DEVELOPMENT OF IRON AND STEEL PROCESSING PLANT IN KENYA

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DECLARATION

This thesis is my original work and has not been presented in any university/institution for a degree or for consideration of any certification.

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APPROVAL

We confirm that the work reported in this thesis was carried out by the candidate under our supervision as University supervisors.

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DEDICATION

This work is dedicated to my dear wife Lilian, daughters Mya and Susan and my parents, Titus and Susan.

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First, I thank the Almighty God for giving me the determination, patience and courage to pursue this course. Secondly, I greatly appreciate and thank my family for the patience, humility, understanding and mutual support they gave me. I am also immensely indebted to my supervisors Prof Muchiri P.N and Dr Bosco Byiringiro for the unyielding support and guidance they gave me during the development of this research. My special thanks also go to the NMC group particularly Eng. Michael Thubi for his immeasurable support and contribution to this research work. Lastly, I appreciate my colleagues for the pieces of advice they gave me no matter how small.

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LIST OF ABBREVIATIONS AND ACRONYMS

AGOA	Africa Growth Opportunities Act
OCS	Organic Coated Steel
ASU	Apparent Steel Use
BF	Blast Furnace
BOF	Basic Oxygen Furnace
BOS	Basic Oxygen Steelmaking
CAPEX	Capital Expenditure
Co.	Company
COMESA	Common Market for Eastern Southern Africa
CRC	Cold Rolled Coil
CSP	Compact Strip Production
DRI	Direct Reduced Iron
DSCR	Debt Service Cover Ratio
EAC	East Africa Communities
EAF	Electric Arc Furnace
EBITDA	Earnings Before Interest Tax Depreciation & Amortization
ERS	Economic Recovery Strategy
FOB	Free On Board
GDP	Gross Domestic Product
HBI	Hot Briquetted Iron
HMS	High Melt Scrap
HRC	Hot Rolled Coil
H/S	Heavy Section
H/TUBE	Heavy Tube

IRR	Internal Rate of Return
IS	Importation Strategy
LAPSSET	Lamu Port- Southern Sudan Ethiopia Transport
LRF	Ladle Refining Furnace
L/S	Light Section
L/TUBE	Light Tube
MRM	Mabati Rolling Mills
MVA	Manufacturing Value Addition
P.a	Per Annum
R & D	Research and Development
Rebar	Reinforcing Bar

NOMENCLATURE

Gj	GigaJoule
Km	Kilometres
Kshs	Kenyan shillings
Kwh	Kilowatt Hour
Mj	Mega Joule
Mw	Mega Watts
Mt	Metric tonne
Nm^3	Normal Cubic metres
Sq	Square
$	US dollar

GLOSSARY OF TERMS

Alloying Element	An element added to a metal to improve the properties of steel.
Basic Oxygen Furnace	Section in an integrated steel mill where molten iron is converted into steel.
Beneficiating	A process of increasing the iron content of low-grade ores.
Billets	Thick bars with a rectangular section.
Blast Furnace	A furnace that smelts iron ore and coke to produce pig iron.
Cold Rolled Coil	Hot rolled steel that has had further processing in cold reduction mills, where the material is cooled (at room temperature) followed by annealing and/or tempers rolling.
Compact Strip Production	A novel technology developed in the 1980s for casting-hot-rolling of thin slabs. It is a new technological innovation following converter steelmaking and continuous casting technology in the steel industry.
Corex	An industrially and commercially proven iron smelting-reduction process. Eliminates the use of a blast furnace, coking and sinter plants.
Direct Reduced Iron	Iron produced from the direct reduction of iron ore (in the form of lumps, pellets or fines) to iron by a reducing gas or elementary carbon produced from natural gas or coal.

Environmental Impact Assessment	An evaluation of possible effects that a proposed project may have on the environment, and to propose mitigation measures against the negative ones
Electric Arc Furnace	A furnace that heats charged material through an electric arc.
Furnace	An appliance in which heat is generated and transferred to a solid or liquid mass so as to affect physical/ chemical change.
Hot Briquetted Iron	A premium form of Direct Reduced Iron (DRI) that has been compacted at a temperature greater than 650° C
Hot Metal	Iron that has been obtained through reduction or smelting used as feedstock to an EAF for steel production.
Hot Rolled Coil	Steel rolled at a high temperature (typically at a temperature over 927^0 C), which is above steel's recrystallization temperature.
Input	What is fed into a transformation process.
Integrated Steel Mill	A steel plant that produces steel from iron ore.
Iron Ore	A rock and mineral from which metallic iron can be economically extracted.
Ladle Refining Furnace	A furnace used to raise the temperature and adjust the chemical composition of molten metal during steel making.

Martensite	A steel microstructure formed when steel heated to very high temperatures (to form a high-temperature phase called austenite) is rapidly cooled, for instance by placing the hot metal in water.
Metal forming	A metal working process whereby the desired shape is obtained through the application of stresses
Metallurgical Coal	Coal used in the production of coke which is used in heating up the blast furnace.
Midrex	A technology used in the production of Direct reduced iron. Can either be coal or gas-based reduction process.
Pearlite	A steel microstructure formed when steel heated to very high temperatures (to form a high-temperature phase called austenite) is slowly and homogeneously cooled.
Pig iron	A metallic product resulting from the reduction of iron ore when smelted in a blast furnace.
Rebar	A steel bar or mesh of steel wires used as a tension device in reinforced concrete and reinforced masonry structures to strengthen and hold the concrete in tension
Scrap	A discarded steel metal for reprocessing.
Slab	A semi-finished steel product obtained by rolling ingots on a rolling mill or processed through a continuous caster and cut into various lengths.
Steel	A grey or bluish-grey alloy of iron with carbon and usually other alloying elements. The combined carbon

	usually ranges between 0.15% to 1.5% above which cast iron is formed.
Thermal coal	This is coal best used for energy production. It has a high calorific value.
Turnkey project	It is a contract under which a firm agrees to fully design, construct and equip a manufacturing facility and turn the project over to the purchaser when it is ready for operation for a remuneration.

ABSTRACT

Steel plays a very key role in the transformation of an economy, as it is the key driver in any industrial revolution majorly being used in transport, building and construction, power generation and machinery. It is in this regard that the study of iron and steel in Kenya is important. This study sought to determine the viability of setting up an iron and steel processing plant in Kenya, develop a process design for such a plant and determine the plant's economic feasibility. This research employed an exploratory study design with its main objective being to develop a process design that could be used in setting up an iron and steel processing plant in Kenya. Data for this study was collected from published works, government agencies and other private bodies, most of which was primarily secondary. Forecasting of demand into the year 2030 was done to establish the probable future market and also the size of the plant. Forecasting was done using trend projection and moving averages time-series model methods. The compounding interest formula was also used for determining future Hot Rolled Coil (HRC) demand. Economic analysis of the proposed Kenyan steel plant was carried out to determine its profitability. The study established that the country has 20 steel mills serving a Kenyan market of 1.6 million tons/year. These steel mills have a combined installed capacity of 340,000 tons of liquid steel, a finished production capacity of 555,000 and 245,000 tons of light long and flat products respectively. However, there is seemingly no production of HRC, heavy sections and steel plate within the country which creates an investment opportunity. Demand for steel in the country was projected to rise from 1.6 million tons (2014) to 7.1 million tons by 2020 and 8.4 million tons by 2030. Of the 1.2 million net imports in 2014, 704,000 tons were HRCs signifying a massive near-term investment opportunity in this area. The study established that with the country investing in this near-term opportunity, it would have a market of about 1 million tons to serve by 2018, a value which was projected to rise to 2.5 million tons by 2020 and 3.6 million tons by 2030. The study also determined that an establishment of a steel mill within the country would best be approached in two phases; *(Phase I)* being to set up an Electric Arc Furnace (EAF) steel plant producing 1 million tons of HRC and the second phase (*Phase II*) would work to supplement the scrap in Phase I through provision of more iron units to the EAF in the form of Hot Briquetted Iron, Direct Reduced Iron or Hot metal as the demand for HRC increases to values beyond 2 million tons by years 2020 and beyond. However, the choice of technology to use for the *Phase II* facility would largely be dictated by the type of iron and coal found present in the country. However, guided by a developed choice matrix, this study proposes the use of Corex Technology as it has the capacity to utilize the locally available resources and has a wide reference having been used in South Africa. The study therefore proposes that the process design for a steel manufacturing plant in Kenya should be approached as follows; A *phase I EAF facility* with an output capacity of 1 million tons per year, a *phase II facility* to supplement the Phase I facility when demand above 2 million tons per year and a *phase III* facility for downstream operations at a later stage.

CHAPTER ONE

INTRODUCTION

1.1 Overview

Kenyan manufacturing activities date back before independence. Three major policy regimes namely; import substitution, market liberalization and export promotion have greatly influenced Kenya industrialization process since independence in 1963 (Chege and Kimuyu, 2014). In overall, import substitution strategy was successful in establishing some primary industries among others; textile mills, dry cells factories, light-bulb manufacturing, automobile assembly and stainless steel tanks, but led to reduced domestic competition and low capacity utilization. The inability of local industries to compete with imports led to the failure of the market liberalization strategy in the '80s. The 1990's export promotion strategy also failed due to mismanagement and poor implementation of fiscal activities. Reforms since 2003 have tried to stabilize the industrial production though, energy, market access and infrastructure remain a big challenge. However, Kenya's future growth in industrialization lies in high-value production, with steel production topping the chart as it is the overly used material in manufacturing, building and construction.

Steel is an alloy of iron and carbon. Different types of steel exist based on the percentage of carbon present in the iron. It has varied mechanical properties making it the highly used metal on earth. Its mechanical properties make steel best suited for most engineering activities ranging from building and construction, manufacture of electrical and mechanical equipment, domestic appliances, automobile industry, transport and communication infrastructure.

In Kenya currently, steel making process is only centred in melting steel scrap in induction furnaces and manufacture of wire and wire products, pipes, cold-rolled steel products and downstream finishing process such as galvanization (Machira, 2011). For the country to grow and industrialize, it then has to grow its steel industry by investing in massive steel production. Construction of an integrated steel mill in the country is one major step towards the realization of this industrialization dream as envisioned in vision 2030. This bold step shall with no doubt be the leader in driving the country's economy forward.

1.1.1 Concept of manufacturing

Manufacturing as a process has evolved over time but the understanding of what it really entails has not consequently evolved too. Manufacturing firms turn ideas into products and services. In today’s globally competitive landscape, manufacturers are inventors, innovators, global supply managers and service providers.

Traditionally, manufacturing has been always defined as the transformation of raw materials into finished goods. A broader definition of manufacturing equates it to the full cycle of activities from research and development through design, production, logistics and services to end of life management within an economic and social context (Livesey, 2006).

1.1.2 Concept of value-addition

Value-added imparted by a process, in economic terms, can be defined as the difference between the value of the outputs and inputs. The cumulative total of these differences for the whole economy is called the Gross Domestic Product (GDP). Value-added can also refer to the increase in material price resulting from processing or manufacturing. However, in contemporary terms, value-addition by a firm or industry goes beyond profit. It not only has a financial component but also a strategic and social value (Livesey, 2006). Strategic value is attained through contribution of research and development (R&D) to the growth of an economy. The social value is attained through the impact of manufacturing on the social setting of an economy.

1.1.3 Iron and steel

Iron is the second most abundant metallic element after Aluminium but is common of all commercial metals. Iron is obtained through refining iron ore in a blast furnace through a redox reaction process. Some charging materials are added during the refining process to help in slug formation, provide fuel for the burning process and also provide the reduction gas. Limestone added helps in slug formation while coke provides the burning fuel as well as the reduction gas, carbon monoxide. (ETSAP, 2010). Steel is an alloy of iron and carbon. It is obtained through processing pig iron in a Basic Oxygen Furnace (BOF). Some alloying elements are added to improve on various mechanical properties of steel.

1.2 Problem environment

Kenya is a sub-Saharan country lying in the East African zone sharing an extended coastline with the Indian Ocean. It is geographically positioned at latitude 5^0N and 5^0S and longitude 34^0E and 42^0E and borders five countries with Ethiopia and southern Sudan being on her northern side, Somalia to the East, Uganda to the west and Tanzania to the south-western side. The country occupies an approximated area of 591,971sq. kms with water occupying an 11,362 sq.kms and dry land taking the other 580,609 sq.kms. The country has a population estimated at 43 million with an almost 50-50 share between the males and females (KNBS,2015).

The country’s political context has been heavily shaped by history of domestic tensions and contestation associated with the centralization of power, high levels of corruption, a tasking struggle for a new constitution (was achieved in 2010) and unsolved social injustices. However, with the promulgation of the new constitution in 2010, a new platform was born. The constitution saw devolution of power and institution of strong bills of rights including social, economic and cultural. The constitution has seen the creation of Acts governing the political environment in the country to enhance political goodwill. This ensures a good political environment and thus stability ultimately creating a good environment for economic growth. This ambient environment is good for the growth of the manufacturing industry through Foreign Direct Investment (FDI) and also domestic investment. A good political environment means good and indiscriminative law enactment, low corruption levels, sustainable taxation regimes and good development policy formulations among others.

Socio-economically, the country has the largest and most diverse economy in the East African region of nearly 5% growth (KNBS,2015). In terms of Human Development Index, the country ranks highest in the region and its entrepreneurship and human capital gives it a huge potential for growth, job creation and poverty reduction. The recent discovery of oil and other mineral resources creates a huge opportunity for the country's economic growth. The country has indulged in the production of enough energy to run the manufacturing sector with the recent launch of the Lake Turkana Wind Project which will add 310 MW into the national grid (LWTP, 2015). The discovery of iron ore and coal in different areas of the country will enable the installation of an integrated steel mill in the country which will aid push the country's economy forward as it has been stipulated in the Vision 2030 flagship.

1.3 Problem statement

The process of industrialization in the country can be dated back to prior independence. However, in recent times, the country has seen the launch of different policy documents to aid in industrialization, and particularly manufacturing, with the most recent one being

Vision 2030 blueprint which is inclined towards making Kenya a middle-income economy by the year 2030 by ensuring an approximate continuous growth of 10% p.a. (Republic of Kenya, 2007). Of importance to this research is the development of an iron and steel integrated mill to aid achieve this mission.

In the pursuit of this dream, researches have been conducted on the feasibility and viability of setting up such a plant in the country by the government and other stakeholders. Particularly, Machira, (2011) looked into the methods used in the processing of steel, iron ore presence and content as well as steel recycling. His important findings were that the country had sufficient iron ore for commercial exploitation with an iron content of 62.35% way above the required 50% without beneficiating. However, more research requires to be conducted on iron quality.

Also, the Kenyan Government has continued showing her commitment towards the implementation of the vision of setting up an integrated steel mill in the country. The government set up a taskforce to look into the feasibility of setting up the plant with the team of experts visiting Pohang steel plant in South Korea seeking to secure collaboration in three main areas that included, manufacturing of spare parts, setting up of a mini steel mill and larger integrated steel mills (Oyuke,2011). In 2011, the Kenyan government signed a Memorandum of Understanding (MoU) with the South Korean steel giant POSCO giving the steel company the mandate to construct the steel plant. However, the company pulled out of the MoU citing non commitment on the Kenyan government (George 2015). In 2015, the Kenyan government signed another pact with the Chinese steel maker, Sinosteel to oversee the construction of the steel plant.

Despite Machira (2011) findings ascertaining presence of iron ore and the continued efforts by the Kenyan government to set up an iron and steel processing plant in the country, knowledge lacks on the type of process design that can be adopted for such a Kenyan steel plant based on the local content. This is occasioned by the reason that no research has been conducted on the process design required for setting up the plant. This research sought to bridge that gap by developing a process design that can be used for setting up such a plant based on Kenya's local content. The research sought to carry out a viability analysis for the establishment of such a plant, develop a process design for the same plant and then carry out an economic analysis of the proposed process design.

1.4 Objectives of the research

The main objective of the research was to develop a process design that could be used to set up an iron and steel manufacturing plant. To achieve this, the specific objectives of the study were;

a) To establish the viability of setting up an iron and steel processing plant in Kenya.

b) To develop a process design for the Kenyan plant.

c) To establish economic viability of the plant.

1.5 Research questions

In providing information on the knowledge gap, the study was guided by the following questions.

1) Is it viable to set up an iron and steel processing plant in Kenya?
2) What process design would be required for setting up an iron and steel processing plant in Kenya?
3) What is the economic implication of such a process design?

1.6 Scope of the study

The research was conducted in Kenya and was aimed at developing a process design that could be used in establishing an integrated iron and steel plant. The research only investigated variables related to this study which included; state of raw materials for production of iron and steel, Kenya's steel demand and economic viability of the proposed plant process design.

1.7 Justification of the study

Kenya trades majorly with raw materials rather than finished products. This causes over-dependence on importation of finished goods hence the country spends more of its Forex in the process. This expenditure has been showing an upward trend standing at Kshs 43.6 Billion in 2010, 62.1 Billion in 2011, 56.7 Billion in 2012, 80.1 Billion in 2013 and 75.6 Billion in 2014 (KNBS, 2015). With the continued spirit to realize Vision 2030, and with the massive industrialization projects stipulated therein, this upward trend shall with no doubt continue to be witnessed. However, most of these products could be produced locally with the development of an integrated steel plant in the country coupled with manufacturing driven by value-addition as envisioned in the Vision 2030 flagship. With the country being more of a consumer than a producer, it loses an opportunity for wealth creation through manufacturing, job creation and technology transfer. Thus, there is a need to explore/strategize and develop opportunities for manufacturing and thus, industrialization of the country. Development of an Iron and Steel processing plant in Kenya is one of the strategies hence necessitating the need to do a research on the viability of the plant as well as develop of a process design for such a Kenyan plant.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In this chapter, the various literature relevant to the research is discussed and evaluated. The literature will form the basis of the research as it informs on available work done unearthing research gaps and potential methodology solutions.

2.2 Overview

The structural transformation of a traditional economy dominated by primary activities into a modern economy where high-productivity activities in manufacturing assume an important role remains a defining feature of economic development (Wim and Adam, 2012). The metal products sub-sector, which falls under the manufacturing sector, plays a vital role in a country's economy, especially with the industrialization strategy. In a global perspective, steel consumption has been steadily increasing over time. World iron and steel production has continued to show a large increase since 2004 (when annual crude steel production achieved the one billion mark for the first time), due to rapidly increasing steel demand in China, India and other developing countries (Machira, 2011). According to a press release by Worldsteel, the production of crude steel in China, Japan and India stood at 65.8, 8.8 and 7.7 Mega tonnes respectively as of July 2015. This makes China the highest producer of crude steel contributing close to 50% of the total world's crude steel. This information is represented in a comparative graph Figure 2.1 below (Worldsteel, 2015).

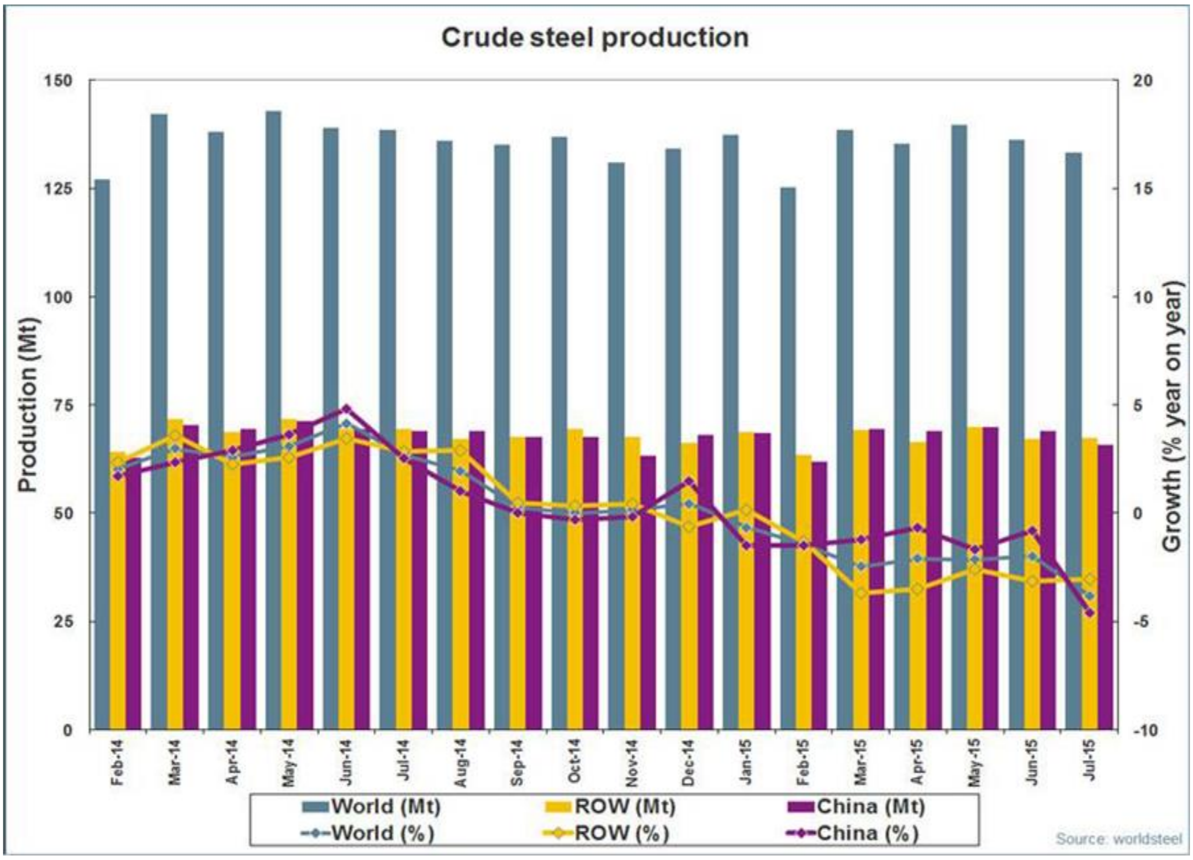

Figure 2.1 Crude steel production

Source: Worldsteel

China's apparent steel use per capita, ASU (Kilogram of crude steel) stood at 567.7 in 2013 up from 508 in 2012. This is an indicator of how the steel industry has contributed to the immense growth of the Gross Domestic Product (GDP) of China, which currently stands at an estimated 7.4% (IMF, 2015). Steel is often used as a barometer for the economic strength of a country implying a very strong direct relationship between the economic take-off of a country and her steel production and usage. This can be further illustrated by the Figures 2.2 and 2.3 (Nae Hee, 2012).

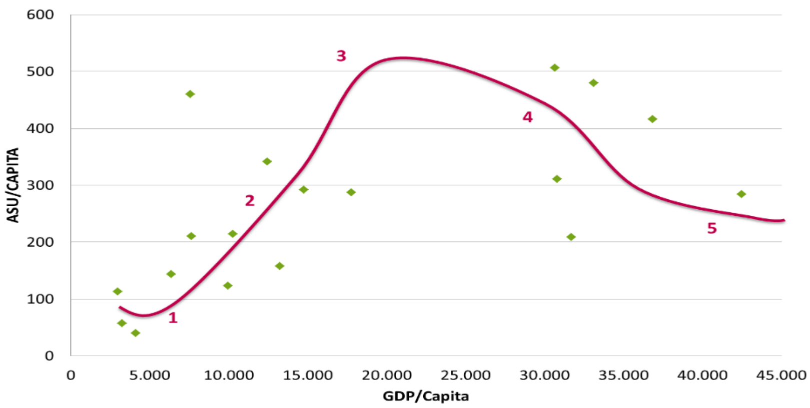

Figure 2.2 Dynamic relationships between GDP per capita and steel use per capita

Source: Worldsteel

The figure 2.2 shows the relationship between apparent steel use per capita and the GDP per capita of a country. The numbers indicated on the curve imply the stages a country goes through as her production of steel and usage increases over time. The graph shows steel as the basis of economic take off for a country Below is the key.

1 - Very low level before economic take-off. **2** - Rapid rise. **3** - Levelling off.

4 – Decline **5** - Stabilization

Figure 2.3 shows steel as a basis for economic take off by comparing apparent steel use per capita against GDP per capita for different countries.

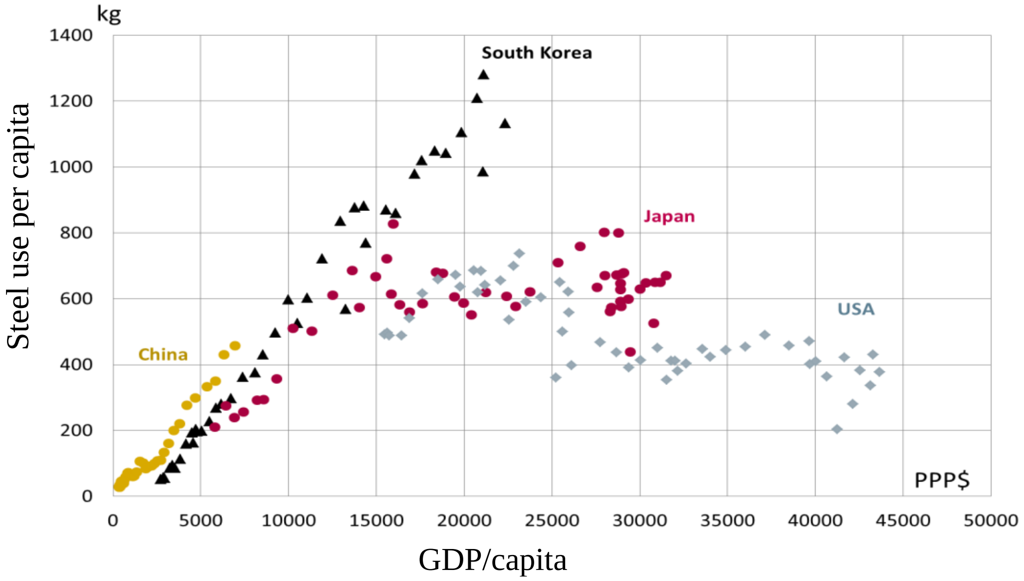

Figure 2.3 Steel use per capita vs. GDP per capita in different countries. Source: worldsteel

2.3 Manufacturing

The concept of manufacturing is as old as the human history starting all the way from the old days when man crafted very archaic and mediocre tools for hunting, defence and farming. Tools used to be produced by use of hands until owners of the then workshops created machines to do the work instead. This change revolutionized the production processes giving in to the industrial revolution in the 18^{th} century which started in England and later stretched to France and Germany. Over the many years, manufacturing has evolved century after century with many advancements in technology and improved production processes being put in place.

Manufacturing in Kenya dates back to prior independence when the country embarked into a rigorous process of Import substitution (IS) through empowering domestic investment, retaining foreign investors and attracting new investors which saw the establishment of different industries in the country. These industries saw the production of goods and services with a substantial local market (Gartz 2008). They included textile mills, dry cell factories, confectioneries, stainless steel tanks and cotton ginneries. Others included vehicle assembly and Agro-processing industries among others in the first decade of independence. The metal sub-sector in the country also saw a robust improvement during this period with industries involved in metal forming being established among them, Mabati Rolling Mills (MRM), Doshi, Insteel, Kaluworks, Galsheet and Africa Steel (Chege and Kimuyu, 2014). The industries were involved in the production of nails, galvanized sheets and pipes. During this period, the manufacturing sector grew very fast than all other sectors not only within the economy but also in the sub-Saharan region. The industries which did well were, among others, steel rolling, galvanizing and vehicle assembly. However, there was a negative effect due to the IS strategy which saw a market liberalization strategy be crafted in the 1980s which performed dismally paving way for the Export orientation strategy in the 1990s. This strategy was purposely put in place to aid in attracting foreign investment into the country.

Iron and steel manufacturing can trace its origin way back to the 19^{th} century when mass production of the same began with the invention of the Bessemer process. Later, this process was followed by the Siemens-Martin process and then the Gilchrist-Thomas process that refined the quality of steel. Mild steel produced replaced wrought iron. The invent of the Basic Oxygen Steelmaking (BOS) process later revolutionized the steel making process leading to low production costs and high quality metal.

2.4 Iron and Steel

2.4.1 Iron

It is the second most abundant metallic element after aluminium but is common of all commercial metals. It has played a role in human history and is an essential part of everybody literally (Geological Society of Australia, 2015). Iron is obtained from iron ore through a reduction process. It was first obtained from meteorites about five to six thousand years ago. The most common iron ores minerals are magnetic pyrites (FeS_2), magnetite (Fe_3O_4), hematite ($Fe_2 O_3$) and carbonates of iron (Siderite-Fe_2CO_3) (Geological Society of Australia, 2015). Traditionally, iron is obtained as the final product of heating a mixture of iron ore, coke, limestone and other fluxes in a blast furnace. The resultant iron is known as pig iron which forms the main raw material for making steel. For economic extraction of iron from the ore, the ore should have at least 50% iron content (Machira, 2011) otherwise it is increased through the beneficiating process.

Currently, there is no commercial production of iron from iron ore in Kenya. The process of quantification of iron ore in the country is still on-going. The process also includes determining the type of iron ore present in the country (NMC, 2015)

2.4.2 Steel

Steel is an alloy of iron and other elements primarily carbon. It is obtained from subsequent re-melting of pig iron in Basic Oxygen Furnace (BOF) where, in the process, carbon is reduced to carbon dioxide (CO_2) and monoxide (CO) in presence of other additives which improve the different qualities of steel. The resulting steel contains less percentages of carbon content in its final form. These percentages mostly reach a maximum of 1.5% present in the steel in the form of iron-carbide. The carbide increases the hardness and strength of the steel. The percentage content of carbon, among other elements give rise to different types of steel as well as determines the properties of the steel (Garg, 2009). Steel can be classified in to plain carbon steels and alloy steels (Garg, 2009). In kenya currently, steel making process is only centred in melting steel scrap in induction furnaces and hotrolling, manufacture of wire and wire products, pipes, galvanized and cold rolled steel products (Machira, 2011).

2.4.2.1 Plain carbon steels

They have a carbon content ranging between 0.05-1.5%. They mostly contain negligible amounts of alloying elements, usually less than 1.65% manganese, 0.6% silicon and traces of other alloying elements. However, they can be classified into low carbon steel, medium carbon steel and high carbon steel. Low carbon steels comprise of the dead mild and mild steels which contain carbon in the ranges of 0.05-0.15 and 0.15-0.3%, respectively (Garg, 2009).

Dead mild steel usually exhibits high malleability and ductility properties as well as high tensile strengths (shown in Table 2.1) making them best suited for use in the automobile industry and in sheet applications. They are also used in the production of tubes.

Table 2.1 Properties of dead mild steel

Dead mild steel					
% Carbon	Brinell Hardness Number (BHN)	Tensile strength (MPa)	Yield strength (MPa)	% elongation	% reduction in area
0.05 to 0.15	100—110	390	260	40	60

Source: Workshop Technology; Manufacturing processes by S.k Garg

Mild steel has a carbon content of 0.15 to 0.3 %. Usually has a bright fibrous structure and exhibits toughness and more elasticity than wrought iron. It is also malleable and ductile and can easily be forged and welded (Garg ,2009). Some of its properties are shown in Table 2.2.

Table 2.2 Properties of mild steel

Mild steel					
% Carbon	Brinell Hardness Number (BHN)	Tensile strength (MPa)	Yield strength (MPa)	% elongation	% reduction in area
0.15 to 0.20	120—130	420	355	36	66
0.20 to 0.30	130—150	555	480	21	55

Source: Workshop Technology; Manufacturing processes by S.k Garg

These steels are commonly used in machines and structure works. e.g. universal beams and gears. Medium carbon steels have carbon from 0.3 to 0.8 %. They are usually produced as killed or semi-killed steels and are hardenable by heat treatment though it is limited to thin sections or to the thin outer layer on thick parts. Medium carbon steels in the quenched and tempered condition provide a good balance of strength and ductility (Garg ,2009). They are mostly used in automobiles for making axles and springs as well as in machinery for making forgings among other uses. Table 2.3 shows the properties of medium carbon steels.

Table 2.3 Properties of medium carbon steels

Medium carbon steel					
% Carbon	Brinell Hardness Number (BHN)	Tensile strength (MPa)	Yield strength (MPa)	% elongation	% reduction in area
0.30-0.40	150-160	700	550	18	51
0.40-0.50	350	770	580	20	53
0.50-0.60	350-400	1200	750	10	35
0.60-0.70	400-450	1235	780	12	40
0.70-0.80	450-500	1420	1170	12	35

Source: Workshop Technology; Manufacturing processes by S.k Garg

High carbon steels are those whose carbon content is more than 0.7%. They have high hardness and low toughness. These properties make them useful in bearing applications where high wear resistance is required. In these applications, the loading is compressive which minimizes the risk of brittle fracture that might occur in tensile loading (McGraw Hill, 1997). Specifically, steel with 0.8% carbon content, finds various uses depending on the microstructure. Two microstructures exist, i.e., pure pearlite and tempered martensite. The 0.8% carbon steel with a pure pearlite microstructure finds use in rail making and in the manufacture of high strength wire for ropes and cables, while the tempered martensite 0.8% carbon steel is mainly used for making bearings. Steel with 1.2% carbon and above finds its use in making files and saws used for cutting other steels (Garg, 2009). Table 2.4 shows the properties of high carbon steels.

Table 2.4 Properties of high carbon steel

High carbon steel					
% Carbon	Brinell Hardness Number (BHN)	Tensile strength (MPa)	Yield strength (MPa)	% elongation	% reduction in area
0.80-0.90	500-600	665	645	12	33
0.90—1.10	550-600	580	415	13	26
1.10—1.50	600-750	500	375	13	20

Source: Workshop Technology; Manufacturing processes by S.k Garg

2.4.2.2 Alloy Steels

They contain alloying elements added to plain carbon steels to improve on steel characteristics. These characteristics include-and not limited to-wear resistance, hardness, tensile strength, corrosion resistance, cutting abilities, elasticity and machinability.

Nickel steel has a percentage of nickel (Ni) varying from 2 to 45. 2% Ni makes steel more suitable for rivets, boiler plates, bolts and gears etc. Ni from 0.3 to 5% raises the elastic limit and improves toughness while steel containing 20% nickel has very high tensile strength. 25% Ni makes the steel particularly stainless and might be used for internal combustion (IC) engine valves and turbine blade. If Ni is present up to 27%, it makes the steel non-magnetic and non-corrodible. Invar (Ni 36%) and super-invar (Ni 31%) are the popular materials for least coefficient of expansion and are used for measuring instruments, surveyor tapes and clock pendulums. 45% Ni steel possesses extension equal to that of glass, a property very important for making links between the two materials *i.e.*, in electronic valves and bulbs (Garg, 2009). Vanadium steel contains vanadium which when added even in small proportion to an ordinary low carbon steel considerably increases its elastic limit and improves the fatigue resistance. Vanadium also makes steel strong and tough. When vanadium is added up to 0.25%, the elastic limit of the steel is raised by 50% and can resist high alternating stresses and severe shocks. These properties make it suitable for making tools and shafts among other uses. Manganese steel contains manganese in different percentages and if added in between 1.0 to 1.5% makes the steel strong and tough. When added in between 1.5 to 5% it makes the steel hard and brittle. 11 to 14% manganese steel with carbon content ranging from 0.8 to 1.5% is very hard, tough and non- magnetic and possesses considerably high tensile strength. Manganese reduces machinability property of steel thoguh it increases forgeability and weldability of the same. Its properties make it suited for heavy machinery, agricultural implements as well as manufacture of shields and helmets.

In Kenya, steel is majorly consumed in the building and construction sector. This steel is classified as either mild steel or high yield steel. Mild steel is normally used for manufacturing mild steel bars, cold worked steel bars and hot rolled steel sections. The maximum allowable contents of elements in the steel are as shown in Table 2.5.

Table 2.5 Product analysis based on maximum element content

MILD STEEL			HIGH YIELD STEEL		
Element	Maximum element content (%)	Standard	Element	Maximum element content (%)	Standard
Carbon	0.28	BSEN 10036:1991 ISO 9556:1989	Carbon	0.200	BSEN 10036:1991 ISO 9556:1989
Manganese	1.600	EN ISO 10700:1995	Manganese	1.500	EN ISO 10700:1995
Sulphur	0.060	EAS 199:2001	Sulphur	0.050	EAS 199:2001
Phosphorus	0.060	EAS 200:2001	Phosphorus	0.050	EAS 200:2001
Nitrogen	0.008	ISO 4945:1977 ISO 10720:1997	Silicon	0.350	ISO 439:1994 ISO 4829-1:1986
			Chromium	0.500	ISO 4937:1986
			Manganese plus Chromium	1.600	AS IN THE RESPECTIVE ELEMENTS

Source: KEBS, KS 18:2010 Kenya Standard: Specification for building and construction steels.

2.5 Iron ore processing

2.5.1 Overview

Metals and their compounds are available from three sources. These, in ranked order, are the earth's crust, oceans, and from recycled scrap (Machira, 2011). The availability of the metals for use is not governed by its abundance alone. For instance, though copper is the third most commonly used metal after iron and aluminium, its concentration in the earth's crust is very low (only about 0.01 %). Also, the annual consumption of iron outstrips that of aluminium, though iron is less abundant than aluminium in the earth’s crust.

High tonnage production of metal depends on accessibility of ore deposits, the richness of ore deposits, nature of extraction and refining process for the metal, chemical and physical properties of the metal and high demand. A metal is commonly used if it is readily available, easily produced with low cost and has desirable properties. The economic recovery of metals from the ores depends on factors such as *content* and *contained value*. The content factor can be illustrated in an ore containing 1 part per million gold, which would be profitable to mine, as contrasted to an iron ore with 45% iron content which would be considered low grade. On the other hand, contained value is dependent on metal content and the current price of the contained metal. Deposits are economically viable to exploit and can be classified as ore deposits if contained value per ton is greater than total processing costs per ton (Machira, 2011).

2.5.2 Pig iron production

Iron exists in the earth's crust in a combined form as oxides. After the iron ore has been mined it is taken for smelting to obtain pig iron. Traditionally, the ore is first roasted with coal and other additives in a moving grate (sintering) to remove impurities such as water, carbon dioxide, sulphur dioxide and arsenic compounds. This leaves a sinter which is mainly granules of magnetite and hematite. The sinter is then cooled and taken through a palletization process to produce small iron ore pellets (ETSAP, 2010). This pelletized sinter is then fed into a blast furnace where it is mixed with high-grade coke and limestone. The charging process is done from above the furnace. Hot air rich in oxygen is then blasted into the furnace from the bottom by use of electric ventilators, creating temperatures of up to 1900°C. The iron ore reacts with carbon monoxide as the charge descends the furnace in a reduction reaction producing iron and carbon dioxide. Any impurities fuse with the limestone to form a slug which floats on the surface of the molten iron (pig-iron) and can be run-off and the molten iron obtained from the base of the furnace (Garg, 2009). The product of the blast furnace is pig iron with 3 to 4% carbon; 1 to 3% silicon; 0.3 to 1.5%

phosphorous; 0.1 to 1.0% manganese and less than 1% sulphur. This molten iron will form the raw material for steel production. This process is shown in Figure 2.4.

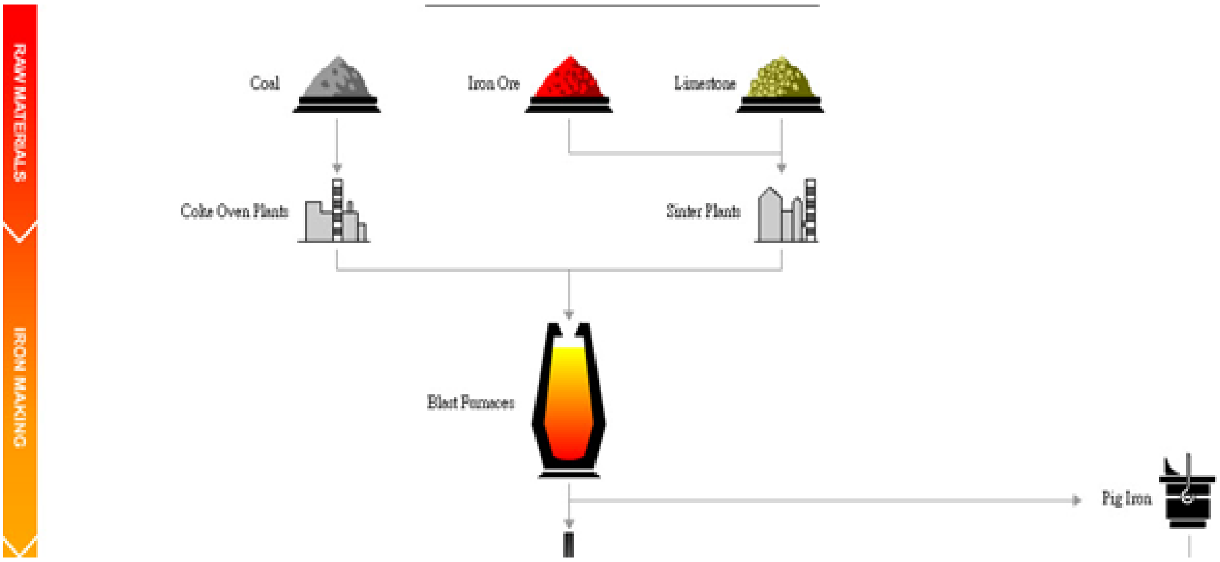

Figure 2.4 Iron ore processing *Source: www.shipplate.com*

In Kenya currently, iron ore smelting is not carried out since an integrated steel plant has not been set up.

2.5.3 Steel making

Two processes exist for making steel; by use of the Basic Oxygen Steelmaking (BOS) or an Electric Arc Furnace (EAF).

The BOS uses a Basic Oxygen Furnace where the main raw materials for steel making comprise molten (pig) iron and steel scrap. In this process, oxygen is injected into the molten hot metal burning out the present carbon. The carbon chemically combines with the blast oxgygen to form CO and CO_2. The process being highly exothermic, cooling is provided by the charged scrap and iron ore during the blowing process. Lime charged into the converter together with the scrap help remove phosphorus and manganese. Inert gas (e.g. argon) is injected into the bottom of the converter to stir melt and slag. This increases productivity and metallurgical efficiency by lowering iron losses and phosphorus content. The amount of O_2 consumed depends on the hot metal composition (ETSAP, 2010).

Addition of alloying elements is done in controlled proportions to get the required steel properties (ETSAP, 2010). The obtained steel can then be cast to create solid steel, usually in the form of slabs, blooms or billets that can be manipulated to manufacture various steel products. In the EAF, scrap is first pre-heated by the EAF exhaust gases (energy recovery) and then charged into the EAF together with lime or dolomitic lime. Lime is used as a flux for the slag formation. Dolomitic lime contains calcium and magnesium whereas normal lime contains more calcium. Charging the EAF is a gradual process. At about 50%–60% load (ETSAP, 2010), the electrodes are lowered to the scrap and an arc is struck. This melts the first load before further loading is done. When fully loaded, the entire content of the EAF is melted. To achieve this result, oxygen lances and/or oxy-fuel burners can be used in the initial stages of melting. The ferrous scrap used in the EAF includes scrap from steelworks and steel manufacturers and consumer scrap since steel is recyclable. These two steelmaking routes are represented in Figure 2.5.

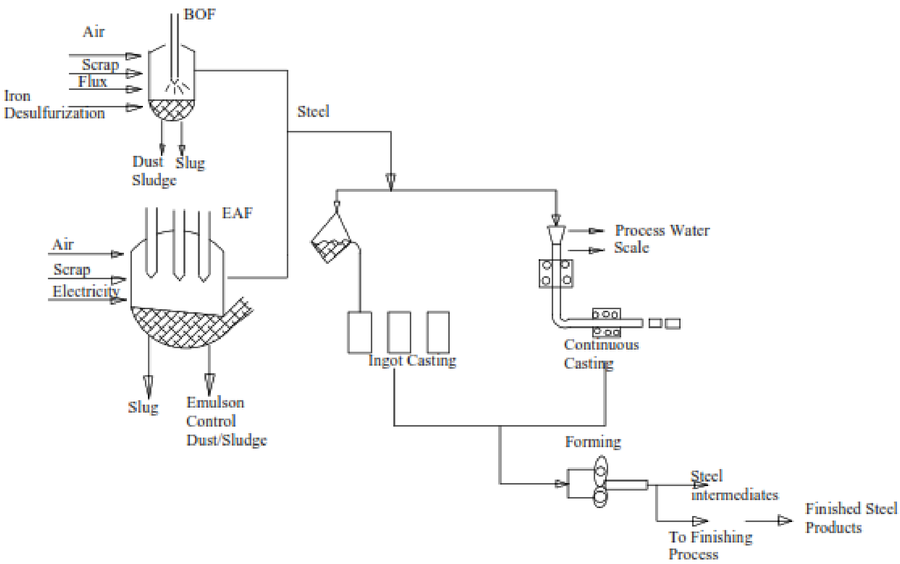

Figure 2.5 Steelmaking process *Source: Worldsteel*

2.6 Inputs to a steel industry

The availability of material inputs is important for a steel industry, as it is for all manufacturing industries (Pennslyvannia Economic League, 2010). Adequate raw materials within the location of the site create an advantage in low production costs due to reduced haulage costs among others things.

2.6.1 Raw materials

Producing steel in a traditional integrated mill requires three core minerals namely iron ore, coal and limestone (Rajput, 2006).

Iron ore exists as an iron oxide. It is the material that is reduced to form pig iron for use in steel making. For economic extraction, iron ore should contain 50% iron content (Machira, 2011). The ore comprises of iron oxides and other impurities in the form of sulphur, magnesium and phosphorus among others which are readily removed during the smelting process (AISI, 2015).

Coal is a readily combustible black or brownish-black sedimentary rock that is composed primarily of carbon, along with variable quantities of other elements such as sulphur, hydrogen, oxygen and nitrogen. Based on its properties, coal can be classified by rank into either “thermal” coal or “metallurgical” coal. (AISI, 2015). Thermal coal is the world’s most abundant fossil fuel and is primarily used to produce energy. It is higher in moisture value, but lower in carbon content and calorific value. Metallurgical coal is less abundant than thermal coal and is primarily used in the production of coke which is used in heating up the blast furnace. It is first roasted in absence of oxygen up to high temperatures of 1100^0C to convert it to almost pure carbon (coke) through the coking process (AISI, 2015). The obtained coke is then used as a heating agent within the blast furnace as well as a reducing agent. Coke ignites when a blast of hot air is passed through it. During the burning process, the carbon combines with oxygen through a redox reaction. Carbon is oxidized to form CO and CO_2 whereas the iron ore is reduced to iron.

Limestone is a naturally occurring mineral. The term limestone is applied to any calcareous sedimentary rock consisting essentially of carbonates. The ore is widely available geographically all over the world. Earth's crust contains more than 4 % of calcium carbonate. Limestone is basically calcite which is theoretically composed of calcium carbonate ($CaCO_3$). When limestone contains a certain portion of magnesium, it is called dolomite or dolomitic limestone (Satyendra, 2013). Limestone is used as a slag former while dolomite is used as a slag former, slag modifier and as a refractory material. Calcium oxide present in limestone fuses with gangue materials present in the iron ore forming slag such as calcium sulphide (Satyendra, 2013).

2.6.2 Electricity

Both types of steel production require massive quantities of energy. Electricity costs are a concern both for plants that utilize electric arc furnaces and for integrated iron and steel producers world over. The cost of natural resources is volatile, making it difficult for steel companies to predict long-term costs (Pennslyvannia Economic League, 2010).

2.6.3 Plant

This comprises the premises, machinery and the equipment required for the iron ore processing and steel manufacturing to take place. For a traditional integrated steel mill**,** the following is required for its set up. *Coke oven*; this is where conversion of coal into coke takes place. It comprises of a dust removal mechanism, pushing, charging systems and a quenching point. *Sintering plant*; Sinter plants agglomerate iron ore fines (dust) with other fine materials at high temperature, to create a product that can be used in a blast furnace. The final product, a sinter, is a small, irregular nodule of iron mixed with small amounts of other minerals. A sintering plant comprises of a stacker, a mixing drum and an electrostatic precipitator. *Blast furnace*; This is where reduction of iron ore takes place. The end-product of the reduction is pig iron which serves as the raw material for steel manufacture in a basic oxygen furnace. It comprises of a tuyere, pig iron machine, gas cleaning mechanisms among others. *Basic Oxygen Furnace*: reduction of iron to steel takes place here. Alloying can also be done at this point to create different types of steel. *Rolling mills*; they convert crude steel into slabs or blooms through continuous casting processes. Hot strip mills produce hot-rolled steel with plate mills producing plates.(European State Environmental Ageny)

For an Electric Arc Furnace (EAF) steel production, the following equipment is required based on the type of feedstock. When the feedstock is;

*Scrap only,*the equipment required include high power alternating current EAF (converts scrap into steel), a Ladle Refining Furnace (LRF), a thin slab caster and a tunnel type equalizing / reheat furnace (European State Environmental Ageny).

Direct reduced iron, the equipment required include a Midrex shaft furnace. This is where iron-bearing material is charged and reduced as it flows downwards by a natural gas which flows upwards resulting into direct reduced iron (Midrex technologies, 2014). Other equipment include an EAF, a Ladle Refining Furnace (LRF), a thin slab caster and a tunnel type equalizing / reheat furnace (European State Environmental Ageny).

Hot metal (Smelt iron), the equipment required includes a Reduction shaft,a melt-gasifier, an EAF, an LRF, A thin slab caster and a tunnel type equalizing/ reheat furnace. It is in the reduction furnace where iron bearing material and additives (limestone and dolomite) are charged into the reduction shaft from above via a lock hopper system where it is reduced directly by a counter-flowing gas to obtain Direct Reduced Iron (DRI) (Siemens Vai,2011) . The metallization degree of the DRI and the calcination of the additives is depended on amount and quality of the reduction gas,the temperature of the reduction gas the reducibility of the iron-bearing material and the average particle size and distribution of the solids charged. The melter-gasifier is divided into three reaction zones; Gaseous free board zone (upper part or dome), Char bed (the middle part above oxygen tuyeres), Hearth zone (the lower part below oxygen tuyeres). Direct reduced iron from the reduction shaft is fed into the melter- gasifier via discharge screws where it is further reduced and melted at the same time giving rise to hot metal. Gasification of coal by use of oxygen also takes place here leading to the production of the reducing gas, carbon monoxide, which is used in the reduction shaft.(Siemens Vai,2011)

2.7 Technology issues relating to steel production

Different technologies for steel production exist. These technologies have been employed in production of steel by different steel makers in the world though with slight variations effected from one plant to another based on the steel requirements of a particular producer.

2.7.1 Scrap-based versus Iron-ore based steelmaking

Two separate paths to making steel exist. The integrated steel production method and the Electric Arc Furnace.

The integrated steel production method. It is characterized by high volumes of production (at least 4 million tons per year is typical) and heavy capital investment. (NMC, 2015). It uses the Blast Furnace (BF) to produce liquid iron, which is then refined in a Basic Oxygen Furnace (BOF) to crude steel. The iron ore needs to be pre-treated, by means of a sinter plant where ore is baked with limestone and coke to fuse the fines into lump material suitable for the blast furnace, or palletized where the same materials are crushed and wet palletized before drying in large kilns (ETSAP 2010). The coke used as a reducing agent and fuel is produced from suitable coal burnt in the absence of air to drive off volatile components, and then water quenched to prevent subsequent re-oxidation (AISI 2015). This is a very difficult process to control environmentally and most European coke making has migrated to areas where environmental legislation is less strict. The hot metal from the BF, depending upon the chemistry of the iron ore and coke, may then need a pre-refining stage to reduce levels of sulphur or phosphorous before being charged to the BOF for steel production.

The mini-mill process route. It uses either steel scrap or iron ore in the form of pellets which have been reduced (oxygen removed, converting the iron ore into metallic iron) called Direct Reduced Iron (DRI). These reduced pellets or scrap are introduced into the EAF which then produces the crude steel with electrical energy providing the heat source (AISI 2015). This latter route is generally considered to be the more flexible, less capital intensive process route when steel volumes between 500,000 and 2 million tons per year are considered (NMC, 2015). The basic module is always a scrap melting EAF, sized for the desired annual level of production and using electrical energy as its main form of heat. There are, depending on regional requirements, a number of variations for the EAF route which can accommodate many different forms of iron unit to economically produce crude steel. These variations may include the use of hot metal from a small blast furnace (so-called mini blast furnace, well known in India, China and Brazil), hot metal solidified into small ingots (pig iron), steel scrap, DRI as pellet, or in a hot briquetted form known as HBI. Hot metal from the smelting of iron ore (e.g. via the Corex process) may also be used as EAF feedstock (Siemens VAI 2011). EAFs are not commercially viable below a heat size of 50 tons. EAFs normally produce 25 – 30 heats per day and are found in melt shops producing 500,000 – 2,000,000 tons per year. (NMC,2015)

2.7.2 Metallic charge options for an EAF

Whilst choice of an EAF steelmaking process route lies normally between scrap-based and iron-ore based steelmaking, an EAF scrap- based steelmaking may also make use of metallic charge which it derives from iron ore. In this respect, the main options are:

- To supplement ferrous scrap with pig iron, which may be obtained from traditional large-scale (multi-million ton) blast furnaces or from so-called mini-blast furnaces
- To supplement ferrous scrap with DRI (sponge iron)
- To supplement ferrous scrap with iron obtained from the smelting of iron ore, e.g. via the Corex process.

DRI supply. Direct-reduced iron is produced by the direct reduction of iron ore (in lumps, pellets or fines) by a reducing agent such as natural gas or coal (ETSAP 2010). Large-scale production of DRI requires low-cost natural gas.

Smelting of iron ore. This can be done using coal or the Corex technology. It is a two-stage process. In a first step, iron ore is reduced to DRI in a shaft furnace by means of reducing gas. In a second step, the reduced iron is melted in the melter-gasifier vessel. The Corex process was developed in the late 1970s by Siemens-VAI, and it is in use by ArcelorMittal in South Africa, POSCO in South Korea, Jindal in India and Baosteel in China (Siemens VAI, 2011).

2.7.3 Continuous casting /Rolling mill

Refined liquid steel needs to be solidified into a section size suitable for downstream rolling into the finished hot-rolled coil (AISI, 2015). The physics of the plastic deformation involved in the rolling process generate little lateral spread of the rolled section and most deformation is seen in longitudinal growth. Accordingly, for a standard HRC with a width of around 1.8 meters, a rectangular cast section (slab) of 1.8m wide is required. Depending on the caster design and process route selected, the thickness of this slab would fall into one of the following four categories; thick slab (normally 200 – 300 mm thick), medium slab (approximately 150 mm thick) thin slab (60 -70 mm thick), very thin slab (30 mm thick) (NMC 2015). These different slab thicknesses are usually associated with one of the following four different rolling mill types. The rolling mill types include; conventional hot strip mills, thin slab-making (Compact Strip Production, CSP), very thin slab production and steckel mill rolling.

The thickness of slab selected for any steelmaking project is largely determined by the steel qualities to be produced (end-use at customer's plant), the annual volume of steel required, and the type of rolling mill/casting machine interface desired.

2.8 Process design

2.8.1 Overview

A process design can be said to be an act of determining the workflow, equipment needs, and implementation requirements for a particular process. Typically, it uses a number of tools including flow charts, process simulation software and scale models (Heizer 2006). Process planning and design is an iterative process which requires inputs to generate an output as shown in Figure 2.6.

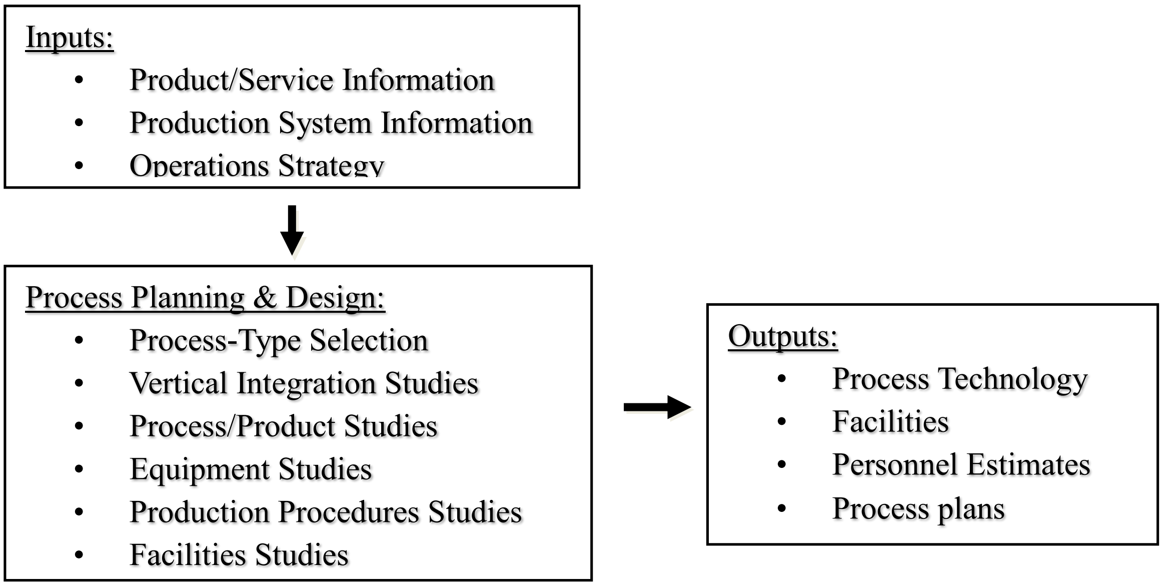

Figure 2.6 Inputs, process planning and outputs

2.8.2 Types of process designs

There are three major types of process designs namely Product-focused, Process-focused and Group technology/Cellular manufacturing (Reid, S & Sanders, R, 2012).

In product-focused design, processes (conversions) are arranged based on the sequence of operations required to produce a product or provide a service. It is also called "production line," "assembly line," and flow line. They are of two general forms; discrete unit (example automobiles, dishwashers) and continuous process (for example petrochemicals, paper).

Process-focused design has processes (conversions) arranged based on the type of process, that is, similar processes are grouped together. Products/services (jobs) move from one department (process group) to another based on that particular job's processing requirements. It is also called "job shop" or "intermittent production". Examples are a machine shop, auto body repair and custom woodworking shop.

In group technology, each part produced receives a multi-digit code that describes the physical characteristics of the part. Parts with similar characteristics are grouped into part families and parts in a part family are typically made on the same machines with similar tooling.

In cellular manufacturing, some part families (those requiring significant batch sizes) can be assigned to manufacturing cells. The flow of parts within cells tend to be more like product-focused systems (Reid, S & Sanders, R, 2012).

2.8.3 Major factors affecting process designs

The choice of a particular process design is affected by nature of demand, degree of vertical integration, product flexibility, degree of automation and product quality. (Reid, S & Sanders, R, 2012). Demand fluctuates over time and is affected by product price, so pricing decisions and the choice of processes must be synchronized. Therefore, production processes must have adequate capacity to produce the volume of the products that customers need and provisions must be made for expanding or contracting capacity to keep pace with demand patterns.

Vertical integration is the amount of the production and distribution chain that is brought under the ownership of a company. This determines how many production processes need to be planned and designed. The decision of integration is based on cost, availability of capital, quality, technological capability, and more. Strategic outsourcing (lower degree of integration) is the outsourcing of processes in order to react quickly to changes in customer needs, competitor actions and technology.

Product flexibility is the ability of the production (or delivery) system to quickly change from producing (delivering) one product (or service) to another. Volume flexibility is the ability to quickly increase or reduce the volume of product (or service) produced (or delivered).

The magnitude of automation within the design system is equally paramount in determining the process design to choose. The process design should also be flexible to any automation changes. The choice of design of production processes is affected by the need for superior quality (Reid, S & Sanders, R, 2012). Steel production process is a product-focused process design.

2.9 Kenya Iron and Steel state

This section looked into the state of iron and steel in Kenya with major emphasis on the state of raw materials needed for the establishment of an iron and steel processing plant in Kenya. However, it is worth noting that Kenya currently has 20 steel makers (Appendix 1) situated in different parts of the country with major preference being Nairobi, Mombasa and Athi-River. Amongst these steel makers, the largest include Athi-river steel, Devki steel mills and Mabati Rolling Mills (MRM) (NMC 2015) These mills involve in scrap-based induction furnace operations and not EAF steel making.

2.9.1 State of raw materials

2.9.1.1 Iron

As early as the 1940s, deposits of iron ore had been prospected in Kenya. The deposits are found in the form of oxides: Magnetite (Fe_3O_4), hematite (Fe_2O_3), goethite, limonite: carbonates-siderite and anchorites (Republic of Kenya, 2014). These iron ore deposits have been in significant amounts in different regions within the country as shown in the Table 2.6.

Table 2.6 Summary of iron ore deposits in Kenya

Location	Type	Quantity	Quality
Marimante Iron Ore Deposit Approximately 108 mile NE of Nairobi in Meru District (38o 57' E 0 10' S	Titaniferous magnetite (Ilmenite)	Area extend float material over 200ft traced for strike distance 0.5 miles	Grab sample assay yield 40-50 % iron and 5-15% TiO_2
Mraru Ridge Iron Deposit Mraru Ridge, 1.8 Km SSW of Ndile Shopping Center 3o 21' S and 38 o 28' E sheet 189/4	Magnetite	Not known	Fe_2O_3 66.98% and 8.7% TiO_2
Wanjala Magnetite Ore Deposit Taita District at location 38 o 10' Eand 3 o 15' S).	Magnetite	Main occurrence 750m long by 3m thick on average Float lateral estimate50m and thickness 0.3-1.5 m	59-63 % iron
Ikutha Iron Ore Deposit 7 Km south of Ikutha shopping center, Kitui District approximately 38 o 11' E and 2 o 8' S).	Magnetite veins	Ore reserve estimate 80,000 tonnes of 66% Fe_2O_3 magnetite concentrate and 31,000 tonnes of 35 % P_2O_5 apatite	58.7 % $Fe_2O_3$and 7.6 % P_2O_5
Bukura Iron Ore Deposit 15 kilometers southwest of Kakamega	Pyrite veins	This lode is estimated to contain 17 million tonnes of ore down to a depth of 90 metres and it is likely the reserves may exceed this figure since lateral extensions are known to exist.	Not done
Ndere Island In Kisumu District the whole of the Ndere Island in the Winam Gulf	Banded limonite ironstones	Many of the ironstone bands are 5 metres thick, but some, less persistent range from 15 to 60	Not done

		metres in thickness	
At Mrima Hill South of Mombasa	Goethite (limonite) and magnetite	3 and 15 million tonnes of Fe_2O_3.	10 to over 50% Fe_2O_3
Uyoma Peninsular, northern shores Lake Victoria	Titaniferous magnetite (Ilmenite)(containing 13% TiO_2) beach sands	The tonnage present is not known but appears to be large and sufficient to warrant further investigation	Magnetite concentrations of up to 90% are known to occur.

Source: Promotion of Extractive and Mineral Processing Industries in the EAC, Kenya Status, Republic of Kenya

Since 2014, exploration of iron ore has been going on in the country. Whilst the approximate locations of the main deposits being known, the size and quality of the deposits are not well understood and there is no significant production as of today (NMC, 2015). Therefore, further drilling is necessary to better understand the quality, consistency, depth and size of these depths.

2.9.1.2 Coal

Coal is readily available in Kenya having been discovered in Kitui, Kwale and Kilifi districts. The deposits in Kitui county are believed to be the largest in Africa and could provide affordable fuel to power industries hence boosting the country's revenue base, but exploration has been held back by political bickering and disputes over the sharing of wealth. The discovery of the coal was estimated at 400 million tonnes of commercially viable coal reserves in Block C in Mui Basin, with an estimated value of Sh3.4 trillion ($40 billion) in 2010. (Mutua, 2018). The concession to extract part of the mineral resources in Block C and D of the Mui Basin was awarded to Chinese firm Fenxi Mining Industry Company. Despite the government determining that coal exploration would start in 2016 (Ministry of Energy and Petroleum Kenya, 2015), the extraction did not take off owing to some political leaders delaying the process of coal mining and coal utilisation by instituting allegations against the Chinese company, among them that it was a briefcase entity lacking the financial government and technical capability to undertake the mining project (Mutua, 2018). However, it is worth noting that research is still underway to determine whether the coal is metallurgical or thermal.

2.9.1.3 Limestone

Limestone is readily available in kenya being plenty in Kajiado area and recently Kitui. Kajiado lies on the popular Mozambique belt. Limestone in Kenya is widely used in cement manufacturing as it forms a core raw material for production of clinker. The mineral is burned at very high temperatures to make clinker, which is then mixed with gypsum to produce cement. Limestone in Kitui has been discovered in Kanziku, Mathima, Simisi and Ngaaie areas and some of the reserves are estimated to hold enough limestone to last cement companies more than 50 years (Philip, 2015). This implies that the raw material is sufficient enough in the country for iron and steel production.

2.9.1.4 Ferrous scrap

Ferrous scrap is used as a raw material in the production of steel in an Electric Arc Furnace (EAF). Steel scrap production levels in Kenya stood at about 250,000 - 300,000 tons per year (EAC,2015) as of 2015. This low production has been attributed to the low steel scrap generation in the country. The main sources of this local scrap are Nairobi area and Mombasa with Nairobi contributing the largest part. However, scrap is also available in other parts of the country though in small quantities. Primary sources of this scrap include; Scrapping of motor vehicles, Ferrous scrap from rail, *as supplied by Kenyan railways***,** Demolition scrap (from pulling down buildings etc.) and Consumer goods.

Scrap export in the country was officially banned in June 2010 by the Kenyan

Government, a move which was initiated to preserve the raw material for use by the local steelmakers in the production of liquid steel.

2.10 Factors that affect the setting up of an integrated steel mill in Kenya

Despite the on-going efforts of determining the viability of setting up an integrated steel mill in Kenya, there are several factors that explain the reason why such a plant has not been set up yet. Some of these factors may include, but not limited to the following;

2.10.1 Insufficient credible information on state of iron and steel raw materials in Kenya.

Though the process of exploration, quantification and determination of quality of the raw materials for iron and steel production in Kenya has been on going, there is no significant credible information on the sources, qualities and quantities of the raw materials particularly iron ore and coal. Much of this is yet to be done making it difficult for potential investors in the sector to commit themselves (NMC, 2015).

2.10.2 Government policies on taxation

A key issue hampering the manufacturing sector has to do with tax policy implementation. For example, Value Added Tax (VAT) refunds from KRA take too long to come through, which constrains activity in the manufacturing sector and limits cash flows. This is a concern for a sector that is capital-intensive. This has become a key worry for industry players, as the money could be used for industry activity. Further, there are concerns about government tariff application which requires to be addressed (Anzetse,2016).

2.10.2 Access to finance

Although there is a willingness to finance the manufacturing sector in Kenya, conditions of financing are unfavourable and reduce uptake. Interest rates are very high, often around the

18% range and, although smaller financing is available via microfinance institutions, this is at even higher rates. Second, low tenure is partly informed by banks wanting to limit exposure to risks associated with the uncertainty of doing business in Kenya. As they stand, conditions of financing are difficult because the manufacturing sector needs patient capital of longer duration, as working capital cycles last six months on average. Thus, although it is relatively easy for formal manufacturers to obtain access to finance, because of the presence of assets that act as collateral, conditions of financing are negative. Both the interest rates and the duration of debt in local markets translate to an inability to access financing. The interest rate issue is of particular concern and puts the manufacturing sector in Kenya at a disadvantage because it is competing with international players, some of whom can access financing at interest rates of 2–3% (Anzetse,2016). Thus foreign manufacturing firms not only can take up such financing but also do not have to push for large profits to meet debt servicing obligations. They can make a 10% margin and still service the loan. In Kenya, the margin has to be far higher if a firm is to service the loan (Anzetse,2016). However, the Kenyan government is trying to make access of financing in Kenya affordable. Recently, the government has introduced an interest rate cap to cushion consumers from exorbitant bank interest rates.

2.10.3 Un-enabling business environment issues

The World Bank Kenya Economic Update (2016) notes that, a comparison of the World Bank's Enterprise Surveys from 2007 and 2013 suggest that the business climate is deteriorating. Firms in 2013 experienced higher financing costs, higher insecurity and more unreliable access to infrastructure. Kenyan firms make 30 contributions a year, and take 201 staff hours to calculate, file and pay their taxes. For traders, logistics are a major hindrance. On average, the procedures and documentation needed to import or export take

26 days; connecting to the power grid in Nairobi requires six steps, takes more than five months and costs on average 10 times the per capita gross national income. Specific elements of this business environment negatively affect the manufacturing sector (Anzetse,2016).

Registration and licensing is a concern as there is no one-stop shop for investors looking to start manufacturing in the country. There is no check-list on how to set up a business and what is required. If there were, all the different requirements come from completely different and unrelated entities. The Kenyan government has however introduced e-platforms to ease the processes of registration and licensing among other issues. These e-platforms include, but not limited to *e*-citizen and *i*-tax.

2.10.4 Electricity concern

The Kenyan population and industrial activity have grown but the production, transmission and distribution infrastructure of electricity has not grown with the same measure. Poor electricity transmission and distribution infrastructure leads to erratic power supply and outages which costs manufacturers as it leads to idle time. Further, power outages mean manufacturers are forced to buy generators, which are an added cost in terms of purchases and operations. Fluctuations in power and power outages lower productivity as machines have to be restarted and machine lifetime is shortened. Early breakdown can occur because of the sensitivity of machines used in production. The Ministry of Industry, Trade and Cooperation (MITC) in Kenya agrees that the issue of high electricity costs in the country perturbs many investors (Lee,2016).

However, the Kenyan government has invested heavily on electricity production. The country has been tapping the geothermal resources in the Rift Valley as part of its broader ambition to add 5,000 Megawatts to its electricity output by 2017(Allan, A. 2015). That will add to the country's existing capacity of about 2,152 MW. The country has close to 3,000 MW of proven geothermal energy in the Rift Valley, but currently exploits just over 390 MW of geothermal capacity. Recently, the country also launched a multi-billion-shilling wind power project in Turkana. The Turkana Wind Project is expected to deliver 310MW worth of electricity with its completion scheduled to be 2017. It is going to be the largest wind power project in Africa. The deal was entered with the Vestas Wind Systems Company of Denmark (LTWP, 2015).

2.10.5 Land

Land tenancy establishment is difficult in Kenya, in that land titles are not clear and sometimes overlap. Thus land issues (land title disputes, long transaction times, corruption) make it difficult to establish business activity (Anzeste, 2016).

2.10.6 Infrastructure issues

The movement of goods from the port in Mombasa to Kisumu and Eldoret is expensive, given the generally poor state of roads. This translates to higher vehicle maintenance costs, which then leads to higher costing of transport services. In addition, congestion is a concern: the movement of goods takes a longer time, thus increasing the cost. A final issue related to transport is corruption, with police often demanding bribes from transporters, thereby driving transport pricing up. However, the Kenya Government through, the Kenya Industrial Transformation Plan (KITP) is doing a lot in terms of improving the infrastructure. It has embarked on building a standard railway gauge (SGR) to lower the transportation costs as well as cut down on the transportation time between destinations. Currently, transportation of cargo from Mombasa to Kampala takes four to five days. It used to take 18 to 20 days about three years ago (Lee,2016)

2.10.7 Labour and skills

Kenyan labour force is well educated but not well skilled. This is echoed by the World Bank Kenya Economic Update, which states that Kenya has a relatively well-educated labour force but a majority of adults remain functionally illiterate (Anzetse 2016). Productive jobs require a skilled labour force. The manufacturing sector, like many sectors in the country, has identified issues with skills in its labour force, with a clear gap between education and skills. The Government of Kenya however recognizes that industrial skills development has been weak and has made an effort to revive institutions that develop technical skills, such National Industrial Training Authority (NITA). It has also embarked on a rigorous campaign of building, funding and fully supporting the technical institutions in the country so as to produce skilled manpower who will take the country's industrial wheel to the next level.

Other issues affecting the setting up of an iron and steel plant in the country include stiff competition from regional and international markets, technology issues, regional import and export tariffs, political instability, corruption among others.

2.11 Investment model

Investment models are tools that are employed to estimate the benefits of an investment or improvements and balance the benefits of these improvements against their costs. Investment models should identify the assumptions made and address how these assumptions alter the estimates (Curlee & Busch 2004). Such models are usually employed when making decisions involving very large investments.

Steel mills are very large industrial real investments. They require large initial investments and have long economic lives. Typical initial costs are US$ 4.2 billion for a 6 million tonnes per year integrated steel plant as proposed in 2009 by Essar Steel Ltd in Bagalkot, Karnataka in India (Essar Steel Ltd,2009). Very large industrial real investments are defined as those with the following three characteristics ;*Large irreversible initial investments* (Investments are said to have a high degree of irreversibility when they have attributes that make capital specific to the product, firm or location), *Long economic lives, usually over five years* (The further into the future projections are made, the more difficult it is to forecast accurately), *Long time to build, usually several months* (Very large investments usually take a long time to build). During the period between the investment decision and completion, no revenues are generated. This should be put into consideration when developing the model. Investment models can be public or private. The best choice is arrived after a cost-benefit analysis is done.

2.12 Summary

From the available literature, the following knowledge gaps are evident.

- Whilst the available data shows that steel consumption trends have been increasing globally, consumption trends in the country have not been well studied and documented. This study looked into steel demand within the country and made a projection of probable usage into the year 2030.
- The Kenyan government has invested alot in creating an enabling environment for the setting up of an integrated iron and steel plant. However, no research has been conducted on the process design of the plant. This study developed a process design which can be used in setting up an iron and steel processsing plant in Kenya based local content.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter provides an overview of the research methods that were used in this study. It outlines the research design, data collection, the type of data collected and data collection procedures. It also describes how the data was analyzed, presented and displayed.

3.2 Research design

The research design adopted for this study was an exploratory research design. According to Polit et.al (2001), explorative designs are undertaken when a new area is being investigated or when little is known in the area of interest. It is used to explain the full nature of a phenomenon and other factors related to it. Steel data in Kenya is scanty and the available one is scattered all over. Little is known in terms of quantities of steel used in Kenyan heavily consuming industries. In this research, steel usage across in the country was explored. The research design assumed two types; case study and analysis of secondary data designs.

3.2.1 Case study

A case study is used in investigating one or a few situations similar to the problem at hand. This research employed case studies to help in developing a process design for a Kenyan steel plant. This was achieved through an extensive desk research on technologies used in setting up plants world over and the best technology was adopted based on the local content. The design developed is best suited for a plant in Kenya. The case studies included China, India, Japan, South Africa and South Korea because they form the major trading partners with Kenya on iron and steel products (Trading Economics,2016). This therefore implies that they are well equipped with the technology needed to produce the steel products suited for the Kenyan market. This technology would easily be emulated to set up an iron and steel plant in the country.

3.2.2 Secondary data analysis

Secondary data is data gathered and recorded by a particular party prior to and for a purpose other than the current study. The data is usually structured to fit into the study it is to be used for whatever purpose intended. In this study, data was obtained from Numerical Machining Complex (NMC), Kenya National Bureau of Statistics (KNBS), Ministry of Industry and Trade Cooperatives (MITC), Ministry of Energy, Ministry of Mining and Petroleum and other key players in the manufacturing industry. The choice of these ministries was because each had a critical part to play in ensuring that the dream of setting up an integrated steel mill was achieved. The data obtained from these different agencies and institutions was structured and analyzed for the use in projection of demand, technical appraisal and financial analysis.

3.3 Data collection

Most of the data collected was secondary data. The following data was sought;

3.3.1 Availability of raw materials

This data was sought from the Ministry of Mining, Ministry of Industry, Trade and Cooperatives, Ministry of Energy and Numerical Machining Complex. It was purposely used in determining the state of raw materials in Kenya for an iron and steel plant in terms of availability, quality and quantity. The data also sought to determine other alternative sources of raw materials in the event that the materials present in the country were insufficient.

3.3.2 Steel usage

This data was used in determining the demand of steel in the country. It informed the study on the Kenya's current steel use trends. It also determined whether steel use in the country was on the rise compared to global steel use trends. The data was used in forecasting to determine the future possible steel demand. This future steel demand was seen as the potential future market for steel. The demand was also used in determining the recommendable annual output capacity for the steel plant in the process design. The data was sourced from local and international agencies and bodies having authority in steel production. The bodies included, but not limited to, KNBS and Worldsteel.

3.3.3 Kenya steel trade

Data on the country's steel trade with her neighbours and the international market was also sought. This data was used to provide information on the type of finished or semi-finished steel products that Kenya largely imported from other countries. Similar data was also sought for the neighbouring East Africa countries, that is Tanzania, Sudan, Ethiopia, Uganda, Burundi and Rwanda. This data was important in determining the current supply gap in the country which would inform an investment opportunity. Steel trade data for the neighbouring countries would serve as information on the potential regional market if Kenya was to set up a steel plant. Any identified supply gap would also inform on the country's steel plant's process design.

3.3.4 Raw material costs

This data comprised costs of raw materials used in the iron and steel plant. The data also consisted of the costs of other consumables used in iron and steel production. The data was used in determing the production cost of the proposed process design viz a viz the revenue to be generated by the same plant. These production costs and generated revenue were used in establishing the profitability of the proposed venture. This economic analysis was also used in ascertainng the viability of setting up the proposed plant.

3.3.5 Human development index

This is a composite index which includes health, education, income, livelihood security and other indicators. It is an indicator showing how successful are achievements in three main fields of human development: healthy life, knowledge and decent standard of living (Knoema, 2017). A country scores a higher HDI when the lifespan is higher, the education level is higher, and the Gross National Income (GNI) per capita is higher hence higher purchasing power. This data was used steel demand projection.

3.3.6 Economic growth

Growth in economy leads to increased job opportunities hence income to many people. This leads to improved living standards for people and their capacity to purchase goes up. This can ultimately impact on steel demand. The data obtained on Kenya's economic growth was used in steel demand projection.

3.3.7 Population growth

High population in a country means more demand and high customer base for a particular product. Population also calls for more expansions in terms of social amenities, infrastructure, buildings and other forms of constructions. Data obtained on population was used in forecasting steel demand and also in determining steel usage per capita within the country.

3.3.8 Process design data

Data projected on steel demand was used to determine the plant output capacity. Data on raw materials informed the design process to be selected for the process design based on local content.

3.4 Data analysis

This research employed several data analysis techniques. Data handling, structuring and projection was done using the MatLab software. Projection of steel demand was done using multiple linear regression and compounding techniques.

Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data (Higgins 2006). Every value of the independent variable *x* is associated with a value of the dependent variable *y*. The population regression line for *p* explanatory variables x_1, x_2, ..., x_p is defined to be $y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_p x_p$. This line describes how the mean response *y* changes with the explanatory variables. The observed values for *y* vary about their means μ_y and are assumed to have the same standard deviation (σ). The population parameters $\beta_0, \beta_1, ..., \beta_p$ of the population regression line are estimated by fitting sample statistics $b_0, b_1, ..., b_p$ in the population regression line. Since the observed values for *y* vary about their means μ_y, the multiple regression model includes a term for this variation. The notation for the model deviations is ε (random error). The model is computed as follows for *n* observations;

$$yi = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + ... \beta_p x_{ip} + \varepsilon_i \quad for\ i = 1,2, ...\ n.$$

For the predictor model, the least squares method was used to determine the regression line and it was based on the expression $min\Sigma(y - \hat{y})$. The predicting model was computed as;

$$\hat{y} = b_0 + b_1 x_1 + b_2 x_2 + ... b_p x_p$$

It is worth noting that, the independent variables should correlate with the dependent variable for multiple regression to be applied effectively. As so, a regression analysis was carried out to determine the correlation between the used variables. The p-value test statistic approach was used to determine the correlation significance.

Multiple regression was employed in forecasting overall steel demand within the country. This was geared towards determining the future demand of steel in the country by 2030. This future demand was perceived as the future steel market. The independent variables used were economic growth, human development index and population growth.

The compounding method is a method used in determining the future value of a present value after a period *n* based on a determined rate. This method was used in calculating the future demand of steel in areas that the usage of time series technique was inadequate. It was computed as follows;

$$y = x(1 + r)^n$$

where; $\boldsymbol{y}$ = predicted value after time *n*. $\boldsymbol{r}$ = compounding rate

$\boldsymbol{x}$ = present value. $\boldsymbol{n}$ = forecasting period

The Intensity of Use Technique (IOUT) can also be employed in forecasting steel usage. This technique has been used by different scholars in determining the intensity of steel use in different countries. The technique is usually modelled for different end-use industries in a country. Roberts (1990) used this approach to estimate steel consumption in the US over the period 1984-2010 by disaggregating the total steel use in the country into the amounts consumed in each of the machinery, transport and infrastructure industries. Crompton (1990) used IOUT to determine steel consumption in Japan over the period 1997-2005. He identified six steel-consuming industries; machinery, electrical machinery and equipment other manufacturing, construction and fabricated metal products.

The model is based on any of the following identities:

$$s_t = \sum_{i=1}^{n} \left(\frac{S_{it}}{P_{it}} X \frac{P_{it}}{GDP_{it}} X \, GDP_t\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

or

$$s_t = \sum_{i=1}^{n} (MCP_{it} \, X \, PCI_{it} \, X \, GDP_t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Equation 2}$$

or

$$s_t = (IU_t \, X \, GDP_t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Equation 3}$$

where S_{it} is the quantity of steel consumed by industry *i*, S_t is the quantity of steel consumed across all *n* steel-consuming industries, P_{it} is the total value of production in industry *i* and $IU_t = S_t / GDP_t$ is the average intensity of steel use across the *n* steel-consuming industries. The MCP_{it} is the material composition of product for industry *i*, which measures the average amount of steel consumed per unit of output in that industry. The PCI_{it} *is* the product composition of income for industry *i* which measures the relative share of that industry's production in GDP. The product of these three components for a steel consuming industry yields the amount of steel used in that industry. A sum of these individual steel uses gives the total domestic consumption for that particular period. Forecasts of these separate components for each industry are used to forecast aggregate steel consumption.

3.5 Economic analysis

Economic analysis was carried out for the proposed steel plant process design to determine its profitability. The Earnings Before Interest, Tax, Depreciation and Amortization (EBITDA) was calculated to determine its profitability. Debt Service Cover Ratio (DSCR) was also calculated to establish the plant's capacity to service any loan incurred during its setup. A Profit & Loss A/C was drawn to aid this process. The following formulas were used;

$$EBITDA = Revenues - (Fixed\ costs + Variable\ costs)$$

$$DSCR = \frac{EBITDA}{Total\ Debt\ Service}$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter is divided into three sections; Kenya's steel demand analysis, Technical appraisal, and Financial Projections.

4.1 Steel demand analysis

This section will look into the status of steel production in the country, present and future demand, steel supply gap and competition.

4.1.1 Steel status in the country

There is no single comprehensive source that clearly outlines the current up- and down-stream steel-making capacity in the country. Moreover, the little available data and information is scanty and scattered all over making it difficult to find a credible source, rich with information. However, as of 2014, the country had 20 steel makers which involved scrap-based induction furnace instead of EAF steelmaking (Metal consulting UK, 2014). These steelmakers have a capacity of producing 340,000 metric tons of liquid steel. Finished steel production capacity in the country is majorly dominated by light long and flat products standing at 555,000 and 245,000 tons respectively (Metal consulting UK, 2014). There is seemingly no production capacity for heavy sections, steel plate and hot-rolled coil within the country. However, it is worth noting that Devki Steel Mills plans an expansion of its steelmaking capacity, with investment in a new 125,000 tons per year melt shop and billet mill in Kitui. Table 4.1 shows the steel producing plants in Kenya as at the end of 2014 and their annual installed capacity.

Table 4.1 Steel producing plants in Kenya as of 2014

Company	**Location**	**Steel**	**CC**	**Plate**	**HRC**	**CRC**	**AlZn**	**Corrugated**	**OCS**	**H/S**	**L/S**	**Wire**	**L/Tube**	**H/Tube**
Apex Steel	Athi River	30									25			
Athi River Steel	Athi River	20									60	20		30
Brollo Kenya	Mombasa													50
Corrugated Sheets	Mombasa							20						5
Devki Steel Mills	Athi River	100									70		10	25
Devki Steel Mills	Ruiru										85			
Doshi Enterprises	Mombasa	30									15			15
Emco Billets	Nairobi	25	20								75			
Insteel	Nairobi													45
Jitan Steel	Mombasa										30			
Kenya United Steel	Miritini	25	25			185	120				30	10		
Mabati Rolling Mills	Mombasa	10												
Morris & Co.									40					
Standard Rolling Mills	Mombasa					60								
Steel Makers Ltd	Athi River	60									60			
Thermal Steel	Mombasa										60	10		30
Tononoka Steel	Nairobi	40									35			
Annual Prod.		**340**	**45**	**0**	**0**	**245**	**120**	**20**	**40**	**0**	**555**	**40**	**10**	**200**
Devki Steel Mill [under construction]	*Kitui*	*125*	*125*											

Units= '000 tons

HRC-*Hot Rolled Coil,*

CRC- *Cold Rolled Coil,*

AlZn- *A zinc or aluminium-zinc coating line,*

OCS -*Organic Coated Sheet (a painted and metal-coated sheet steel product).*

The ***light long*** *category shown above includes medium and light sections, bar, rebar, and wire rod,*

H/S *– Heavy section,* ***L/S*** *– Light section,* ***L/Tube*** *– Light tube,* ***H/Tube*** *– Heavy tube,* ***Steel***-*Liquid steel*

Source: Metal Consulting UK

4.1.2 Kenyan steel trade

Kenyan trade in steel has increased significantly since 2010 from net imports of 695,000 tons (2010) to 1,167,000 tons in 2014. By way of comparison, Ethiopia, Tanzania and Sudan recorded steel net imports of 780 000, 710 000 and 380 000 tons by 2014 respectively (EAC, 2015).

Out of the 1,167,000 tons net steel imports in Kenya in 2014, approximately 740,000 tons comprised of hot-rolled coil, which was majorly imported from South Africa, India, Japan and South Korea.

4.1.3 Steel production and demand in Kenya

Statistical data for steel production in Kenya is scarce. However, a simple approach was carried out to get an estimate of the values:

- The amount of steel scrap used in the industry provided an estimate of liquid steel production.
- Liquid steel production levels together with billet import volumes were used to give a fair estimate of probable light long production volumes.
- Assumptions about flat product plant capacity utilization (which for steel mills is normally in the 50-90% range) provided further estimates of cold rolled and coated product production volumes with the upper limit on Kenyan flat product production set by the volume of hot-rolled coil imports.

Table 4.2 shows Kenyan steel demand from 2010 to 2014. The demand for steel can be seen to rise from 804,000 tons to approximately 1.6 million tons. The calculated steel demand compared well with world steel estimates.

Table 4.2 Kenyan steel demand in tons, 2010-2014

	Steel demand ('000 tons)				
	2010	**2011**	**2012**	**2013**	**2014**
Production from semi-finished	91	105	121	140	150
Production from liquid steel	18	18	18	225	242
Imports	695	1088	807	1145	1167
Total (Demand)	**804**	**1211**	**946**	**1510**	**1559**
World Steel Association Estimate	***808***	***1218***	***960***	***1316***	***1342***

(Source: Kenya Association of Manufacturers,2014 & Worldsteel, 2016)

4.1.3.1 Steel demand projection

Projection of demand of steel between 2010-2030 was determined using multiple regression to ascertain the probable future steel market. The data used was based on Human Development Index (HDI), population and economic growth. Table 4.3 shows steel demand in Kenya (2010-2014), projected HDI (2010-2030), projected population (2010-2030) and projected economic growth (2010-2030).

Table 4.3 Steel demand, HDI, population and GDP growth rate data.

Year	Steel demand ('000 tons)	Population (million)	Human Devt Index	GDP growth rate
2010	804	40.3	0.5	5.8
2011	1211	41.4	0.6	6.1
2012	947	42.4	0.6	4.6
2013	1510	43.7	0.6	5.7
2014	1559	44.9	0.6	5.3
2015		46.7	0.6	5.7
2016		47.8	0.6	5.8
2017		49.1	0.6	5.0
2018		50.4	0.7	5.4
2019		51.7	0.7	6.0
2020		52.9	0.7	6.1
2021		54.2	0.7	6.4
2022		55.5	0.7	6.4
2023		56.8	0.7	5.1
2024		58	0.7	5.1
2025		59.3	0.7	5.3
2026		60.6	0.7	5.3
2027		61.8	0.8	5.4
2028		63.1	0.8	5.5
2029		64.4	0.8	5.6
2030		65.7	0.8	5.7

Sources: UN worldometer (population data), Knoema (HDI data), Knoema & International futures (GDP growth rate data)

To determine the correlation between steel demand (dependent variable), Human Development Index (HDI), population and economic growth regression analysis was carried out at a confidence level of 0.95 and the parameters chosen were found to be positively correlated with a p- value of less than 0.05 and a coefficient of determination of 0.99 as shown in Table 4.4.

Table 4.4 Regression analysis

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.99999294							
R Square	0.99998589							
Adjusted R Square	0.99994355							
Standard Error	2.50813554							
Observations	5							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	3	445728.5093	148576	23618.2	0.004783236			
Residual	1	6.290743896	6.29074					
Total	4	445734.8						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-20851.799	325.7096052	-64.02	0.00994	-24990.33203	-16713.3	-24990.332	-16713.266
Population (million)	-53.861517	6.500478196	-8.2858	0.07646	-136.4579242	28.73489	-136.45792	28.7348895
Human Devt Index	40328.1747	1060.178378	38.039	0.01673	26857.33119	53799.02	26857.3312	53799.0182
GDP growth rate	330.319239	2.550886225	129.492	0.00492	297.9071567	362.7313	297.907157	362.731322

Using the data in Table 4.4, the regression model (predictor model) was computed as follows.

Taking x_1, x_2 and x_3 to represent population, HDI and GDP growth rate respectively, the predictor model, $\hat{y} = b_0 + b_1x_1 + b_2x_2 + \ldots . b_px_p$, was computed as follows;

$$\hat{y} = -20851.8 - 53.9x_1 + 40328.2x_2 + 330.3x_3$$

The projected steel demand is as shown in Table 4.5

Table 4.5 Projected steel demand 2010-2030

Year	Steel demand ('000 tons)	Population (million)	Human Devt Index	GDP growth rate	**Projected steel demand ('000 tons)**
2010	804	40.3	0.5	5.8	*802.8464892*
2011	1211	41.4	0.6	6.1	*1208.044541*
2012	947	42.4	0.6	4.6	*945.2595922*
2013	1510	43.7	0.6	5.7	*1510.059324*
2014	1559	44.9	0.6	5.3	*1556.141877*
2015		46.7	0.6	5.7	*1834.276145*
2016		47.8	0.6	5.8	*2062.631099*
2017		49.1	0.6	5.0	*1943.628882*
2018		50.4	0.7	5.4	*6500.507734*
2019		51.7	0.7	6.0	*6906.454836*
2020		52.9	0.7	6.1	*7141.636371*
2021		54.2	0.7	6.4	*7434.229388*
2022		55.5	0.7	6.4	*7614.819315*
2023		56.8	0.7	5.1	*7311.991311*
2024		58	0.7	5.1	*7480.55592*
2025		59.3	0.7	5.3	*7659.54997*
2026		60.6	0.7	5.3	*7813.087272*
2027		61.8	0.8	5.4	*7975.213692*
2028		63.1	0.8	5.5	*8123.293749*
2029		64.4	0.8	5.6	*8264.329931*
2030		65.7	0.8	5.7	*8396.542538*

The projected steel demand values (2010-2014) compared well with the actual values within the same period. This implies that the predictor model was valid. Steel demand was projected to rise from 0.804 million tons in 2010 to approximately 8.4 million tons by 2030. When expressed in per capita basis and compared to the world context, the steel use intensity in Kenya is seen to be unduly low. This illustrates a need to invest in the steel industry. Table 4.6 compares Kenya steel use per capita in 2015 to that of other key global steel industry players, Africa and the world. It was found out that Kenya uses 37.2 kg of steel per person compared to the world's 208 kg/capita.

Table 4.6 Comparison of Kenya's steel demand per capita to other economies (2015)

	Kenya	**Africa**	**World**	**S.Africa**	**USA**	**China**
Steel demand per capita (Kg/capita)	37.2	32.8	208	97.1	298.8	488.8

(Source: Worldsteel,2016)

Assuming the country's economy will continue to grow towards a rate of double digits as envisaged in vision 2030 blueprint and that the population will continue to rise, Table 4.7 shows the future steel use per capita (kg/capita) by 2020, 2025 and 2030. It can be seen that the demand use per capita rises to 127.8 up from 39.3 as of 2015.

Table 4.7 Future Kenya steel demand intensity per capita (Kg/capita)

Year	**2015**	**2016**	**2020**	**2025**	**2030**
Population size, (million)	46.7	47.8	52.9	59.3	65.7
Steel Demand '000 tons	1834	2062	7141	7659	8396
Steel demand, Kg/capita	**39.3**	**43.1**	**135.0**	**129.2**	**127.8**

4.1.4 Steel supply gap in Kenya

The amount of steel imported into Kenya today (as of 2016) together with some of the steel which is currently imported by Kenya's neighbouring countries represents an immediate steel production opportunity. Still, in the longer term, the additional output should be possible because of the expected steel demand growth in Kenya.

4.1.4.1 Near-term supply gap based on imports

An appraisal of the capacity structure of the Kenyan steel sector (Table 4.1) indicated that there is presently no Kenyan production of hot-rolled coil. Moreover, import statistics showed that in 2014, imports of hot-rolled coil averaged 740,000 tons, a figure that has ranged between 400,000 tons and 740,000 tons since 2010. The appraisal also indicated a combined average of 391,000 tons worth of HRC imports in the neighbouring countries (NMC, 2015). Table 4.8 shows the amounts of HRC imports in Kenya and her neighbours.

Table 4.8 HRC imports in Kenya and her neighbours (2014)

Country	Current imports '000 tons	
Kenya		**740**
Ethiopia	43	
Madagascar	1	
Mozambique	15	
Somalia	0	
Sudan	63	
Tanzania	229	
Uganda	40	
Total	**391**	
		391
Total HRC imports 2014		**1121**

Source: Numerical machining

Significant volumes of semi-finished steel (mostly billet) are also imported into Kenya, with 2014 imports standing at 168,000 tons/year. It is noted, however, that Devki's capacity expansion plans which involve a construction of a 125,000 tons/year billet plant at Kitui should largely substitute these billet imports.

The biggest immediate volume opportunity for Kenya, therefore, lies in the production of hot-rolled coil which is quantified on the basis of:

- 100% import displacement of current HRC imports into Kenya.
- 50% share of current HRC imports into neighbouring countries.

Based on this analysis of HRC imports, it was found out that a near-term supply gap (year 2014) stood at about 936,000 tons (Table 4.9).

Table 4.9 The near-term HRC supply opportunity.

Country	Current imports ('000 tons)		Kenya steel industry share ('000 tons)	HRC supply opportunity ('000 tons)
Kenya		740	100%	**740**
Ethiopia	*43*			
Madagascar	*1*			
Mozambiqu	*15*			
Somalia	*0*			
Sudan	*63*			
Tanzania	*229*		50%	**196**
Uganda	*40*			
Total	***391***			
		391		
Total 2014		1121	83%	**936**

Since it would be some time before any new mill was constructed, the near-term supply gap was better expressed in terms of the expected demand in the years 2018 and beyond. By that time, the near-term supply gap of hot-rolled coil was likely to be at least 1 million tons/year taking 5% growth in demand between 2014 and 2018. The 5% growth in demand was taken based on the growth rate of the economy which averaged 5 % (KNBS, 2015) and particularly in the construction sector which is the major consumer of steel products. The future HRC steel demand values were computed through a compounding process. The computation formula was as follows;

$$y = x(1 + r)^n$$

Using the HRC import amounts in Table 4.9 and taking a 50% share in all the imports in the neighboring countries, a 100% share in Kenyan imports, a 100% output capacity and a 5% growth in the HRC demand, the future potential orders of HRC from the year 2018 was envisaged as shown in table below 4.10. Table 4.10 shows the projected HRC demand in Kenya and her neighbours by 2018. The compounding period was between

2014 and 2018.

Table 4.10 Future potential demand (HRC) 2018 and beyond

Country	Potential sales ('000 tons)
Kenya	856
Tanzania	133
Sudan	37
Ethiopia	24
Uganda	23
Others	9
Total Sales (Potential	**1082**

It is envisioned that this demand will continue to grow as the economy of the country and that of her neighbours grows.

4.1.4.2 Longer-term supply gap based on demand growth

The growth in the market expected beyond 2018 will lead to an increased need for a supply of large amounts of HRC hence a longer-term supply gap. This will spark a need for a longer-term solution. Though Kenyan iron-ore is contemplated to be available from 2018 (NMC 2015), the Lamu Port Southern Sudan Ethiopia Transport (LAPSSET) rail network will possibly not be functional by that time, and still probably not earlier than 10 years (until after the Lamu Port is fully built), therefore it would be more appropriate to assess the longer-term supply gap between years 2020-2030. This supply gap was however quantified on the basis of the following;

- Taking a 1 million ton HRC supply gap as at 2018 through 2030. This was based on the the projected HRC demand by 2018 (Table 4.10).
- Recognizing an expected growth of Kenyan flat-rolled steel demand between 2018 and 2020 / 2030. This was based on the premise that the steel consuming industries in the country shall continue to thrive and grow at a rate averaging that of the

economy currently standing at 5% (KNBS 2015). The rate was taken to remain steady through out the forecast period.

- Recognizing also the growth in Kenyan steel tube demand, on the basis that hot or cold rolled steel coil is the main feedstock for the production of the welded tube.
- Assuming some degree of steel demand growth in the adjacent steel markets of Tanzania, Sudan, Ethiopia and Uganda. This was based on the premise that the steel consuming industries in the neighbouring countries shall continue to thrive and grow at rate of 10% as witnessed in the construction sector which recorded >10 % growth in Uganda (Anita 2018).

Based on this, the future HRC demand was analyzed using a compounding formula. Table 4.11 shows the expected HRC steel demand between 2020-2030. The flat products and tube demand values in 2015 were Kenya imports obtained from Worldsteel (2016). This projection was done through a compounding method between 2018 and 2030.

Table 4.11 Longer-term HRC supply opportunity

		HRC Demand estimate ('000 Tons)		
Year	**2015**	2020	2025	2030
Near-term supply gap,2018		1000	1000	1000
Kenya flat-rolled demand growth (~5%)	850	1084	1318	1682
Kenyan growth in tube demand (~5%)	76	97	117	150
Demand growth in adjacent steel markets (~10%)	196	315	462	744
TOTAL TONNAGE		**2496**	**2897**	**3576**

From the analysis above (Table 4.11), it is evident that the demand of HRC will grow from 1 million tons in 2018 (Table 4.10) to 2.496 million in 2020, 2.897 million in 2025 and 3.576 million tons in 2030 given that favourable economic conditions prevail.

4.1.5 Regional and international competition

Competition in Kenya was found to be very insignificant in flat-rolled production as only Mabati Rolling mills and Devki showed a meagre production of the same. However, no competition was registered for the HRC production in the country. Regionally, a survey into the main steel producers in Tanzania, Uganda, Sudan, Madagascar and Mozambique (NMC, 2015) identified a steel production pattern similar to the Kenyan in that;

- There was a fair number of small steelmakers, who mostly have <100 ,000 tons/year of capacity.
- Producers of light long steel products dominate [for supply of light sections, bar, rebar, rod].
- There was a handful of tube makers (mostly welded tube), and some wire drawing capacity.
- There was one dominant producer of cold -rolled coil.
- There was no capacity for production of heavy section, plate or hot rolled coil.

Though the analysis identified lack of competition in HRC production in the region, it further identified the SAFAL Group as a key competitor due to its broad presence in Africa an indicator it would still be a key customer for HRC products in future.

Internationally, Kenya's main source of HRC products is South Africa, Japan, India and South Korea. From this, it can then be inferred that her main competitors are Arcelor Mittal South Africa's Vanderbijl park facility, Tata Steel's Jamshedpur Plant in India, Nippon Steel & Sumitomo Metals' Kimitsu Works in Japan and POSCO's Kwangyang

Plant in South Korea.

4.2 Technical appraisal

This section looks at the state of raw materials required, the probable technology for the establishment of the Kenyan steel industry, the preferred requisite plant configuration and land requirements.

4.2.1 Raw materials

4.2.1.1 Ferrous Scrap

Steel scrap production levels stood at about 250,000 - 300,000 tons per year (EAC,2015) as of 2015. This has been attributed to the low steel scrap generation in the country. The main sources of this local scrap are Nairobi and Mombasa areas. Nairobi area contributes the largest percentage of local steel scrap. However, scrap is also available in other parts of the country though in small quantities.

Due to the limited nature of the raw material in the country, South Africa will play a very key role in supplying this commodity. It is worth noting that South Africa's annual net exports for ferrous scrap stand currently (as of 2016) at 1.2 million tons (Worldsteel 2016). Much of this scrap has been mostly exported to India, Pakistan, Malaysia, Vietnam and Indonesia.

4.2.1.2 Iron ore

Since 2014, exploration of iron ore has been going on in the country. Whilst the approximate locations of the main deposits are known, the size and quality of the deposits are not well understood and there is no significant production as of today, 2016. (NMC, 2015).

Based on a report by the Republic of Kenya on the status of iron ore in the country (Table

2.6), there are eight main deposits. These are at:

- Coast region covering Jaribuni in Kilifi, Mrima Hill in Kwale and Wanjala mining & Mraru ridge in Taita Taveta
- Eastern region covering Ikutha in Kitui and Marimanti in Tharaka Nithi
- Western & Nyanza covering Homa Bay, Uyoma peninsular, Ndere Island and Bukura near Kakamega.

Regarding these sites,

- There have been preliminary aerial surveys at Taita Taveta where the ore is found to be very high quality with 67% iron (Fe) content.
- The Tharaka iron ore quality is largely uncertain. A grab sample assay yielded a 40%-50% Fe content. A 80 km rail link between Tharaka and Isiolo town to the north (one of the resort cities planned under Vision 2030) would give Tharaka iron ore direct access to the LAPSSET railway link and thus a direct access to Lamu Port.
- The Kitui iron ore is found to have a 58% Fe content.
- Homa Bay is determined to contain hematite. Notably, Prime Steel (a new steel plant) located at Muhoroni some 75 km to the north-east of Homa Bay has been constructed.

Generally, further drilling is necessary to better understand the quality, consistency, depth and size of these deposits. In this respect, one significant limitation is the lack of drilling equipment. Presently, there is just one drill site (NMC,2015), but with 5 or 6 drill sites, much faster progress would be made in understanding the potential of these deposits. Since it is expected that at least 1-3 years' work will be required for testing any deposit, with a further 1-2 years' effort required to prepare any such site for commercial exploitation, it is considered by the ministry of mining that it will be at least 4 years before commercial exploitation of Kenya's iron ore mines can commence.

In summary, it is probable that good quality Kenyan iron ore with 65% Fe content could be available from 2018 (NMC,2015).

4.2.1.3 Thermal and metallurgical coal

Kenya does not mine any coal today. According to the ministry of mining, there are however two substantial coal basins in the country. These are:

- The Mui Basin, which lies to the south-east of Mwingi and has an estimated 400 million tons of coal identified so far.
- The Taru Basin located to the west of Mombasa.

It is considered the Mui Basin is the larger of the two coal reserves. Moreover, according to the ministry of mining, it is believed that Kenya has thermal coal (steam coal) only. However, exploitation process of the first block of coal in the Mui Basin is in progress. This coal could be transported to coastal sites, either with the construction of a 150-km rail link to the north linking with the LAPSSET rail network; or with the construction of a 150-km rail link to the south, linking with the Mombasa / Nairobi railway.

In summary, it is probable that Kenyan thermal coal supply will be available from 2018. Kenyan supply of metallurgical coal at this point, however, seems less likely. Thermal coal is also readily available in Tanzania. For both thermal and metallurgical coal, import from South Africa, China or Australia is another feasible option.

4.2.2 Technology issues relating to steel production in Kenya

4.2.2.1 Scrap-based versus Iron-ore based steelmaking

The integrated steel production method is characterized by high volumes of steel production (at least 4 million tons per year) and heavy capital investment. It is a massive venture which requires many installations ranging from a sinter plant, coking plant, Blast Furnace (BF), Basic Oxygen Furnace (BOF) and downstream finishing process. The coking process is a very difficult process to control environmentally as well as the gases produced by the BF. This technology is best suited for high annual productions.

The mini-mill process route uses either steel scrap, hot metal, direct reduced iron or hot briquetted iron in steel production. It is considered to be the more flexible, less capital intensive process route when steel volumes between 500,000 and 2 million tons per year are considered. They normally produce 25 – 30 heats per day and are found in melt shops producing 500,000 – 2,000,000 tons per year. (NMC,2015)

Given these economies of scale, an EAF would be the low-cost selected production option for a 1 million tons per year plant in Kenya.

4.2.2.2 Metallic charge options for the EAF

The choice of an EAF steelmaking process route lies normally between scrap-based and iron-ore based steelmaking with scrap-based steelmaking being the cheaper route. However, that withstanding, EAF steelmaking may also make use of metallic charge which it can derive from iron ore. In this respect, the main options for the source of the metallic charge may be:

- pig iron, which may be obtained from traditional large-scale (multi-million ton) blast furnaces or from so-called mini-blast furnaces

- direct reduced iron (sponge iron)
- hot metal obtained from the smelting of iron ore, e.g. via the Corex process.

With respect to the different metallic charge options for an EAF steelmaking process, unavailability of both commercial iron ore and coking coal and a projected HRC demand of 1 million tons by 2018, a mid-sized Kenyan steel plant with ~1 million tons/year capacity would be the best near-term option. This plant would be dependent upon foreign-imported scrap as the main source of raw material. Over time, a significant proportion of this scrap [perhaps 40-50%] could be replaced by blast furnace hot metal, DRI or Corex hot metal if steelmaking economics allow. The appropriate technology for producing the feed to the EAF as HRC demand grows (Longer-term supply gap) would be determined progressively through a comparison of the available options (BF hot metal, DRI and Corex hot metal) based on liquid steel cost production, ability to use locally available raw materials, production rate, operating cost, environmental impact, complexity and logistics.

4.2.2.3 Continuous casting /Rolling mill options

Refined liquid steel needs to be solidified into a section size suitable for downstream rolling into the finished hot-rolled coil. Different rolling mills exist and a choice of one type is depended on the thickness of the slab to be obtained as the end product. A standard HRC slab would fall into one of following four categories; thick slab (normally 200 – 300 mm thick), medium slab (approximately 150 mm thick), thin slab (60 -70 mm thick) and very thin slab (30 mm thick) (Carpenter 2004). Depending on the caster design and process route selected, these different slab thicknesses are usually associated with any one of the following four rolling mill types; conventional hot strip mills, thin slab-making (Compact Strip Production, CSP), very thin slab production and steckel mill rolling.

Between 2010 and 2014, the majority of Kenyan hot rolled flat product imports were in the form of a wide coil, were un-pickled and were below 3 mm in gauge (NMC, 2015). These market requirements would be well-served by a thin-slab (CSP) facility configuration hence the best choice for a Kenya EAF steel mill.

4.2.2.4 Downstream finishing operations

Since there is sufficient pickling, cold rolling, galvanizing and organic painting capacity already installed in the country, it would not be important to install any downstream finishing capacity with the installation of a 1-million ton/year HRC production EAF (Near-term supply gap). Rather, the Kenyan EAF steel mill would supply these existing operations, with HRC sold to the local market. In this manner, the mill’s marketing strategy would be to only compete against HRC imports, and not against other established Kenyan businesses. Equally no coil slitting or flat plate production is foreseen at this stage.

It is strongly recommended, however, that sufficient space should be allocated to the steel mill project to allow for future expansion and downstream processing plants as the economy grows and the supply/demand balance changes. Cold rolling and perhaps also coating and welded tube-making would be seen as the main downstream options, but not until some years after plant-start-up.

4.2.3 Preferred production process route for a Kenyan steel mill

From foregoing considerations relating to;

- the near- term and longer-term steel supply gap in Kenya
- raw material availability in Kenya, and
- technology issues

The following indications may be drawn concerning the preferred Kenya steel production process route.

a) Based on the near-term and projected HRC supply gap of 1 million tons by 2018 (Table 4.10), an investment in a 1 million ton/year HRC output mini-mill, which is scrap-fed, is presently the most plausible option for Kenya than a traditional integrated mill. This scrap-fed mini mill is labelled as *Phase I*.

b) Non-availability of local iron ore presently and in the near-term, coupled with the abundant availability of ferrous scrap in South Africa, reinforces the initial choice of a scrap based mini-mill *(Phase I)*. Locating the mill at Lamu Port / Mombasa rather than at Athi River offers easy access to imported scrap.

c) The scale of the plant at 1 million tons HRC further indicates that EAF is more appropriate. The availability of a new coal-based 900MW power plant at Lamu in the near- term reinforces the logic for investment in an EAF steel plant.

d) Based on the large imports of un-pickled, wide hot rolled flat coils of below 3 mm in gauge (implies market), a thin slab CSP appears to be the preferred casting route. Proven technology and relative operational simplicity are important attributes that favour this choice of technology.

e) No near-term need is envisaged for pickling or other downstream plants, as the principal market for Kenya HRC is considered to be Kenyan, with the main market justification for Kenya being import displacement.

f) Based on the longer-term supply gap (beyond 2020/2030), a larger-capacity facility can be envisaged with a flat-rolled capacity [hot rolled coil alone] of 2 million tons by 2020, or 2.9 million tons by 2025. This later facility investment is labelled as *Phase II*.

g) Downstream plant for cold rolling could be added also at these later stages of the Kenya steel mill development. This stage is labelled as *Phase III*.

Steelmaking in *Phase II* could also be supplemented by a blast furnace pig iron produced from locally- mined Kenyan iron ore and/or by gas-reduced DRI or Corex.

It is, however, worth noting that, Kenyan iron ore quality will have an important bearing on any future facility configuration. High-quality iron ore (65 % Fe content or higher) will lend itself best to the production of DRI and could be a lucrative source of revenue, especially if abundant low-cost natural gas is available. Medium quality ore will, in turn, be better suited for blast furnace use (either as a lump, pellets, or fines) whilst low-quality ore will require further beneficiation prior to conversion into pellets for blast furnace feedstock.

In summary, from the above considerations and inferences, it is evident that the development of a steel mill plant in the country would better be approached in two phases. *Phase I* would be the development of an EAF having a capacity of 1 million ton/year production of HRC which would be used to serve the immediate HRC supply gap. This *Phase I* plant would include a thin slab CSP but no downstream finishing processes such as pickling as this is sufficiently provided at the moment by the already existing plants. Moreover, this installation would be primarily to serve the existing steel mill plants with HRC as their raw material but not compete with them.

As demand for HRC grows, with the growth of economy and industrialization, to values about and above 2 million tons/year (the year 2020 and beyond), the need for expansion of the 1 million ton/year EAF plant would then suffice giving birth to *Phase II*. This phase would include an enhanced capacity for more production of the *Phase 1* plant. The supplement (to scrap used in Phase I) feedstock for this *Phase II* plant would be obtained through either of the following options; blast furnace hot metal, DRI or Corex hot metal if steelmaking economics allow. It is, however, important to note that at a later time, a *Phase III* installation of downstream processes such as cold rolling can be done.

4.2.4 Specifications of the requisite plant

This section looked in the equipment requirement for the proposed phases, the appropriate technology for Phase II, consumables needed in HRC production, plant's process waste, land requirements, labour requirements and capital investment costs.

4.2.4.1 Equipment selection criteria

The equipment specified in the succeeding sections was based upon established and proven technology and world best practice for efficiency and low-cost production and has due regard to local conditions and what is expected to be a largely inexperienced workforce. The end-use of the HRC has been defined as generic. This implies a usage in general structural / fabrication applications, coil for welded pipe-making and coil for production of galvanized and/or corrugated sheet. A standard coil width of 1.8 m has been assumed. This is based on that, the majority of HRC imports in to the country were of this range and were of below 3 mm in thickness (NMC, 2015). The specified rolling mill will produce strip which is between 2 and 20 mm thick.

4.2.4.2 Equipment specifications

This was done for each of the envisaged phase. The specifications were based on the envisaged HRC output capacity of the proposed design.

Phase I

Production of 1 million tons HRC in Phase I is envisaged hence the following plant equipment specifications was proposed.

a) High power alternating current Electric Arc Furnace (EAF) with a 120-ton tap weight. EAFs are only commercially viable if they are able to run 30 – 50 heats per day,each heat size being above 50 tons (NMC, 2015). A 120 ton tap weight EAF would deliver 1 million tons of HRC annually.
b) Ladle Refining Furnace (LRF) transformer rating of 16 MVA.
c) Thin slab caster to produce slabs of 1.8 m wide and 70 mm thick (choice based on majority of HRC imports in the country)
d) Tunnel type equalizing / reheat furnace.

Phase II

Phase II is more difficult to unequivocally define from the standpoint of the production process that could be used to supply additional iron units [for the higher volumes of output], a difficulty that arises only because of uncertainties regarding the quality of the available iron ore, coal and gas. However, the approaches below summarize the main options for a Phase II plant.

a) A 2 million tons/year conventional blast furnace producing hot metal as supplementary EAF feedstock, if medium grade iron ore deposits and metallurgical grade coal are found. Blast furnace coke could also, be imported. The large size of this blast furnace might necessitate some export of pig iron.
b) Two or more mini blast furnace units of 200,000 tons/year capacity to provide liquid iron to the EAF at up to 40% of the metallic charge if medium grade iron ore deposits and low-quality coal are available. Quality issues might, however, arise in the use of mini-BF pig iron for flat product production, thus significantly limiting the contribution of this feedstock to total metallic charge.
c) 1 million tons/year direct reduction (DRI) modules with a hot charging facility to

the EAF, if suitable high-grade iron ore deposits and natural gas fields are found.

d) A Corex unit of 1million tons/year production if medium grade iron ore and low-quality coal are found.

Production of Corex iron units is often significantly less capital intensive than blast furnace operation, as the Corex technology does away with the potential need for coke or sinter plants (Siemens VAI, 2011). Corex operation is also more environmentally friendly than blast furnace operation. Steel plants using the Corex process are successfully operating in South Africa, China and India. The steel companies employing Corex technology in these aforementioned countries include Baosteel of China, Essar Steel Ltd of India and ArcelorMittal of South Africa (Siemens VAI, 2011). Table 4.12 shows a matrix which can be used to determine the most suitable technology to supply additional iron units for Phase II.

Table 4.12 Main options for the supply of additional iron units for Phase II

	Technology			
Parameter	**Conventional BF**	**Mini BF**	**DRI**	**Corex**
Production rate	Too high	Small	Average	Average
Capital cost	Very high	Small	Medium	High
Raw materials	BF grade ore, coking coal	BF grade ore, industrial or coking coal	High-grade ore, natural gas	BF grade ore, industrial coal
Product	Can be high in sulphur and phosphorous	Can be high in sulphur and phosphorous	Perfect for EAF	Can be high in sulphur and phosphorous
Hot charge	Yes	Yes	Yes	Yes
Operating cost	Low	Medium	Low, but depends on natural gas pricing	High, needs carbon monoxide-generation for economic viability

Environmental	High	High	Low	Medium
Logistics	Complex	Complex	Simple	Complex
Footprint	Large	Medium	Small	Medium
Complexity	High	Low	Medium	High

The relatively high capital cost of a large blast furnace might make this an unattractive option, but it would be a very profitable one if the economics of pig iron exports were attractive.

Although the low capital cost and relative simplicity of the mini BF are attractive, the limited production volume calls for multiple units to adequately service the EAF. Since this is a coal-burning process, the negative environmental impact would be increased. Again, the potential of steel quality issues requiring a liquid iron pre-treatment stage (added conversion cost and complexity) make this a less attractive choice.

A DRI module producing around 1 million tons/year, assuming that large quantities of low-cost natural gas and quality iron ore is available, would also be another feasible option. Midrex Corporation (owned by Kobe Steel of Japan), the world-leading supplier of DRI technology advises that a coal-based gasifier can be provided if natural gas is not available but this coal-based technology almost doubles the capital cost of the Midrex module and the technology has as yet rather limited references.

The economics of Corex production is known to be very dependent on the use to which the export gas can be put, but a successful track record in South Africa (Siemens VAI 2011) and elsewhere may suggest iron ore smelting to be an appropriate technology for Kenya steel production.

In summary, the Corex technology appears to be the most appropriate technology for adoption in Kenya for the Phase III plant. This is because its pros and cons balance giving rise to good economies of scale.

Phase III

Downstream integration opportunities would arise as the evolution of the steel market progresses, and would be likely to include an acid pickling line, cold rolling of hot-rolled coil and zinc galvanizing; possibly also organic coating or even welded tube production. It is important to recognize that any future steel supply gap would be very much dependent on competitor investments. At the same time, however, downstream investments by Kenya steel production could add significant value and could markedly contribute to higher future profitability.

It should be noted, however, whilst growth in long product demand, which will also create a significant opportunity for investment in long product production, the ‘hybrid' nature of the proposed EAF feedstock is considered by this study to lend itself far more to the production of flat rather than long products. This is because the quality of flat-rolled steel is typically much better than that of long products. Whilst EAF technology trends are evolving and cannot be assumed to be standing still, steel cleanliness considerations point the preferred steel production product mix to flat rather than long products.

4.2.4.3 Other consumable needs

The following major consumables would also need to be provided for the production of HRC.

a) Gaseous Oxygen at ~35-38 Nm^3/ton.This would ideally be needed to be provided by an on-site Air Separation Unit (cryogenic technology). This unit would also provide Nitrogen and Argon gas for process requirements.

b) Metallurgical quality Burnt Lime (CaO) at 25 kg/ton. The exact amount would depend on the scrap quality.

c) Dolomitic Burnt Lime (MgO.CaO) at 15 kg/ton. Again, the exact amount would depend on the scrap quality.

d) Both lime streams are mined as the carbonate and require calcining to convert to the oxide (heating to break down the $CaCO_3$ to CaO and CO gas). If no calcining plant exists close to the new steel mill, then consideration would have to be given to the provision of an in-house calcining module.

e) Graphite electrodes (EAF and LRF), ferro-alloys, refractories, key spare parts such as caster moulds and mill rolls and other minor consumables would all need to be imported initially.

4.2.4.4 Plant's process waste

The EAF process would generate around 7% of slag per ton of liquid steel (European State Environmental Agency 2015) produced in *Phase I*. This would be equal to some 70,000 tons per year. Generally, this slag will be collected, cooled, crushed and graded for construction use in foundations as hardcore and as an additive to cement. A specialist contractor can be used to provide the equipment, knowledge and labour for this requirement.

The filter bag-house used to de-dust EAF off-gas generates some 1.5% of dust per ton of steel (European State Environmental Agency 2015). This dust contains many oxidizable metallic elements driven off from the scrap in the melting process. These include mainly zinc, and some less desirable heavy metals such as arsenic, mercury and chromium. If the dust is landfilled there exists, the possibility that rainwater will leach these heavy metals into the surrounding area. Best practice is to find a specialist firm that will buy the dust to recover the zinc.

The casting and rolling process generate some 2 – 2.5% of iron oxide in the form of mill scale as part of the cooling process (European State Environmental Agency 2015). This is collected and may be sold. If mini blast furnaces are installed, this iron oxide may be used as part of the blast furnace burden.

4.2.4.5 Land requirement

The ideal site for the steel mill would be one with flat stable soil conditions, not subject to flooding or seismic disturbance, and have good access to a deep-water port, road and rail connections. Freshwater, electrical power and natural gas in suitable quantities should ideally also be available in close proximity to the steel mill. Labour should be available from local conurbations at short distance with good transport to and from the site. Mombasa and Lamu have many of these attributes.

In contemplating future land requirements, planners should consider the *Phase II* and even *Phase III* facility configurations in addition to *Phase I* needs. Too many steelmaking projects have ended up effectively "landlocked" due to a lack of foresight in the initial planning process. The study, therefore, proposes that the Kenya steel production site to be conceptually developed to allow for the following process requirements both presently and in the future:

a) 1 million ton per year EAF-based CSP type production unit for hot-rolled coil, including scrap storage yard, slag processing area and all auxiliary equipment. This is based on the HRC future market by 2018 (Table 4.10) and the import preference of 3 mm thick in Kenya.

b) A second similar module to increase production in the future to 2 million tons/year output [or more]. This is based on the future HRC demand in the years 2020 and beyond (Table 4.11)

c) Either a large 2 million tons /year blast furnace; or a one 1 million tons /year DRI module with hot charging equipment to the EAF(s) which can be sized to feed one or two EAFs; or a 1 million tons /year Corex unit.

d) A pickle line with cold rolling, galvanizing and slitting equipment (for Phase III expansion).

e) Maintenance workshops, warehouses, and consumables storage.

f) Other ancillary buildings. May include, but not limited to administration, medical and social amenities.

A typical 6 million ton/year integrated steel mill would occupy a land acreage of 3500 acres based on the proposed steel mill in Karnataka (Essar Steel Ltd, 2009). Based on an appraisal by the Numerical Machining Complex 2015, the study approximates the following land areas at the conceptual stage of the decision-making process.

Table 4.13 Land area requirements estimates

Plant or Use	**Land Area (hectares)**
Initial CSP Steel Mill	20
Second mill	15
BF / DRI module with ore and DRI storage areas	10
Downstream finishing facilities	15
Ancillary buildings and storage	5
Waste processing and storage	5
Future pellet plant with ore beds and material handling equipment	30
Total land area	**100**

4.2.4.6 Labor requirements

A good rule of thumb for a developed steel company is to produce some 2,000 tons per man-year employed (metal consulting, UK 2014). In this case that would imply a workforce of 500 employees for 1 million tons /year of EAF-based HRC production. However, when allowing for the presence of an expatriate start-up group of experienced management and operators, working together with the local and future management and operators, training requirements and a certain level of early attrition, this number would likely go up. Based on an appraisal by the Numerical Machining Complex, the study proposes at least 800 persons in the early years.

A key factor in employee selection should be to identify local employees having the right level of basic education, and equally importantly a strong work ethic to succeed in an unfamiliar industrial environment involving shift working schedules and personal accountability at all levels.

4.2.4.7 Capital investment costs

Given that there is no experienced parent steelmaking company yet behind this initiative, and that there is little heavy industry infrastructure developed, the study considered the only way to approach this project would be as a turnkey contract (also known as EPC – Engineer, Procure and Construct) to one of the major equipment manufacturers. The EAF and CSP technology is essentially of European origin, but the major suppliers are all used to working with contractors from the Far East (China, Korea, Thailand etc.) to deliver a competitively priced project.

Based upon other recent turnkey projects of similar size elsewhere such as in the Middle

East, a comprehensive package of 1 million ton/year HRC production should be expected to fall within the $800 – $1,000 million range (Essar Steel Ltd, 2009). This estimate does not include investment in working capital. It also further assumes that gases are purchased off-site i.e. that no investment is required in an air separation unit.

4.3 Financial projections

This section quantifies the requirements for the establishment of *Phase I* Kenyan steel plant in monetary terms to determine whether such a venture would be profitable.

Phase I

4.3.1 Raw material costs

Whilst it is understood that domestic ferrous scrap in Kenya has (from time to time) been priced somewhat below the world price because of the Kenyan scrap export ban, this differential is presently small. The mill-delivered scrap cost from Kenyan scrap suppliers stood at Kshs 24 per Kg in the 1st quarter of 2016 translating to approximately USD 233/ton while world scrap prices stood at USD 300/ton in the same period (EAC, 2015). Because of the probable low availability of Kenyan-origin scrap and because of the small size of any price differential against the principal import sources, the study, therefore, assumed that all Kenya steel plant scrap sourcing to be from imports at world scrap prices. These prices were calculated as an average of different market prices for the purposes of this economic analysis. It is therefore important to note that these prices may vary from one market to another. The study also based the prices for iron ore pellets, thermal coal and coke on the world prices. Table 4.14 shows the prices of all these commodities as at 2016.

Table 4.14 Raw material costs

Commodity	**2016 price assumption**
Ferrous Scrap	$214/ton works delivered
Iron ore lump, 62% Fe	$75/ton Fe works delivered
Iron ore BF pellets, 65% Fe	$95/ton Fe works delivered
DRI pellets, 66.5% Fe	$100/ton Fe works delivered
Thermal coal	$50/ton works delivered
Metallurgical Coke	$200/ton works delivered

Source: Steelorbis,2016; CRU International Ltd,2016

4.3.2 Labour costs

Based on the appraisal by Numerical machining complex aforementioned in the preceding section (4.2.4.6), 800 employees would be required for Phase I production of 1 million tons HRC. Based on KNBS statistics 2016, a $4501 p.a average workforce labour cost was estimated. This estimate also factored a 7% inflation rate in wages as in prices. However, it is worth noting that there exists a great marked variability in average Kenya earnings both in public and private and therefore this labour cost estimate should be interpreted with caution.

4.3.3 Energy costs

4.3.3.1 Electricity prices

Kenyan electricity prices are understood to be slightly high in the international context (Table 4.16) with current electricity price (2016) being close to ~$0.07-0.09 / kWh as shown in Table 4.15. However, electricity prices within this price range compare significantly well with those in other large economies.

Table 4.15 2016 Electricity charges in Kenya.

Tariff	Charges (KSHS)		
	Fixed charge	**Energy charge (per kWh)**	**Demand charge (per kVA)**
CI1 (Commercial, 415 V)	2 500	9.20	800
CI2 (Commercial, 11 kV)	4 500	8.00	520
CI3 (Commercial, 33 kV)	5 500	7.50	270
CI4 (Commercial, 66 kV)	6 500	7.30	220
CI5 (Commercial, 132 kV)	17 000	7.10	220

Source: Energy Regulatory Commission,2016

Table 4.16 shows a comparison of international prices for the small commercial tariff CI1 to that of Kenya.

Table 4.16 International electricity price comparison to Kenya.

	CI1 Commercial tariff, 415 V								
country	UK	Germany	Turkey	India	France	Russia	China	USA	**KENYA**
Price ($/kWh	0.08	0.07	0.06	0.05	0.06	0.04	0.05	0.04	**0.09**

Source: OECD,2016

Nonetheless, Kenyan electricity prices tariffs are expected to continue to fall significantly in the coming years, as power generation capacity in Kenya expands in line with National Energy Policy.

Since in practice it requires about 360-400 kWh of electricity to smelt a ton of steel (Jeremy J,1997), this study therefore determined that the 11kV commercial tariff would be sufficient for an EAF-type steelmaker based in Kenya. For the financial projection, the study held the electricity charges for the 11kV commercial tariff constant for the entire period of projection. This implies a $ 0.08 per Kwh price between 2016-2020 (Table 4.17)

Table 4.17 Projected electricity prices assumed in the financial projections (VAT excluded)

Year	2016	2017	2018	2019	2020
Industrial tariff ($/ kWh)	0.08	0.08	0.08	0.08	0.08

4.3.3.2 Heavy fuel oil & natural gas prices

The study assumed a Kenyan heavy oil price of ~$750/ton (NMC, 2015). With a net calorific value of 41 MJ/kg, this predicts a heavy fuel oil price of ~$14/ GJ. This price was assumed to stay constant in real terms during the forecasting period.

Natural gas was also assumed at $14/GJ (NMC, 2015). This is just under 20% cheaper than the current world price of $17/GJ (OECD, 2016). With natural gas deposit found in the country offshore, this is probably a realistic assumption. For this study, a $ 14/Gj price for natural gas was used.

However, it is worth noting that with the full operationalization of natural gas and oil production in the country (in future), these prices are bound to change downwards.

4.3.4 Steel selling prices

4.3.4.1 Local steel prices

Kenyan local prices for rebar and CRC were found to be very high compared to the international market prices. A snapshot of prices as at 2014 showed that Kenya steel prices for rebar and CRC stood at an average price of 60% above FOB world steel prices (Table 4.18). This could be explained by the relatively high Kenya electricity prices and existent import tariffs. These tariffs exist in Kenya [and across COMESA in general] on a variety of different steel products imported from non-COMESA trading partners.

Table 4.18 Comparison of Kenyan and world steel prices, 2014

	Kenya	World
Rebar ($/ton)	998	638 (FOB)
CRC ($/ton)	1245	694 (FOB)

The present level of these import tariffs range from zero on semi-finished steel products such as billet and slab; to 10% on rebar and CRC; through to 25% on high-value downstream steel products such as galvanized and organic coated steel products as shown in Table 4.19. Considering these tariffs, in the context of overall steel price level, the following can be inferred;

- First, it is notable that steel production capacity exists in Kenya for those products which attract an import tariff. These include rebar, CRC, coated products and welded tube. Additionally, it seems that no steel production capacity exists on those products which do not attract an import tariff. These products include billets, slab, heavy sections, and hot rolled coil.
- Second, whilst the price premium depicted in Table 4.18 may partly be accounted for by the 10% import tariff on rebar and CRC, it may also be the case that greater competition in the supply of Kenyan rebar is the factor that underlies the smaller premium on this product relative to CRC.

Table 4.19 Kenyan import tariffs on steel products, 2016

Product	Import tariff
Semi-finished steel	
Billet	0%
Slab	0%
Flat products	
Hot rolled plate	0%
Hot rolled coil & sheet	0%
Cold rolled coil & sheet	10%
Hot dip galvanized sheet	25%
Organic coated coil & sheet	25%
Long products	
Heavy Sections	0%
Light sections	10%
Rebar	10%
Wire rod	10%
Steel wire	10%
Tube products	
Welded tube	25%

Source: KRA,2016

High transport costs from steel suppliers in South Africa, India, South Korea and Japan undoubtedly also contribute to the Kenyan price premium (NMC, 2015).

It is worth noting that the Kenyan government introduced a Kshs 20,000/ton specific tax to iron and steel imports in the 2016 budget to cushion steel producers within the country (Republic of Kenya, 2016)

However, the world steel prices have dropped significantly with a rebar selling at $ 440 FOB as at fourth quarter of 2016. These prices (shown in Table 4.20) will be used for this study.

Table 4.20 Rebar and CRC steel prices, Q4,2016

Product			Min & Max Prices	Daily Avg. Price
Long Products	Rebar	FOB $/ton	$ 420.00 - 460.00	$ 440.00
Flat Products	CRC	FOB $/ton	$ 450.00 - 460.00	$ 455.00

Source: Steelorbis,2017

4.3.4.2 International iron and steel prices

Hot rolled coil

Presently, as of 2016, HRC prices have stabilized at ~$450 / ton fob basis (Steelorbis, 2017). On the basis of a $450/ton FOB selling price, it would be expected that a realized ex-works HRC price (for all customers) of $440/ton is possible. A price level of $440/ton is, however, extremely conservative, as this assumes no price premium. Based on an appraisal conducted by the Numerical Machining Complex in 2015, an average transport cost of $75/ton from Kenya’s main suppliers can be assumed. This implies that a price premium of ~$75/ton can be adopted, meaning an ex-works HRC price assumption of $515 per ton. This is the HRC price used for the profitability analysis.

Pig iron

Internationally traded pig iron prices are at $240 per ton (Steelorbis 2017). On the basis of a $240/ton FOB international selling price, it is assumed that a realized ex- works pig iron (from a Kenyan coastal merchant pig iron plant) of $230/ton where this is applicable (NMC 2015). However, this study used the international FOB prices for pig iron.

4.3.5 Summary of raw material prices and cost assumptions

Table 4.21 gives the principal prices for raw materials and other cost assumptions used in the financial evaluation in this study. The study assumed the prices to remain steady over the projection period.

Table 4.21 Raw material prices and other calculated costs.

Parameter	**2016 - 2020**				
Ferrous scrap, $/ton, works delivered	214	214	214	214	214
Iron ore lump, 62% Fe, $/t wks deliv	75	75	75	75	75
BF pellets, 65% Fe, $/t wks deliv	95	95	95	95	95
DRI pellets, 66.5% Fe, $/t wks deliv	100	100	100	100	100
Thermal coal, works delivered, $/t	50	50	50	50	50
Metallurgical coke, works delivered, $/t	200	200	200	200	200
Labour cost, gross $/year	4501	4501	4501	4501	4501
Electricity, US cents/kWh	8	8	8	8	8
Heavy fuel oil, $/GJ	14	14	14	14	14
Natural gas, $/GJ	14	14	14	14	14
Water, $/t	0.02	0.02	0.02	0.02	0.02
Hot rolled coil, international FOB, $/t	450	450	450	450	450
Hot rolled coil, Kenya Steel ex-works, $/t	515	515	515	515	515
Pig iron, international fob, $/t	240	240	240	240	240
Differential, scrap vs HRC FOB, $/t	**236**	**236**	**236**	**236**	**236**

From all the values in Table 4.21, perhaps the most important with respect to assessments of potential profitability is the differential between the scrap price and the international FOB HRC price. This is calculated at $236 per ton and compares well with the global average of $244/ton (Steelorbis 2017).

4.3.6 Cost structure

Table 4.22 sets out an approximate breakdown of production costs for 2020, which is the first year when the Kenya steel plant is assumed to be operating at 100 % capacity, that is 1.0 million tons of HRC. The consumption rates were as per Worldsteel 2016 estimates (Worldsteel 2016).

Table 4.22 Production cost breakdown, 2020

Item	Unit	Consumption	COST $/ton	COST ($/million ton HRC) ('000) p.a
Variable costs				
Scrap	214 $/ton	880 kg/ton	171.2	171,200
Energy	$ 0.08/Kwh	400 Kwh/t	32	32,000
Ferro-alloys	1167 $/ton	~14 kg/ton	16.34	16,340
Oxygen	$0.07/Nm^3	~38 Nm^3/t	2.66	2,660
Natural gas	$ 0.75/Nm^3	~3.9 Nm^3/t	2.93	2,930
Refractory	685 $/ton	9 kg/ton	6.17	6,170
Limestone	30 $/ton	64 kg/ton	1.92	1,920
Coal	50 $/ton	16 kg/ton	0.8	800
Total			234.02	**234,020**
Fixed costs				
Labour	$ 4501	800 persons		3,600
Other fixed costs			8.1	8100
Total			11.5	**11,500**
Total Production Cost			**241.52**	**244,520**

The breakdown illustrates the critical importance of scrap to the cost structure. Scrap accounts for some 70 % of total production costs. The profitability of the operation hinges on the spread between the ex-works price of HRC and the delivered cost of scrap.

Energy is also a significant cost accounting to about 13% of the total production cost. This implies that the electricity tariff is an important variable. Typically for steelworks, fixed costs represent a small proportion of total operating costs, about 5% (NMC 2015)

4.3.7 Profitability

Table 4.23 sets out a simplified Profit & Loss Account (P&L a/c) for 2020, 2025 and 2030.The revenues and costs are assumed to increase by ~2% annually based on an appraisal by NMC. The values for the year 2020 were populated based on information given in table 4.22 for the fixed and variable costs. The revenue was populated based on the determined Kenyan HRC ex-works steel price (Section 4.3.4.2). The 2% annual increment was computed based on a compounding formula.

Table 4.23 Profit & loss account, 2020

Item	2020 '000s USD		2025 '000s USD		2030 '000s USD	
Revenues		**515,000**		**568,602**		**838,881**
Variable costs	234,020		258,377		285,269	
Fixed costs	11,500		12,697		14,018	
Production costs		**245,520**		**271,074**		**299,287**
EBITDA		**273,480**		**301,944**		**544,470**

With an EBITDA (2020) of about 53% of revenues shows the project would be profitable. The profit would continue to grow with a decrease in depreciation and finished loan repayment. this implies that by 2025 the plant would be making good returns and sufficient interest to offset any outstanding finance charges. The EBITDA increases to 65% of revenues by 2030 a sign of good profits. These EBITDA values signify values of DSCR presumably above 2.0 by 2025 which would attract investors. However, it is worth noting that the above P&L account serves only as an indicator of the possible growth and outcome and as such it should be interpreted with caution. The P&L a/c does not account for all the variable and fixed costs incurred during the production of steel as well as any unexpected economic dynamics during the forecast, which if well captured the EBITDA would fall to values of about 16~20% of revenues approximately every year.

PHASE II

This Phase is primarily an expansion installation to supply additional iron units to the Phase I EAF case. Although it is difficult to define, from a production process standpoint, which installation would fit due to uncertainties regarding the quality of ore, coal and gas in the country, different options are available. Phase II would have an HRC steel output of at least 2 million tons (Table 4.10). Table 4.24 shows the different options with their respective Capital Expenditure (CAPEX) as per an appraisal by NMC.

Table 4.24 CAPEX for Phase I and Phase II options

Option	**Phase I** **EAF** (Scrap Only) (1 million HRC output p.a)	**Phase II** (2 million HRC output)		
		(a)BLAST FURNACE	(b) DRI	(c) COREX
Crude steel, $/ton	460	432	472	415
Capex, $ million (real terms)	900	2567	2261	2281

Source: NMC, 2015

This analysis shows that;

- Crude steel cost reduces by $28/ton by moving from a purely scrap-based charge (Phase I) to a 50:50 scrap: hot metal charge in the blast furnace scenario (Phase IIa). However, capital costs are highest in this scenario, attaining $2.6 billion in real terms for production of 2 million tons/year of hot-rolled coil. On the other hand, however, this option does allow for the sale of merchant pig iron, a factor which could sway potential investors in favour of this scenario.
- Crude steel costs deteriorate by $12 per ton in moving from a scrap-based scenario (Phase I) to DRI-based steelmaking assuming a 40% direct reduced iron charge. Here, capital investment costs amount to $2.26 billion in real terms. The deterioration in liquid steel costs in this scenario is not especially surprising. This is

because DRI production is typically only economic when natural gas prices are extremely low (as in many parts of the Middle East).

- Crude steel costs reduce by $45/ton with Corex. Smelting reduction using the Corex process thus emerges as the preferred means for supplementing scrap in the EAF for the perspective of minimizing liquid steel costs, although the ability to use the Corex off-gas for electricity generation is an important related assumption.

With a total capital investment cost of $2.28 billion, scenario II c is not a low-cost investment option. However, unlike Phase, I which uses only imported raw materials (i.e. imported scrap); or Phases II a or II b which also rely on mostly imported raw material, the Corex scenario assumes sourcing of Kenyan iron ore and sourcing of Kenyan thermal coal. Table 4.25 shows various sourcing assumptions of the various options outlined in table 4.25.

Table 4.25 Raw material sourcing assumptions for the various scenarios

Scenario	Phase I Scrap only	Phase II a Blast furnace	Phase II b DRI	Phase II c Corex
Scrap	South Africa	South Africa	South Africa	South Africa
Iron ore pellets	n/a	Kenya	Kenya	Kenya
Iron ore lump	n/a	n/a	n/a	Kenya
Blast furnace coke	n/a	China/ Japan	n/a	n/a
Thermal coal	n/a	n/a	n/a	Kenya
Natural gas	n/a	n/a	Kenya	n/a

NB. Phase II b (DRI) assumes that Kenyan iron ore is DRI quality

On the matter of Kenya's future dependence on imported scrap, it is to be noted that up to 80% of EAF metallic requirements could be provided by Corex hot metal (NMC 2015). This means that on a *Phase II* HRC sale weight of 2 million tons/year, scrap purchasing requirements could be reduced from 1.4 million tons/year [at 80% scrap charge] to ~0.352

million tons/year [at 20% scrap charge] without cessation of steel production. This computation was based on the amounts of high melt scrap required for production of 2 million tons HRC which stands at 880kg/ton HRC (Worldsteel 2016).

4.4 Choice of Kenyan steel mill process design.

The study identified the following key important findings which were used as the reference in helping to come up with the most appropriate Kenyan steel mill process design;

a) The country is in the process of iron ore exploration and that the identified amounts are not yet fully quantified and graded a process which would be possibly through not later than 2020. However, the prospects of finding iron ore of quite good quality are very promising. This implies that iron ore for use in steel production in the country is still unavailable at the moment.

b) The amount and type of coal present in the country is yet to be determined and quantified. This implies that, there is no local metallurgical and thermal coal for use in steel production currently. Thermal coal is readily available in Tanzania. For both thermal and metallurgical coal, import from South Africa, China or Australia is another feasible option.

c) Scrap produced within the country is of low amounts (~ 250000 tons/ year), but this commodity is available in plenty in South Africa which makes her a good import source. An indicator that scrap-based steel production is currently the most preferred route to steelmaking within the country presently.

d) There is currently no production of HRC within the country and her neighbours. An indication of an existing opportunity in HRC supply presently.

e) Between 2013-2016, a majority of Kenyan hot rolled flat product imports were in the form of wide coil below 3mm in gauge. This implies that the Kenyan market would well be served by a thin-slab CSP facility which has the capability of producing such thin products.

Based on these key findings, coupled with the 1 million HRC supply gap (Table 4.10), the study therefore proposes that setting up a Kenyan Steel mill would be best approached in a two-phase design. The first phase being setting up an EAF with a 1-million-ton output HRC capacity (*Phase I*) to serve the near-term supply gap. This plant would then be expanded later (as steel demand grows as per projection) to a capacity of 2 million tons and more (*Phase II*).

Phase I

Once set, this phase would comprise of a 1-million-ton capacity EAF which would use majorly scrap produced within the country supplemented with imported High Melt Scrap (HMS) from South Africa. This facility would supply the near-term HRC steel gap within the country (primarily) and the neighbouring countries. The following is the proposed plant configuration:

- Thin slab caster to produce slabs of 1.8m wide and 70 mm thick. This thin-slab CSP would be able to produce coils of 3 mm in gauge which is primarily the majorly used coil thickness within the country.
- High power alternating current Electric Arc Furnace of 120-ton tap weight. With a minimum of 25 heats per day, this EAF would comfortably produce 1-million tons/year.
- Ladle Refining Furnace, transformer rating of 16 MVA
- Tunnel type equalizing / reheat furnace.

Phase II

Increased demand for HRC would call for high amounts of HRC output per year. This would mean that a supplement for scrap will be needed for this to be achieved. These supplements may include either DRI pellets, HBI, Pig iron or hot metal obtained through smelting of iron ore.

DRI is obtained through direct reduction of iron ore by use of a reducing gas such as natural gas or coal. Pig iron is produced in a traditional blast furnace through reduction of iron ore by carbon. Hot metal is produced through smelting iron ore using coal or Corex process.

For a choice of the best technology for Phase II, best suited for Kenya, to provide the feedstock supplement to scrap (both local and imported), different comparison matrices and approaches were considered as shown in Table 4.12, Table 4.24 and Table 4.25.

Based on these different comparison approaches, it is evident that the Corex process is the most appropriate technology choice for Phase II.

The process design for the plant would therefore comprise the following;

- **A Corex plant** to produce hot metal which would be the required supplement for the scrap into the EAF
- **An EAF** -for production of liquid steel
- **CSP (Compact Strip Productin**- for production of a Hot-rolled coil with thickness as small as 3mm

4.4.1 Proposed process design flowchart for a Kenyan steel mill

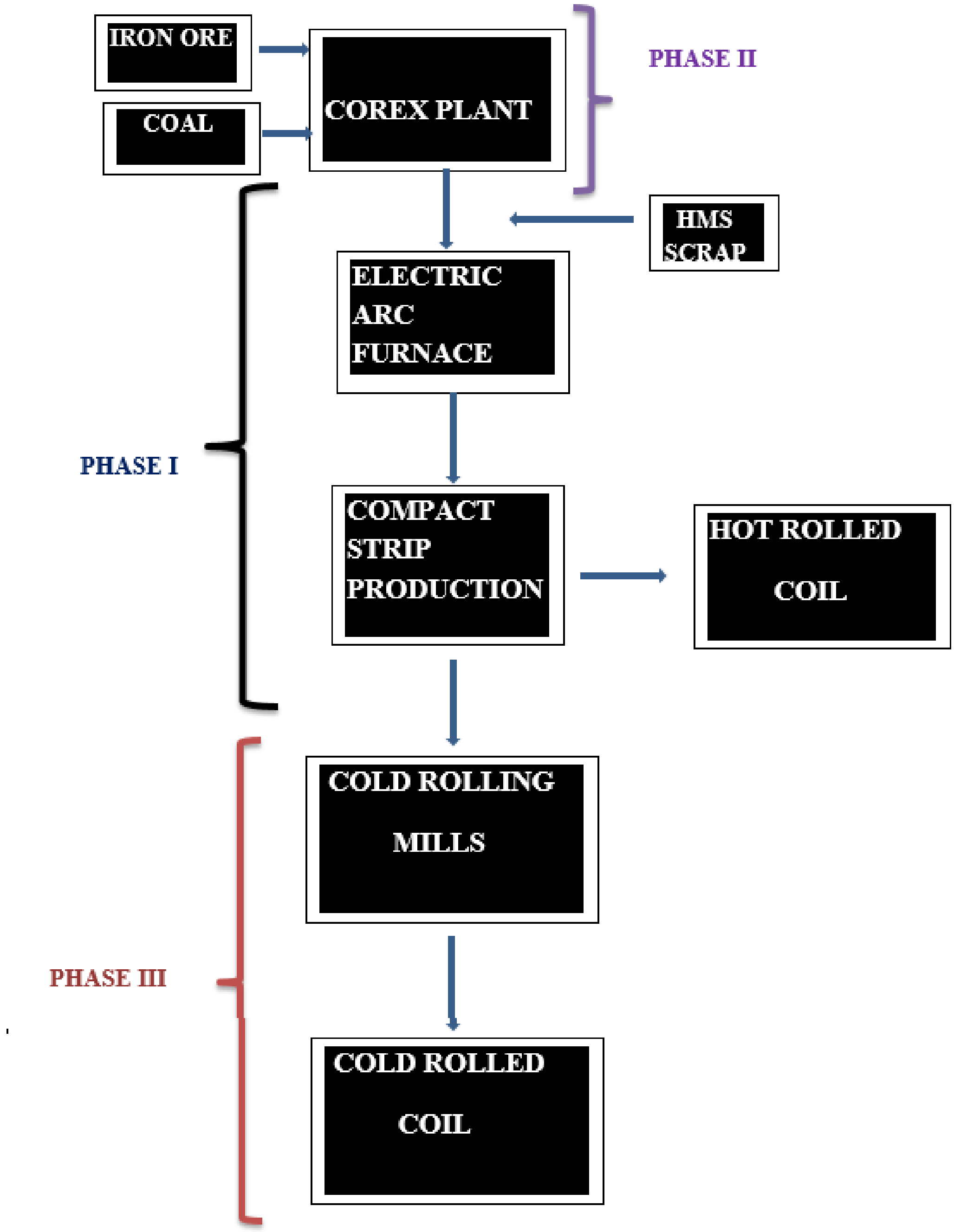

Figure 4.2 Proposed process design flowchart for a Kenyan steel mill

4.4.2 Design parameters

4.4.2.1 Corex plant

The most important part of the Corex plant is the process reactors; the reduction shaft furnace and the melter-gasifier. The design parameters of these process reactors were informed by the desired output by the Corex plant which was calculated to average about 1 million tons HRC. This output capacity called for a Corex plant of 80-125 t/hour production.

The reduction shaft furnace

Here, iron ore is charged via a lock hopper system and reduced to DRI by a counter-flow reduction gas (CO). For a 1 million-ton HRC output the following dimensioning was envisaged;

Table 4.26 Reduction shaft furnace dimensions

Reactor	Diameter (metres)	Comment
Reduction shaft	7.2	Design selection

The melter-gasifier

It can be divided into three reaction zones; Gaseous freeboard zone (upper part or dome), Char bed (the middle part above oxygen tuyeres), Hearth zone (the lower part below oxygen tuyeres). Direct reduced iron from the reduction shaft is fed into the melter-gasifier via discharge screws where it is further reduced and melted at the same time giving rise to hot metal. Gasification of coal by use of oxygen also takes place here leading to the production of the reducing gas, carbon monoxide, which is used in the reduction shaft.

For a 1 million-ton HRC output the following dimensioning was envisaged;

Table 4.27 Melter-gasifier dimensions

Reactor	Diameter (metres)	Comment
Melter-gasifier	7.5	Design selection

4.4.2.2 Electric arc furnace

For a 1-million ton EAF the following salient features were envisaged;

Table 4.28 EAF dimensions

Design	Specification	Comment
Type of furnace	EBT with water-cooled roof and side panels	Design Selection
Shell diameter (ID)	Approx 4600 mm	
Electrode diameter	Approx 500 mm	
Pitch Circle Diameter (PCD)	Approx 1200 mm	
Tilt on slagging side	15 degrees	
Tilt on tapping side	25 degrees	

4.4.2.3 Thin slab caster

For a 1-million HRC production, CSP technology will be used. The thin slab caster of the following design parameters was envisaged.

Table 4.29 Thin slab caster dimensions

Design	Specifications	Comment
Capacity	1.5 million tons per year	Design selection
Casting Strands	1	
Cast thickness	~50-90 mm	
Strip width	~800-2150 mm	
Strip thickness	~0.8-25.4 mm	

4.4.3 Proposed process design

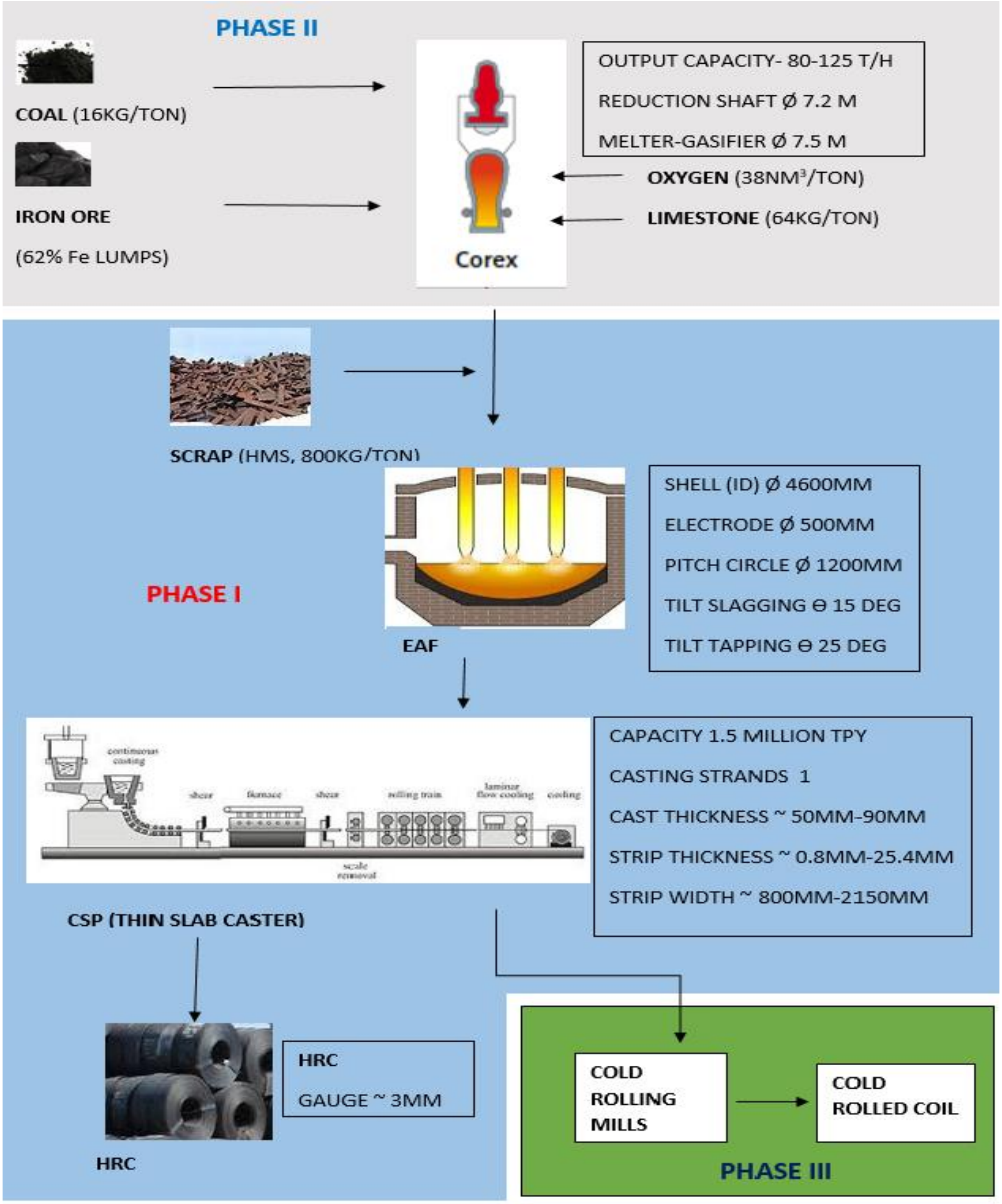

Figure 4.3 Proposed process design for a Kenya iron and steel plant

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Overview of research objectives

This research was geared towards determining the viability of setting up an iron and steel processing plant in Kenya, development of a process design for such plant and an economic analysis for the proposed plant.

5.2 Summary of results

5.2.1 Viability of setting up an iron and steel processing plant

As at end-2014, there were approximately 20 operational steelmakers in Kenya located mostly in or around Nairobi and Mombasa. Athi River Steel, Devki Steel Mills and Mabati Rolling Mills are the largest of these firms.

These steel plants have a combined liquid steel capacity of 340,000 tons/year. Hot rolling of light long products (sections, bar, rod) with a finished product capacity of about 555,000 tons/year dominates the steelmaking output. This activity, together with the cold rolling of coil with a finished production capacity of 245,000 tons/year, and production of the welded tube with a finished production capacity of 200,000 tons/year, accounts for the majority of finished steel production.

Feedstock for these downstream facilities is partly from semi-finished steel (steel billet) which is produced from the melting of ferrous scrap. As of 2014, this steelmaking was estimated at 250,000 tons. However, the most feedstock for downstream Kenyan steel plant is supplied by steel imports, which amounted to 1,167,000 tons in 2014 and 1.5 million tons in 2015. These imports were mostly in the form of hot rolled coil (740,000 tons of imports-2014), which was partly used for further processing into cold rolled coil and welded tube.

With no significant exports, the Kenyan finished steel demand in the year 2014 was assessed at 1,167,000 tons rising to 2,062,631tons in 2016. A further forecast showed demand values of 7,141,636 tons and 8,396,542 tons in 2020 and 2030 respectively. This pace of steel demand growth represents strong justification from the market standpoint for new investment in steelmaking.

Looking at the steel supply gap, the near-term opportunity is for investment in steelmaking plant for production of 1 million tons/year of hot-rolled steel coil. The market for this steel was assessed as primarily Kenyan, with some exports to neighbouring countries. However, the longer-term opportunity was judged as being far more significant, amounting to HRC production of 2.3 million tons by 2020 and 2.7 million tons by 2025 or even 3.2 million tons of hot-rolled coil production by 2030. Local competition for production of HRC was judged as currently insignificant, and the Safal Group was identified as an important potential customer for the future. Currently, the estimated demand for HRC within the country and its neighbours stands at 1 million tons (as at 2016) projected to grow to values of 2.5 million tons in 2020 and 3.6 million tons by 2030.

Ferrous scrap was found to be less abundant in Kenya with its generation currently at standing at ~250,000-300,000 tons/year. This scrap was mostly consumed by indigenous steelmakers. In the broader geographic region, scrap is however plentiful in South Africa, which annually exports 1.2 million tons/year. This South African scrap could represent a future source of iron units for a Kenyan Steel plant.

It was probable that Kenya also would have access to good quality domestic iron ore.

Whilst it is hoped that this domestically sourced raw material [if proven] might be extracted as soon as 2018, the absence of a rail transport network precluded the use of Kenyan iron ore for large-scale steelmaking for several years beyond that point, possibly not until 2023-25.

In a nutshell, it is very viable to set up an iron and steel processing plant in Kenya.

5.2.2 Proposed plant process design

Reviewing the technical issues in the context of a new Kenyan steel production plant (including BOF vs EAF steelmaking, different electric steelmaking technology, and different casting and rolling options) and in the context of Kenya's raw material and energy availability in the short- and medium-terms, the study considered that Kenya's interests would best be served by investing in EAF steelmaking, compact strip production and in-line production of HRC. The equipment specification, raw material needs, process waste characteristics; and the land, labour and capital needs of such a facility were described. Supplied with imported scrap and powered by locally produced electricity, such a facility could accordingly be fully operational by 2020. By this stage the new Phase I facility could employ a labour force of 800 and supply 1 million tons/year of hot-rolled coil to the domestic and regional market, largely displacing current Kenyan steel imports. Such a facility would have a capital cost of $1billion. For optimization of the Phase I facility to a more profitable Phase II facility which would wholly utilize the Kenyan indigenous raw materials, three options were compared; An investment in blast furnace ironmaking, involvement in DRI production or commencement of iron ore smelting through the Corex route. Across these options, the Corex route stood out as being by far the most attractive with respect to the cost of liquid steel. The Corex scenario was also noted as having lower total capital investment costs than the blast furnace scenario (and was preferred to all other scenarios because of Corex' potential to use indigenous Kenyan iron ore and coal). DRI-based steelmaking was not assessed as economic in Kenya, largely because of the expected mediocre future cost of natural gas.

The proposed plant process design would consist of an EAF (Phase I) and a Corex Plant (Phase II).

5.2.3 Economic feasibility

A financial model for the Phase I Kenyan steel plant demonstrated that with 2030 EBITDA at $500m, the *Phase I* operation would be profitable. However, it is worth noting that the performance of the project is highly sensitive to the "spread" between the delivered cost of scrap and the ex-works price of HRC. An increase in the HRC price/ton would increase the internal rate of return on the project. Also, a reduced import tariff on HRC, a reduction in the cost of the metallic charge, by replacing some of the scraps with locally produced hot metal or a reduction in the electricity tariff would also help increase the IRR of the project.

Assessments of future Kenya's steel plant cost competitiveness indicated that whilst the Kenyan steel plant might in Phase I be at threat from some lower-cost international suppliers of HRC (especially from India), the cost-benefit of Corex-based steelmaking in Phase II would (together with transport costs from South Africa, India, Korea and Japan) provide the plant with a small but significant cost advantage in serving its domestic and regional customer base against largest competitors. This is an important conclusion and emerges largely [from transport cost considerations] because of Kenya's distance from its largest steelmaking competitors.

5.3 Conclusion

The results of this study indicated that the demand for steel in the country was on the rise with an increase from 1.2 million tons in 2014 to 2 million tons in 2016. However, this demand is expected to rise to 7.1 million tons in 2020 and 8.4 million tons by 2030. Growth in HRC demand within the country and her neighbours was also found to rise from ~1 million tons (as of 2016) to 2.5 million tons in 2020 and 3.5 million tons by 2030. The study also found out that the process of exploration and quantification of iron ore and coal within the country was on course though at a very slow pace.

This study also determined that, until the quality and magnitude of Kenya's iron ore deposits are confirmed, investment in scrap based steelmaking could go ahead with production of up to 1 million tons per year of hot-rolled coil via compact strip production, with sales mostly directed at the domestic market. Whilst such a Phase I investment would be profitable, the internal rate of return, however, would not be especially appealing to potential investors given the magnitude of the initial investment outlay of approximately $900 – $1000 million.

As and when iron ore and coal deposits are confirmed, broader options arise. From a review of the available commercially-proven steelmaking technologies, the study considered that Corex-based smelting of iron ore (using Kenyan thermal coal as the main reductant) would be a good choice for a Kenyan steel plant as this selection of technology would likely offer the Kenyan plant a far lower cost of liquid steel than scrap-based, blast furnace pig iron-based or DRI-based technologies.

The study also determined that with an introduction of a HRC import tariff, more intensive use of Corex and downstream investment in cold rolling, the Phase II plant (producing in excess of 2 million tons HRC) would attract high IRR and become more profitable and would be of real interest to a broad range of international steelmakers, despite a total capital cost outlay that is likely to exceed $2.4 billion in real terms. A greenfield steel plant, producing 2 million tons/year of HRC and displacing most current Kenyan steel imports, employing a labor force of 800, using significant volumes of Kenyan-mined iron ore and coal and generating EBITDA level profits of over $440m per year by 2030 is thus not only an exciting vision, but also a very realistic opportunity.

5.4 Recommendations

Based on this research work, the following recommendations are advanced;

- On the basis that the steel mill investment appears to be viable, the government or stakeholders should endeavour investing in this industry. In this respect, there is no benefit to be gained in waiting for Kenyan iron ore or coal reserves to be proven. The project can start, based on scrap-based steelmaking (none in Kenya currently) and evolve over time to make use of indigenous Kenyan steelmaking raw materials, a strategy that makes full use of the flexibility of electric steelmaking with regard to use of different types of ferrous raw materials.

If such a plant was to be established,

- A task force should be constituted to look into the best place to locate the mill based on availability of raw materials, energy and transport system.
- A task force should be constituted to scout for the best investor into such a venture as well as equipment sourcing.
- The process of exploration and quantification of the Kenyan iron ore and coal should be fast-tracked may be through an increase in the number of drilling sites.

5.5 Research contributions

5.5.1 Contribution to theory and knowledge

The study determined that there was an HRC supply gap within the country and her neighbours an opportunity which should be captured and utilized. The study also identified a research gap of non-availability of a process design for a Kenyan steel plant which it went further and filled by developing a process design which can be used in developing a Kenyan iron and steel processing plant.

5.5.2 Contribution to policy making and practice

Steel is with no doubt Kenya's key driver to industrialization and as such, policies on the exploration and exploitation of this mineral require to be put in place. Based on the research findings, the establishment of an iron and steel processing plant in Kenya is viable and therefore policymakers should develop policies governing iron ore exploration, steel production and handling, taxation and steel import tariffs among others.

5.6 Future research

Due constraints of time, resources and limited scope, the study recommends the following for further research;

- Determination of quantity and quality of iron ore within the country.
- Determination of coal quantity and type within the country.
- Environmental impact assessment of such a plant.
- Appropriate location for such a steel mill.
- Detailed financial analysis of the Phase II steel project (when the amounts and qualities of Kenyan iron ore and coal are known)

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APPENDICES

Appendix i: List of steel makers in Kenya

	Company	Location
1	Apex Steel Ltd	Nairobi
2	Accurate Steel Mills	Nairobi
3	Devki steel Mills	Ruiru
4	Steelmakers Ltd	Mombasa
5	Mabati Rolling Mills (SAFAL Group)	Mombasa
6	Standard Rolling Mills	Mombasa
7	Morris & Company	Athi River
8	Roll Mill Kenya	Athi River
9	Tononoka Steels Ltd	Nairobi
10	ASP Company Ltd	Nairobi
11	Insteel Ltd	Nairobi
12	Prime Steel	Kisumu
13	Blue Nile Rolling Mills Ltd	Thika
14	Accurate Steel Mills Ltd	Nairobi
15	ASl Gravure Ltd	Nairobi
16	Tarmal Steel	Mombasa
17	Brollo Kenya Ltd	Mombasa
18	Emco Steel Works Kenya Ltd	Athi River
19	Athi River Steel Plant Limited	Athi River
20	Eldoret Steel Mills	Eldoret

Source: Numerical machining complex, 2014

Appendix ii: Estimate raw materials price

Material	Unit	Cost, US $/t
Scrap	ton	214
Ferro-alloys	ton	1167
Calcined lime	ton	80
Calcined dolo	ton	60
Fluorspar	ton	170
Limestone	ton	30
Dolomite	ton	28
Carburizer	ton	165
Pet coke	ton	300
Iron ore lump	ton	75
Iron ore fine	ton	50
Coke	ton	200
Non-coking coal	ton	50
PCI coal	ton	75
Oxygen	Nm^3	0.07
Argon	Nm^3	0.523
Nitrogen	Nm^3	0.07
LPG	Nm^3	0.75
Fuel oil	ton	750

Source: Steelorbis; CRU international Ltd,2016

Appendix iii: Population growth forecast in Kenya 2010-2030

Year	Population (million)
2010	40.3
2011	41.4
2012	42.4
2013	43.7
2014	44.9
2015	46.7
2016	47.8
2017	49.1
2018	50.4
2019	51.7
2020	52.9
2021	54.2
2022	55.5
2023	56.8
2024	58.0
2025	59.3
2026	60.6
2027	61.8
2028	63.1
2029	64.4
2030	65.7

Source: UN Worldometer,