied to the source of the raw material. In the steel recycling process route there is much flexibility because the raw materials (steel scrap) can be sourced from any where and transported to the plant location. While in the case of integrated process route (BF/BOF) and the Direct Reduction Route the plant need to be sited to a place that is close to the source of the raw material. This is done to reduce the cost of transporting the huge raw materials (iron ore, coke etc) to the production site.

4.7 Endless Recycling Potential

Steel scraps are 100% recyclable and it does not degrade during the recycling process like other recyclable materials such as paper. As such it can be recycled over and over again without losing its quality. Steel recycling therefore represents one of the most effective and valuable strategies for saving resources. Table 4.1 below summarises other saving obtain from producing new steel from recycling of steel scrap.

Table 4-1 Summary of the benefits of using iron and steel scrap instead of virgin ore to make new steel

Savings sources	Percentage savings
Energy	74%
Raw material(iron ore)	90%
Reduction in water use	40%
Water pollution reduction	75%
Air pollution reduction	86%
Reduction in mining waste	97%
Reduction in consumer waste	105%

Source: Institute of Scrap Recycling Industries

4.8 Comparison of LCI of steel produced from virgin ore and recycling

The life cycle assessment (LCA) is a holistic approach to evaluate the environmental performance of a product by considering the potential impacts of that product from all stages of manufacturing, product use and end-of-life stages, some times called cradle-to-gate approach. It comprises of goal and scope definition, life cycle inventory, life cycle impact assessment and finally interpretation of the result.

Though Life Cycle Inventory is outside the boundaries of this work, but I consider it important to be highlighted as a way of further buttressing the energy savings for steel production from steel scrap.

Steel is one of the most recyclable materials in the world and therefore it is important to consider recycling in life cycle assessment studies involving steel, more especially steel scraps that are recycled from a product at the end of its useful life (EOL). In addition, steel scrap is a vital input to the steel making process, and this input of steel scrap should also be considered in investigating the Life Cycle Inventory of steel. Figure 4.2 illustrates the cyclic flow of steel starting from the extraction to processing, manufacturing, uses and its end of life recycling.

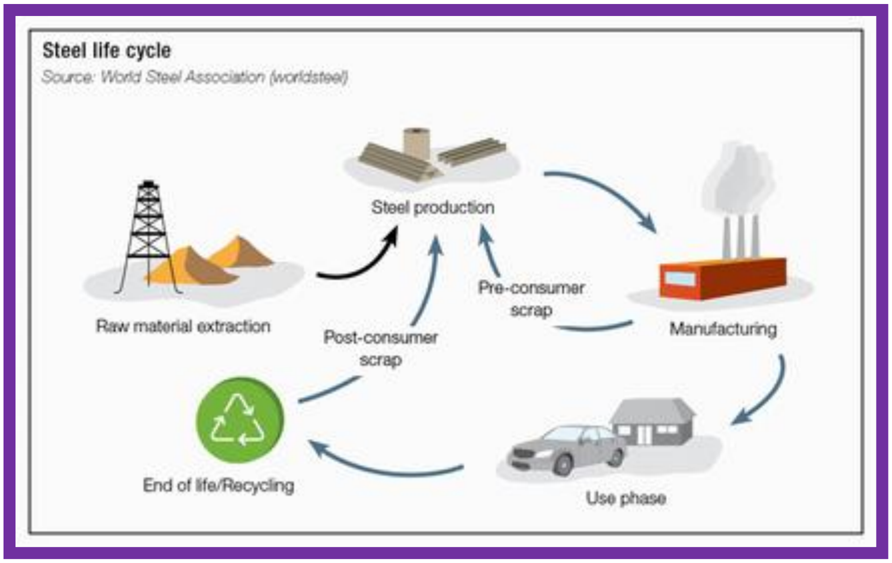

Figure 4-2 Steel life cycle (source: world steel association)

4.8.1 Data collection for the Life Cycle Inventory and its Analysis

The data collection and analysis of this Life Cycle Inventory shown in the tables below was carried out by worldsteel association and has undergone critical review from an independent Critical Review Panel (CRP) of LCA specialists. These data that was used for this Life cycle inventory analysis was collected by world steel association from different steel producing companies all over the world. These companies contributing data for the LCI study of world steel association account for 39.7% of global crude steel production outside that of the former USSR and China. Companies in Europe, and Far East Asia were well represented and a typical range of operating configurations included, North America is included in the global averages (world steel association). As such the result of the analysis given below was based on the world steel association data and not mine. The reference year for this data is 2000 to 2007. These data are for cradle-to-gate. That is, it covers all of the production steps from raw materials in the earth (i.e. the cradle) to finished products ready to be shipped from the steelworks (i.e. the gate). It also includes the credits associated with recycling the steel from the product at the end of their useful life. It does not include the manufacture of downstream products or their use. The result of this analysis was personally requested by me for the completeness of this work and the life cycle analysis was conducted and released by world steel association on February 2010

The general life cycle equation used by the world steel association for the "closed material loop recycling methodology" is applied as shown by the equation shown below:

LCI for 1 kg of steel product including recycling = X – (RR – S) × Y(Xpr – Xre)

where:

X is the cradle to gate LCI of the product

(RR – S) is the net amount of scrap

RR is the end of life recycling rate of the steel product

S is the scrap input to the steelmaking process

Y(Xpr - Xre) is the value of scrap

Y is the process yield of the EAF (i.e. >1kg scrap is required to produce 1kg steel)

Xpr = the LCI for 100% primary metal production. This is a theoretical value of steel slab made in the BF/BOF route, assuming 0% scrap input.

Xre = the LCI for 100% secondary metal production from scrap in the EAF (assuming scrap = 100%)

This LCI data below were calculated for products derived through the blast furnace/basic oxygen furnace route (based on iron ore and steel scrap), known as the primary route and the electric arc furnace route (based on 100% steel scrap), which is the secondary route. Sixteen products were included in the studies which are the main finished products of the steel industry. They include hot rolled coil (with and without pickling), cold rolled coil (with and without finishing), hot dip and electrically galvanized sheet, painted sheet, tinplate and tin-free sheet, welded and UO pipe, sections, plate, rebar and wire rod. The products are of general relevance to a wide range of downstream applications including those in the construction, automotive and packaging sectors. The inputs are expressed in kilogram while the outputs are expressed in gram.

4.8.1.1 LCI data analysis: cradle to gate for steel production from virgin ore(primary route)

Table 4.2, 4.3 and 4.4 shows the input elements in kilogram and their corresponding emissions to the environment, air and fresh water respectively in grams. While table 4.5 shows the summary of its environmental indicator of the LCI in terms of global warming potential and energy demand from renewable and non-renewable resources for steel produced from virgin ore.

Table 4-2 Input mass(kg) and its emission(gram) for steel LCI produced through virgin ore(source:world steel association LCI report, 2008)

Inputs (mass, kg)	Cradle to gate
Crude oil (resource)	0.0008594971
Hard coal (resource)	0.7822917
Lignite (resource)	-0.003791867
Natural gas (resource)	0.01228506
Uranium (resource)	2.366164E-007
Iron ore	1.349514
Dolomite	0.03662349
Limestone (calcium carbonate)	-0.01008424
Tin ore	1.512103E-016
Water	14.62153
Carbon dioxide	0.01465696
Ferrous scrap	0.1214011

Table 4-3 Emission of steel produced from virgin ore to air(mass in grams)(source:world steel association LCI report, 2008)

Inputs (mass, kg)	Cradle to gate
Cadmium (+II)	6.278E-005
Carbon dioxide	1889
Carbon monoxide	22.73
Chromium (total)	0.000179
Dioxins (unspec.)	1.802E-009
Hydrogen chloride	0.03695
Hydrogen sulphide	0.2828
Lead (+II)	0.002751
Mercury (+II)	7.109E-005
Methane	5.284
Nitrogen dioxide	0.01641
Nitrogen oxides	2.429
Nitrous oxide (laughing gas)	0.006713

NMVOC (unspecified)	0.2507
Particles to air	1.517
Sulphur dioxide	2.689

Table 4-4 Emission of steel produced from virgin ore to fresh water (mass in grams)

	Cradle to gate
Ammonia (NH4+, NH3, as N)	0.003486
Biological oxygen demand (BOD)	0.002891
Cadmium (+II)	3.045E-005
Chemical oxygen demand (COD)	0.1211
Chromium (total)	5.084E-005
Iron	0.003285
Lead (+II)	1.096E-005
Nickel (+II)	0.0001066
Nitrogenous Matter (unspecified, as N)	0.1935
Phosphate	6.037E-005
Phosphorus	0.0004734
Solids (dissolved)	0.01005
Zinc (+II)	

Table 4-5 Environmental indicators of LCI of steel produced from virgin ore(cradle-to-gate)

	Cradle to gate
Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	2.009421
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	21.63931

4.8.1.2 LCI data analysis for 1kg Steel Scrap (recycling) is given below

Life Cycle Inventory for one kilogram of steel scrap analyzed shows the emission (of steel produced from scrap through recycling) to the environment, air and fresh water shown in tables 4.6, 4.7 and 4.8 respectively. Then table 4.9 showed the summary of its overall environmental indicators in terms of global warming potential and energy demand from renewable and non-renewable resources.

Table 4-6 Inputs mass in kiligram and its emission in gram for Life cycle inventory of steel produced from scrap

	Scrap LCI
Crude oil (resource)	-0.01763265
Hard coal (resource)	0.740115
Lignite (resource)	-0.0494894
Natural gas (resource)	-0.05367357
Uranium (resource)	-3.057218E-006
Iron ore	1.415598
Dolomite	0.03607125
Limestone (calcium carbonate)	-0.05547075
Tin ore	-8.815403E-017
Water	13.06657

Table 4-7 Emission to air for steel produced from recycling(steel scrap)

	Scrap LCI
Cadmium (+II)	5.044E-005
Carbon dioxide	1409
Carbon monoxide	22.62
Chromium (total)	-0.0001464
Dioxins (unspec.)	-1.064E-008
Hydrogen chloride	0.03143
Hydrogen sulphide	0.3725
Lead (+II)	0.001814
Mercury (+II)	-9.828E-006
Methane	4.291
Nitrogen dioxide	0.01432

Nitrogen oxides	1.354
Nitrous oxide (laughing gas)	0.005271
NMVOC (unspecified)	0.1594
Particles to air	1.397
Sulphur dioxide	1.789

Table 4-8 LCI result showing Emission to fresh water(in grams) for steel produced from steel scrap recycling

	Scrap LCI
Ammonia (NH4+, NH3, as N)	0.002327
Biological oxygen demand (BOD)	0.01092
Cadmium (+II)	1.916E-005
Chemical oxygen demand (COD)	-0.007725
Chromium (total)	-3.48E-005
Iron	-0.07544
Lead (+II)	-0.0001005
Nickel (+II)	6.097E-005
Nitrogenous Matter (unspecified, as N)	0.122
Phosphate	-0.0001758
Phosphorus	-0.0005332
Solids (dissolved)	0.006315
Zinc (+II)	-0.0008956

Table 4-9 Overal LCI result showing the environmental indicators of steel produced from steel scrap recycling

	Scrap LCI
Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	1.51211
Primary energy demand from renewable. And non renewable. resources (net cal. value) [MJ]	13.40748

Comparing the result of the Life Cycle Inventories of steel produced from virgin ore and steel produced from scrap recycling, the analysis shows that producing steel from the virgin ore has a global warming potential(GWP 100 year) in kgco$_2$-equivalent of 2.009421 and primary energy demand of 21.63931MJ as shown in table4.8 above. While producing steel from scrap has a global warming potentials (GWP 100years) in kgco$_2$-equivalent of 1.51211 and primary energy demand of 13.40748MJ as shown in table 4.9 above. This implies that for each kilogram of steel produced from scrap it has energy savings of 8.23183MJ/KG (see table 4.10) compared to producing from virgin ore.

Also , comparing the ratio of energy consumed for steel production from the primary and secondary(recycling) route with the corresponding Life Cycle Inventory energy demand of the two processes. There ratio calculation is shown in (1) and (2) below.

1. Blast furnace/basic oxygen furnace or Direct reduction energy ratio= energy comsumed for one ton of semi-finished steel produced divided by the LCI energy demand per kilogram of steel which is 0.77:1(16.81/21.63). This implies that the ratio of the energy consumed for producing one ton of steel from virgin ore

to its energy demand from renewable and non-renewable resources is 0.77: is to 1

2. Scrap recycling energy consumption ratio=energy consumed for on ton of steel produced divided by LCI energy demand per kilogram of steel which is 0.19:1(ie 2.48/13.40). This implies that the ratio of energy consumed for producing on ton of steel from srcap to its energy demand from renewable and non-renewable resources is 0.19 is to 1.

Table 4.10 show the final comparison of the energy demand of steel produced directly from iron ore and steel produced from recycling of steel scrap and the coresponding savings that could be achieved when steel is produced from steel scrap recycling.

Table 4-10 Table showing the comparison of the overal environmental indicators for LCI'S of steel produced from virgin ore and the one produced from steel scrap recycling

Production Route+LCI	Global Warming Potential (GWP100Years){kgco$_2$-Equiv}	Primary Energy Demand (MJ)
Iron Ore(credle-to-gate LCI)	2.009421	21.63931
Steel Scrap(Recycling LCI)	1.51211	13.40748
Savings	0.497311	8.23183

Chapter five

SOURCING OF THE STEEL SCRAP

Steel scrap has been traditionally obtained from three sources. ”home scrap” derived within the steel production plants. Prompt scrap derived from the manufacture of steel products and obsolete scrap that is steel scrap that has come to the end of their useful life. The reuse of steel scrap has always been an integrated part of the steelmaking process. For instance, for the past 50years, more than 50% of the steel produced in the United States has been recycled into a multitude of new steel products [16]. These new steel products will eventually be re-melted again in mini mills to make new steel.

The steel scrap cycle consists of scrap collection and sorting, distribution and trade, treatment and processing as shown in the figure 5.1 below.

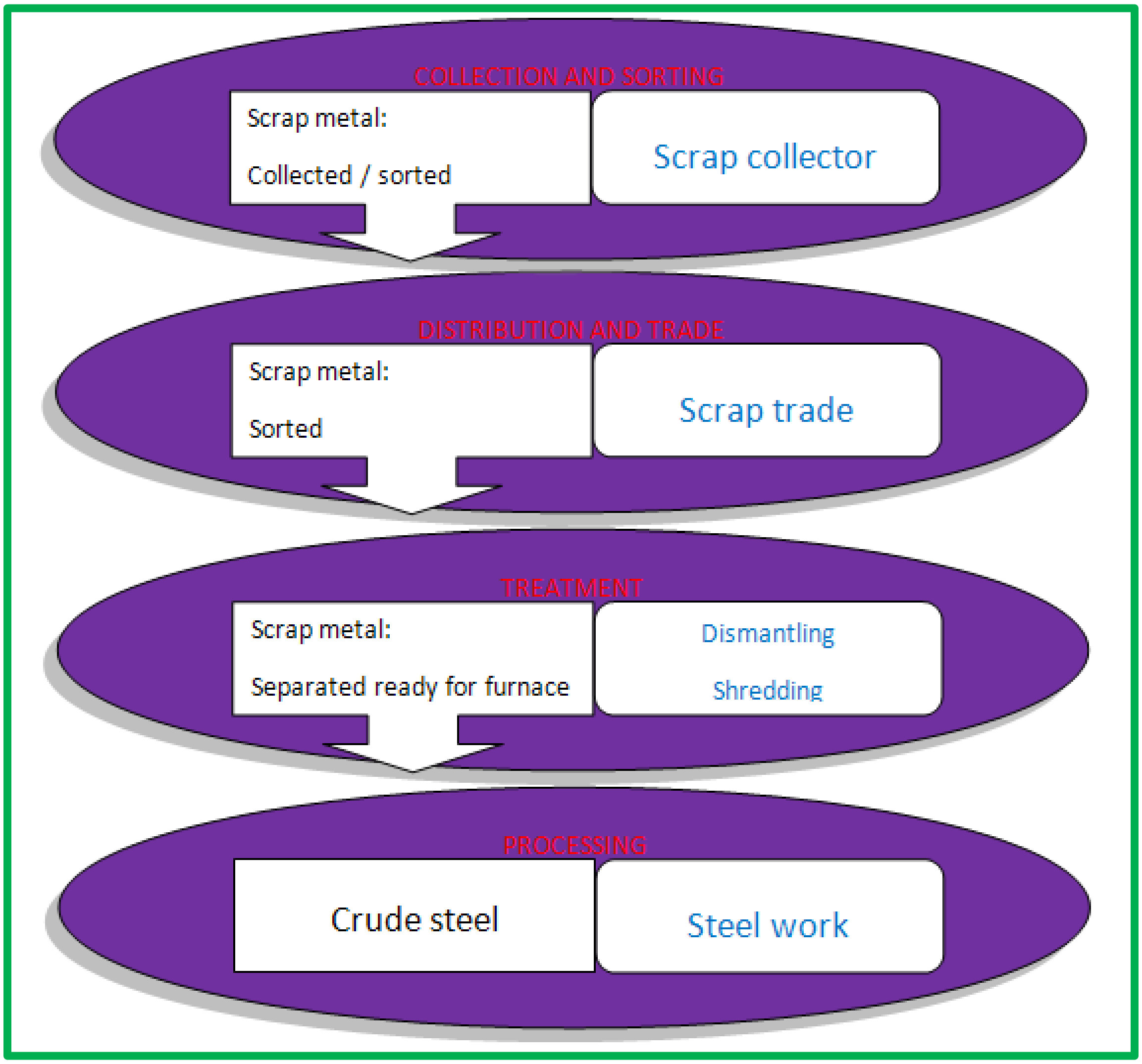

Figure 5-1 The steel scrap cycle(collection, distribution, ttreatment and processing) [16]

Along this recycling chain, steel scrap is cleaned to become the secondary material for final steel product production.

The two types of process route used in today's steel mills require more steel scrap than ever as a result of the enormous amount of energy savings and lower carbon dioxide emission. The basic oxygen furnace (BOF) blends molten iron with approximately 25% steel scrap and the electric arc furnace (EAF) uses 100% scrap (world steel report 2004). With these efficiencies in steelmaking through recycling, it has created the need for more external sourcing of steel scrap. As the methods below are ways in which steel scrap can be sourced. These methods are almost the same with the waste management collection approach.

The following methods of sourcing of steel scrap represent the means in which the input feedstock to mini mill is to be supplied in other to sustain the steel production through the recycling route.

5.1 The curb-side collection program

This is a service provided to households in the urban and suburban areas aiming at removing

Figure 5-2 A recycling truck collecting the contents of a recycling bin(source:ACTT_recycling_Truck.jpg)

The household waste materials (in this case steel scraps). This is accomplished by personnel (usually government or contracted agents) using purpose built vehicles to pick up household waste (in this case steel scraps). Through this means, iron and steel scraps will be collected which are finally sold to the steel producing companies (usually mini mills) who are the final consumers.

Steel scrap collected through this means requires further sorting and cleaning. Scraps collected through this means are more of steel cans and some other household appliances. When these scraps are purchased by the steel producing companies, they are further process and are finally used to produce new steel products. These scraps will be specifically for steel production through the electric arc furnace route which consumes 100% scraps. Steel scraps that are collected through the curb-side program normally falls into the category of obsolete scraps.

5.2 Drop- off collection program

In this case, the waste producer (steel scrap) carries the scrap to the central collection location. This is normally an installed or mobile collection station or even processing plant. In this situation the producer of the waste most have sorted the steel scrap and then drops it off at the appropriate bin at the collection centre. Because of the increasing demand for the steel scrap, this drop-off method is now done with an exchange of cash for the steel scrap. In this situation, the scrap is weighed and valued and the producer being paid the money equivalent of the scrap. This method is the easiest way of collection but it suffers from low and unpredictable throughput. The only motivating factor here is the cash equivalent the producer gets.

5.3 Buy-back centre

In this case, steel scraps which are clean steel scrap are purchased from the owners. The steel scrap is weighed and graded before payment is made to the owner. This will provide a clear incentive for use and also create a stable supply. The post–processed scrap can be sold to the steel manufacturing companies.

With the increasing shipment of fairly used cars, fridges and other metal bodies, this method will increase the supply of abandoned steel materials to the buy-back centres.

5.4 Use of agents

This is the process of using personnel who will go from house to house or companies and fabrication shops to source for steel scraps. Other sources are machineries, construction and demolished buildings. Here mini mills use their own agents who are paid on commission bases. They will be provided with vehicles which will enable the agents to travel into the rural areas to source for the scraps from the owners. This method provides a very high supply because the agents will be so dedicated to their job knowing that the more scrap they are able to purchase the more money they get.

5.5 Scrap importation

Scrap importation still remains another avenue to source for scrap. With the low level of development of steel industry in most West Africa states, it will give Nigeria the opportunity to source and buy steel scrap from neighbouring countries at a reduced price and transport it to

Nigeria. The fifteen members of Economic Community of West African States (ECOWAS) enjoy free trade relationship among its members. As such this will lead to zero tariff for the movement of the locally sourced scraps from these countries to Nigeria. With the quantity of scrap expected to be sourced locally and those to be sourced and supplied from the West African counties, it will be more then enough as the input raw materials for the mini mills which will definitely boost Nigeria's steel production locally.

Chapter six

CONCLUSION

This research work focused on investigating the energy saving from producing steel through recycling of steel scrap as a way of enhancing efficiency in process industry. Nigeria steel industry was sited as a focal point in this study .The steel industry in Nigeria has suffered a huge set back as a result of unavailability of quality Iron ore and coke-able coal which are the major raw material for steel production through the primary or direct reduction process. Through the findings of this work, recycling of steel scrap is suggested as an alternative to boost the local content of steel production, reduce energy consumption, carbon dioxide emission (as the world production and manufacturing system is going green) and also reduce the overdependence of the country on imported semi-finished steel product. It has become an established fact that energy efficiency has been an issue of concern in the world at large. This has become imperative because of the high cost of energy, scarcity of resources and carbon dioxide emission to the environment as a result of its combustion and above all making goods produced to be competitive.

In this study, three questions were answered.

1. The amount of energy that could be saved from producing steel from steel scrap (recycling) rather than producing from Iron ore(virgin material)
2. The benefits of producing steel from scrap

3. How the recycling process could be sustained in Nigeria contest in terms of steady supply of the input steel scrap.

The two process routes for steel production were investigated. The secondary process route (recycling) and the direct reduction (Direct Reduced Iron) process and data from literature was used to take care of primary production route (the integrated process). The data for this research work was collected from a steel company in Nigeria which started operation about six months ago. The data for energy consumed for producing steel from the secondary process and the direct reduction process were collected for a period of one month when the company ran full production through this two process route. A weighted average of the energy consumed was calculated for the direct reduction process and the recycling process route to know the amount of energy required to produce one ton of steel. The result of the computation showed that the direct reduction route consumes at total of 16.81GJ/T while the recycling route consumes a total of 2.5GJ/T of crude steel produced. This shows an energy saving of 14.30GJ/T of steel produced through the recycling route.

Apart from the energy saving potential, producing steel through the secondary route has other benefits such as conservation of natural resources. Recycling reduces the consumption of valuable minerals (iron ore, coal, limestone, water etc). The natural habitation is also protected if steel is produced through recycling of steel scrap.

The environment is protected if steel is produced from scrap as such the need for extraction, refining and processing of raw materials which create substantial air and water pollution will be minimized. Consumption of iron and steel scrap reduces the burden of landfill disposal and prevents the accumulation of abandoned steel products in the environment. Also a substantial amount of money could be made by owners of steel scrap who sale them to the scrap sourcing agents or through the buy-back collection program.

The endless recycling potential of steel gives it an added advantage as steel scrap can be recycled over and over again without losing the quality or the properties of the steel. The low capital investment in terms of starting-up of mini-mills compared to the integrated route (blast furnace and basic oxygen furnace) is further advantage of recycling. Location of the plant is also another advantage as the mini-mill (EAF) can be sited any where and closer to the market while the integrated route is location sensitive as the plant has to sited to a place near to the sources of the raw materials(Iron ore).

A further investigation on the life cycle inventory of steel produced from scrap and steel produced from Ore showered that for one kilogram of steel produced from ore has a global warming potential of 2.0098kgco_2-equivalent and also has a primary energy demand both from renewable and non- renewable sources of 21.639MJ while steel produced from steel scrap has a global warming potentials of 1.5kgco_2-equivalent and 13.407MJ primary energy demand.

Finally, in other to provide a steady supply of steel scrap as feedstock to the secondary process route, steel scrap can be sourced/supplied through the use of company agents who go from house to house, manufacturing companies, fabrication shops etc to buy the steel scrap also the buy-back, drop-off and curb-side collection programs remains another promising sources in which scrap could be sourced and supplied to the mini-mills. Also considering the free trade relationship that exist among the Economic Community of West African States (ECOWAS) steel scraps could be sourced from these countries and being transported to Nigeria to supplement the locally sourced once.

Future research

A similar study should be carried out with more elaborate and sufficient data from different companies in different context (in different countries for instance). More so, the cost benefit analysis of scrap recycling for all the stakeholders involved, not limited to steel companies alone but also the local communities, waste facilities and so on should further be investigated in other to justify the findings of this thesis work.

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Appendix

Appendix 1: Top steel producing countries

Serial number	Country name	Amount in million metric tons(MMT)
1	China	567.80
2	Japan	87.50
3	India	62.80
4	Russia	60.00
5	United States	58.2

Source: World steel in figures, 13, July, 2010

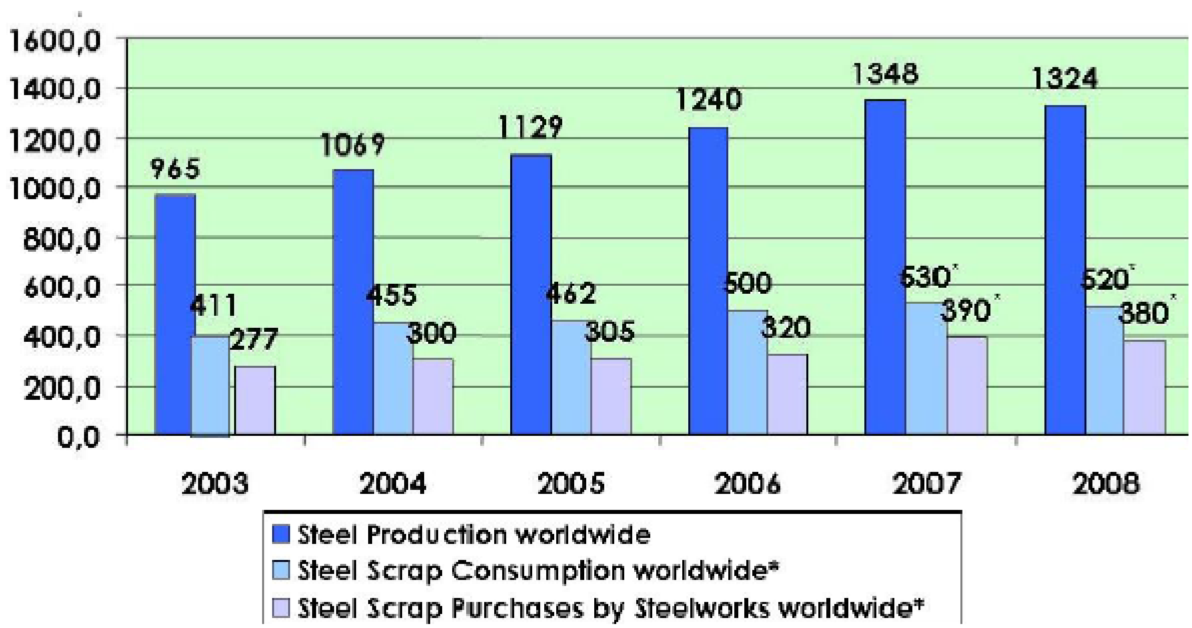
Appendix 2: By–products and waste comparison between integrated route (Blast furnace/Basic Oxygen Furnace) and mini mills (recycling route-EAF) [14]

By-products and waste	Integrated route(kg/ton)	By-product and waste	Mini mills(kg/ton)
Blast furnace slag	250	EAF slag	116
BF dust and sludge	25	EAF dust	18
BOF slag	135	Metallic waste	11
Metallic wastes	7	Refractory wastes	10
Refractory Waste	5.5	others	5
Total	423	Total	160

Appendix 3: Scrap Top Exporting/Importing Counties

EXPORT(In Million Tons)			IMPORT(In Million Ton)		
Country	2002	2003*	Country	2002	2003*
USA	9.00	10.80	Turkey	9.90	11.80
Germany	7.50	6.70	China	7.90	9.20
Japan	6.00	5.70	South Korea	7.20	6.00
France	5.80	5.10	Spain	5.50	6.30
Russia	5.80	6.00	Italy	4.00	4.00
UK	5.60	7.20	Germany	4.00	4.40

2003* data includes estimates Source: Iron and Steel Statistics bureau



Appendix 4: Worldwide steel production, steel scrap consumption and purchase (million tons) [9]