

A framework for electricity generation  
opportunities in the South African  
integrated iron and steel industry: The  
ArcelorMittal Newcastle case

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Dissertation submitted in partial fulfilment of the requirements for the degree,  
*Master of Engineering* at the Potchefstroom Campus of the North-West  
University, South Africa

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November 2011

## **Acknowledgements**

I want to thank my Heavenly Father for the opportunity and the talents he has blessed me with to achieve this milestone in my career. Thank you for Your love, guidance and the countless blessings throughout my years of study.

To my fiancé and best friend, Megan Kruger, thank you for all your support, patience and love throughout this time. I appreciate and love you so very much.

Prof. Piet Stoker, my supervisor, thank you for the inspiration and the contributions that you had in this study and in the development of my professional career.

A special thank you to my parents for their unconditional love, support and advice that has brought me to where I am today and has laid the foundation for my future.

Lastly, I want to thank ArcelorMittal Newcastle and my fellow postgraduate students for their support and motivation to succeed. It is truly appreciated.

## **Abstract**

Electricity availability and the costs thereof in South Africa were traditionally considered an abundant and low cost commodity, but in recent years this situation has changed altogether. Industries are challenged by a strained national electricity grid and tariff increases more than four times the national inflation rate over the past two years, with further tariff increases expected in subsequent years; thus, exposing industries to significant business risks that may jeopardise the sustainability of industries. With the majority of the national electricity supply derived from coal, South Africa's push to reduce carbon emissions exerts even more pressure on industries as electricity usage is inextricably linked to its carbon footprint. In addition, South Africa's reliance on cogeneration from industries for its 2010 – 2030 electricity capacity plan further promotes industries to become more self-sufficient concerning electricity generation. In view of the above, there is a need in the South African integrated iron and steel industry for a framework that collectively addresses the governing factors pertaining to electricity generation in this industry, technical and economical quantification of available technologies and implementation of these technologies.

This dissertation researches the current driving/governing and the remediating factors to become more self-sufficient in terms of electricity generation. A framework for electricity generation opportunities in the integrated iron and steel industry is developed from the literature study and the researcher's own experience. The framework embodies four building blocks into a single and all-encompassing framework, which provides the necessary governing factors that quantify the potential need to pursue electricity generation/cogeneration, the technical and economical implications and, inevitably, the implementation requirements and guidelines. Validating the framework against case studies pertaining to ArcelorMittal Newcastle realised a correlation of between 84.6% to 97.6% concerning the technical parameters. In addition, the validation process also indicated that the framework is aligned with current practices applied by ArcelorMittal South Africa. The framework will enable South African integrated iron and steel industries to expand and adapt their own procedures to be specific to their operational requirements. The implementation of the framework should be tailored to address the specific needs concerning cogeneration in industry.

**Keywords:**

- Cogeneration
- IRP 2010
- Demand vs. Supply of Electricity
- Integrated Iron and Steel Industry
- Electricity Generation Technologies
- CDM Funding
- Power Conservation Programme
- Carbon Tax
- Cogeneration Costs
- Cogeneration Funding

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## Nomenclature

AM	<i>Adequacy Metrics</i>
AMDEC	<i>ArcelorMittal Design Engineering Centre</i>
AMEU	<i>Association of Municipal Electricity Undertakings</i>
AMSA	<i>ArcelorMittal South Africa</i>
BFG	<i>Blast Furnace Gas</i>
BOF	<i>Basic Oxygen Furnace</i>
°C	<i>Degrees Celsius</i>
c	<i>Cent – South African Currency</i>
CAPEX	<i>Capital Expenditures</i>
CCGT	<i>Combined Cycle Gas Turbines</i>
CDM	<i>Clean Development Mechanism</i>
CDQ	<i>Coke Dry Quenching</i>
CER	<i>Certified Emission Reductions</i>
CLS	<i>Corporate Legal Services</i>
CO	<i>Carbon Monoxide</i>
CO <sub>2</sub>	<i>Carbon Dioxide</i>
COG	<i>Coke Oven Gas</i>
DME	<i>Department of Minerals and Energy</i>
DNA	<i>Designated National Authority</i>
DOE	<i>Department of Energy</i>
DSM	<i>Demand Side Management</i>
EAF	<i>Energy Availability Factors</i>
EIA	<i>Environmental Impact Assessment</i>
EL	<i>Emergency Level</i>
ESCO	<i>Energy Services Company</i>
FGD	<i>Flue Gas Desulphurisation</i>
g	<i>Gram</i>
GHG	<i>Greenhouse Gas</i>
GJ	<i>Gigajoules</i>
GLF	<i>Gross Load Factor</i>
GMB	<i>Global Management Board</i>
GWh	<i>Gigawatt Hour</i>
HP-Steam	<i>High Pressure Steam</i>
HR	<i>Human Resources</i>
IAC	<i>Investment Approval Committee</i>
IRP 2010	<i>Integrated Resource Plan 2010</i>

<i>IRR</i>	<i>Internal Rate of Return</i>
<i>J</i>	<i>Joule</i>
<i>Kg</i>	<i>Kilogram</i>
<i>Km</i>	<i>Kilometer</i>
<i>kPa</i>	<i>Kilopascal</i>
<i>kWh</i>	<i>Kilowatt Hour</i>
<i>LNG</i>	<i>Liquefied Natural Gas</i>
<i>LP-Steam</i>	<i>Low Pressure Steam</i>
<i>m</i>	<i>Meter</i>
<i>m<sup>3</sup></i>	<i>Cubic Meter</i>
<i>MCDF</i>	<i>Multi-Criteria Decision-Making Framework</i>
<i>MCR</i>	<i>Maximum Continuous Rating</i>
<i>min</i>	<i>Minutes</i>
<i>mm</i>	<i>Millimeter</i>
<i>MVA</i>	<i>Megavolt Ampere</i>
<i>MW</i>	<i>Megawatt</i>
<i>MYPD</i>	<i>Multi-Year Price Determination</i>
<i>NERSA</i>	<i>National Energy Regulator of South Africa</i>
<i>NGO</i>	<i>Non-Governmental Organisation</i>
<i>NPV</i>	<i>Nett Present Value</i>
<i>OCGT</i>	<i>Open Cycle Gas Turbine</i>
<i>ORC</i>	<i>Organic Rankine Cycle</i>
<i>PCP</i>	<i>Power Conservation Program</i>
<i>PDD</i>	<i>Project Design Documents</i>
<i>PIN</i>	<i>Project Idea Note</i>
<i>ppm</i>	<i>Parts Per Million</i>
<i>PRS</i>	<i>Pressure Reducing Station</i>
<i>s</i>	<i>Seconds</i>
<i>SWH</i>	<i>Solar Water Heating</i>
<i>SME</i>	<i>Subject Matter Expert</i>
<i>TPF</i>	<i>Technology Payment Factor</i>
<i>TRT</i>	<i>Top-Pressure Recovery Turbine</i>
<i>UE</i>	<i>Unserved Energy</i>
<i>UNFCCC</i>	<i>United Nations Framework Convention on Climate Change</i>
<i>W</i>	<i>Watt</i>
<i>ZED</i>	<i>Zero Effluent Discharge</i>

# **Chapter 1**

## **Introduction**

*This chapter introduces the dissertation, focussing on the objectives, scope and outline of the research.*

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## Chapter 1 : Introduction

### 1.1 Introduction

The integrated iron and steel industry is synonymous with very energy intensive processes, with large amounts of the energy being used in the form of electricity. The processes required by this industry are also large contributors of greenhouse gas (GHG) emissions (Gielen, 2003). Therefore, this dissertation researched the factors governing electricity generation in this industry and quantified the technological and economical implications of pursuing the various electricity generating technologies in order to provide the integrated iron and steel industry of South Africa with a framework that collectively address these factors. The ArcelorMittal Newcastle Works (hereafter referred to as ArcelorMittal Newcastle) was the subject for the case study conducted in this dissertation. The research also included the reduction of GHG emissions that these cogeneration technologies can potentially yield, as this factor had to coincide with the cogeneration framework. This argument was founded on the basis that the GHG emission reductions could contribute to the revenue of the particular cogeneration technologies and consequently influence the economic viability of these technologies.

For most of the industrial development period, it was considered that South Africa had some of the least expensive and most readily available electricity (Wikipedia, 2010) to fuel the growth of its energy intensive industry. It is estimated that the industrial sector of South Africa consumes 37.7% of the country's electricity (South Africa, 2008). For this reason, the comment can be made that Eskom – who is the only public electricity supplier in South Africa – subsidised the growth of the South African industries to the extent where Eskom now has to relook its pricing and expansion strategy in order to meet the demand for electricity. The unfortunate events of 2007 and 2008 where South Africa experienced rolling electricity “blackouts” simply emphasised the inadequacy of the electricity network to meet the demand for electricity. This situation, where the demand outweighs the supply, led to the imposing of electricity consumption restrictions and acquiring help from industries to reduce their electricity consumption by at least 10% (South African Government Information , 2008). According to Corrie Visagie, head of the integrated demand management division, the following factors resulted in South Africa experiencing pressure on the electricity grid (Visagie, 2010):

1. “South Africa is experiencing limited new generation capacity, resulting in reserve margins reducing to unacceptable levels of around 8% (normally 15% is considered to be the minimum reserve margin).
2. The availability of generation plants has reduced due to the fact that these plants are operated above their maximum continuous rating (MCR) for considerable amounts of time and there are insufficient time periods available for maintenance on these plants.”

The result is that the electricity network will remain under pressure until new base load power plants are commissioned. In order to address the issues with regards to the base load capacity, Eskom is in the process of constructing a 4,332 megawatt (MW) coal-fired power station, Medupi, and is planning to commission Kusile from 2017 - 2020, another 4,332 MW coal fired power station (Department of Energy, 2010). However, these power stations are not going to be realised without a definite cost implication. Thus, the electricity consumers will have to contribute towards the funding of these projects, and this is achieved mainly by the increase of electricity tariffs. South Africa already experienced a 24.8% increase in electricity tariffs as from 1 April 2010, with further increases approved by the National Energy Regulator of South Africa (NERSA) of 25.8% and 25.9% planned for 2011/12 and 2012/13, respectively (Engineering News , 2010), in order to fund the expansion program of South Africa's electricity entity.

As with most other companies, the increase in electricity tariffs will definitely increase the production costs of the integrated iron and steel industry, resulting in a higher cost per tonne of steel products produced. The cost of electricity is not the only problem industries have to contend with; as mentioned earlier, the 10% reduction in electricity consumption poses another problem for the prospects of increasing production or expansion of any integrated iron and steel industries as these changes usually coincide with an increase in electricity consumption. Merely in the realm of electricity cost and the availability thereof, industries are challenged with a multidimensional problem concerning the balancing of these factors in a very competitive market.

In addition to the electricity dilemma confronting industry, another factor that must be taken into account is that, in efforts to reduce GHG emissions in South Africa, the introduction of a carbon tax in the South African Economy is a very real possibility.

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Carbon taxing has already been enforced in the automotive industry, where new passenger vehicles are taxed based on their certified carbon dioxide (CO<sub>2</sub>) emissions at R75 per g/km for each g/km above 120 g/km (Engineering News , 2010). A similar principle is mentioned in the 2010 Integrated Resource Plan (IRP 2010) and is likely to be applied in the industrial sector. Deputy President, Kgalema Motlanthe, has indicated that he is currently in favour of the carbon tax, but he neglects to elaborate on when this tax will be implemented nor how the revenue will be used by the South African Government (Businessday, 2010). However, there are some indications that the revenue generated from the carbon tax can be used to rebate CO<sub>2</sub> emission reduction projects, which will be welcoming for the South African industrial sector.

Currently, a company can derive benefits from driving the reduction of its GHG emissions. Firstly, if a carbon tax is introduced in South Africa, a company will obviously strive to minimise its GHG emissions as it will be taxed on these emissions. Secondly, a company can reduce its carbon footprint and sell these reduced GHG emissions as Certified Emission Reductions (CERs) under the Clean Development Mechanism (CDM). However, a company is only granted permission to trade CERs from a project if they can prove that the project (which will reduce the GHG emissions) shall only be economically viable if the revenue generated from the CERs is included in the rebate for that particular project.

In order to become more self-sufficient with regards to electricity generation, a number of mechanisms were identified to facilitate electricity generation for the South African integrated iron and steel industry. It will simultaneously contribute to reducing the total GHG emissions of the industry (including secondary GHG reductions because increased industrial cogeneration will decrease electricity purchased from Eskom; thus, less GHG emissions are produced to supply the industry with electricity). The following cogeneration mechanisms pertaining to each particular plant in the integrated iron and steel industry are tabulated below:

<b>Plant</b>	<b>Planned cogeneration technology</b>
Blast Furnace	Top-pressure Recovery Turbine (TRT) Technology Blast Furnace Gas (BFG) Recovery
Steel Plant	Basic Oxygen Furnace (BOF) Gas Recovery

	BOF Gas Latent Heat Recovery
Process Steam Generation	Substituting Pressure Reducing Stations (PRS) with Back Pressure Turbines
Coke Ovens	Coke Oven Gas (COG) Recovery COG Latent Heat Recovery Coke Dry Quenching
Sinter Furnace	Waste Heat Recovery from Sinter Machine and Sinter Cooler
Hot Rolling Mills	Waste Heat Recovery by means of Organic Rakine Cycle (ORC) Technologies

**Table 1.1 - Cogeneration Technologies Relevant to the ArcelorMittal Newcastle Works**

Each of the abovementioned plants and its associated technologies were researched and scrutinised in order to determine the viability for the implementation in the South African integrated iron and steel industry.

## 1.2 The Research Problem

Up to 2009, electricity in South Africa was considered a relatively low cost commodity compared to other countries. Until 2007 it was readily available, where after South Africa's electricity demand started to exceed its supply capacity (Visagie, 2010). When the integrated iron and steel industry came to existence in South Africa there were no real incentives in driving cogeneration in this industry, but the recent events where electricity tariffs and the availability thereof became problematic put the drive for increased cogeneration capacity at the opposite end of the spectrum. Businesses, like ArcelorMittal South Africa (AMSA), acknowledged that the security of electricity supply poses a threat to their operations, which must be addressed accordingly (ArcelorMittal South Africa, 2011).

Furthermore, the climate change issue, where South Africa made some commitments on 31 July 2002 by the signing of the Kyoto Protocol (UNFCCC, 2006), had also put pressure on industries to reduce the GHG emissions. Government's commitments to reduce the country's GHG emissions, like noticed with the 2010 Integrated Resource Plan (IRP), was another factor that had to be considered when researching businesses

response to the electricity situation in South Africa, as there is a strong interconnection between electricity generation in and GHG emissions.

The integrated iron and steel industry provides ample possibilities to generate electricity (refer to Table 1.1) and in parallel to reduce GHG emissions as identified by the Sector Policies and Programs Division Office of Air Quality Planning and Standards from the U.S. Environmental Protection Agency (Sector Policies and Programs Division Office of Air Quality Planning and Standards, 2010). However, these cogeneration projects usually result in a very long payback and consequently a relatively low Internal rate of return (IRR) (Sector Policies and Programs Division Office of Air Quality Planning and Standards, 2010). Most businesses use the IRR of a project as one of the decisive criteria to determine whether a project will be registered on their capital expenditure (CAPEX) budgets, and with the relatively low IRR that can be expected from these projects, they are seldom pursued. However, mechanisms do exist to improve the economical viability of these cogeneration projects, like registering these projects as CDM projects in order to generate CERs that would contribute to the revenue of the project, making it economically more attractive.

**In view of the above, it follows that it is necessary and opportune to research cogeneration in the context of the South African integrated iron and steel industry that collectively address the following:**

- 1. Factors governing cogeneration in the industry;**
- 2. Quantifying cogeneration technologies from a technical and economical point of view;**
- 3. Factors pertaining to the implementation of these cogeneration technologies.**

### **1.3 Objectives and Scope of this Study**

Recent studies have indicated that there is indeed scope for electricity generation opportunities and GHG mitigation in the iron and steel industry (Sector Policies and Programs Division Office of Air Quality Planning and Standards, 2010). However, none of these studies focuses on the South African iron and steel industries, and very few of

the proposed technologies are actually implemented in South Africa's integrated iron and steel industry. For this reason, the research aimed to develop a framework that critically evaluated the governing and technical factors as well as the economic viability of implementing the various cogeneration technologies, as identified in Table 1.1.

In order to achieve the objective of the study, the following outcomes were required from the research:

1. Identify and quantify the cogeneration technologies related to the integrated iron and steel industry in terms of capital investment requirements, generation capacity and consequently GHG emission reductions.
2. Determine the governing factors that prompt the necessity for the implementation of cogeneration technologies. These factors include:
  - a. Electricity availability and costs in South Africa
  - b. Quantify the carbon tax implications
  - c. Government expectations from industry, referring to the IRP 2010
  - d. Adherence to corporate policies and meeting environmental and legal responsibilities
3. Critically evaluate the economic viability of the various cogeneration technologies in terms of IRR. Revenue from CERs as well as the savings from carbon tax were included in the IRR studies.
4. Determine the implementation parameters for the pursuing of these technologies. Implementation timelines, operational support and personnel requirements were also researched.

It is expected that the outcome of this study will be beneficial to the iron and steel industry of South Africa as it defined an electricity generation framework in which the cogeneration related factors ought to be addressed.

### **1.3.1 Delimitations of the Study**

1. The study researched implemented cogeneration projects pertaining to the iron and steel industry. Manipulation of research data was required in order to adopt it to the current and local (South African) situation.

2. Financial feasibility studies were conducted pertaining to the various electricity generation technologies. The study made provision for the following circumstances where the project did qualify as a CDM project and has generated CERs, and where the project has not qualified as a CDM project; as well as when the project generated savings from carbon tax.
3. The research led to the development of a unique framework for the South African iron and steel industry concerning cogeneration by elaborating on a similar framework done by Wilson concerning zero effluent discharge (ZED) in the South African iron and steel industry (Wilson, 2008).
4. Although a plant's electricity requirements and GHG emission reduce through energy efficiency projects, the aim of this research was not to investigate energy efficiency in this industry, but rather expanding its cogeneration ability and consequently reduce its GHG emissions and electricity demand from Eskom.
5. The study was generalised for the integrated iron and steel industry of South Africa, but ArcelorMittal Newcastle was the subject for the case study.
6. The intention of this study was not to develop an action plan for the industry in terms of cogeneration projects. Rather, it serves as a tool that can direct the decision making process when the iron and steel industry pursue cogeneration projects.

### **1.3.2 Limitations of the Study**

For the purpose of this paragraph, the limitations to this study refer to a set of parameters on the application or interpretation of the results of the study. The following limitations were identified:

1. All historical project data concerning implemented cogeneration projects relates to non-South African countries. Costs variances of required capital expenditures between countries were not determined in this study. Possible changes in capital investments were absorbed through sensitivity analyses.
2. Complete historical data (meaning, capital investment requirements, generation capacities, infrastructure specifications, etc.) of implemented cogeneration projects were limited, resulting in some instances where the population group used for the statistical averaging were very small.

## **1.4 Research Outline**

Chapter 2 of this study represent the literature review concerning the following subject matter:

1. An overview of the integrated iron and steel plant;
2. The current demand versus supply situation of electricity in South Africa, focussing on the current shortfall of electricity and South Africa's response to this situation including the climate change mitigation (with special attention to the IRP 2010);
3. The advances that have been made with regards to electricity generation and reduction of GHG emissions in the iron and steel industry;
4. The processes involved in CDM funding for electricity generation projects, stemming from a climate change mitigation mechanism.

Chapter 3 focused on the development of the framework to define the electricity generation opportunities for the integrated iron and steel industry of South Africa. In Chapter 4 ArcelorMittal Newcastle was the subject for the case study. The aim of this chapter was to validate the framework that was developed in Chapter 3.

Chapter 5 maintained the validation process of the developed framework, supported by the case study from Chapter 4. Chapter 6 highlighted the conclusions that were drawn. Based on these conclusions, recommendations were made concerning the deployment of the electricity generation framework for the South African integrated iron and steel industry, and further research that may be required was identified.

## **Chapter 2**

### **Literature Review**

*This chapter provides a literature-based overview of the South African integrated iron and steel industry, specifically focusing on the current electricity and carbon emission situations as well as government's requirements concerning cogeneration. The available electricity generation technologies and CDM funding for this industry are also researched.*

## Chapter 2 : Literature Review

### 2.1 Introduction

South Africa has a long and established iron and steel industry, with the first blast furnace being constructed in South Africa in 1901 by Mr. C.L. Green at Sweetwaters, near Pietermaritzburg (South African Iron and Steel Institute, 2008). Although this operation utilised a blast furnace, it was still not a fully-fledged integrated iron and steel works. Nonetheless, it still marks the start of this industry in South Africa, which developed to the extent that by 2008, South Africa was the world's 21<sup>st</sup> largest crude steel producer (South African Iron and Steel Institute, 2009) with 1,326.5 million tonnes produced for 2008. South Africa's first integrated iron and steel plant dates back to 1934, when Iscor's Pretoria plant tapped its first iron (ArcelorMittal South Africa, 2010). Thus, South Africa is a well-established and definite contender in the world's iron and steel industry.

With South Africa's participation in the world's iron and steel industry defined, the intention of this chapter was to give an overview of the following:

1. What this industry entails as this proved to govern the cogeneration technology research;
2. Research the current electricity demand versus supply situation. Government's requirements derived from the IRP 2010 were researched with emphasis on cogeneration requirements and reducing GHG emissions;
3. Identify the cogeneration technologies pertaining to each plant that constitutes an iron and steel works;
4. Lastly, the CDM process was studied in order to quantify the stakeholders involved if this process is followed as well as to determine a timeframe in which this process can be executed.

Although this chapter identified the technologies available to contend with cogeneration in the industry, it was only quantified in the following chapter, during the electricity generation framework development. The ultimate goal of the literature study was to provide a foundation on which to base the electricity generation framework for the integrated iron and steel industry.

## 2.2 The Integrated Steel Plant

The *integrated steel plant* is epitomised by the eight interrelated metallurgical processes that are required to process raw materials to the final steel products, namely:

### 1. Coke Production

Diemer explained that coke is produced by the anaerobic distillation of coal in coke batteries at a very high temperature (approximately 1,000-1,200 °C). This carbon product is used to fuel the blast furnace and to provide a reducing atmosphere. Modern blast furnaces consume approximately 290 to 320 kg coke per tonne of hot metal (Diemer et al., 2004). Deimer continued to elaborate that coke can be produced in non-recovery plants or in by-product recovery coke oven batteries. The South African integrated iron and steel industry produces coke using the latter process, which recovers tar, light oils, ammonia, and coke oven gas (COG) from the vapours generated in the coke ovens. The COG is used as a process fuel throughout the integrated steel plant, from fuelling the coke oven batteries (approximately a third of the COG produced by the coke oven battery is used to sustain the combustion processes in the coke oven battery) to sustaining combustion processes in boilers, open or closed cycle gas turbines, blast furnace stoves, and reheating furnaces.

### 2. Sinter Production

The sintering process converts fine-grain raw material into course-grained sinter, and it recovers some of the waste material generated at an integrated steel plant, which would have been stockpiled or discarded. The raw material is typically a blend of fine iron ore, concentrates, coke, reverts (blast furnace dust, mill scale, etc.), fines from the sintering process and trim materials (limestone, calcite fines and other materials required for the specific metallurgical composition of the sinter). The sinter is produced by the fusion of the sinter feed (Diemer et al., 2004). The heat input for the fusion process is sustained by the combustion of COG or natural gas in the sinter hood. The final product is a hard-fused material with a relatively low density in order to increase the permeability of the burden in the blast furnace.

### 3. Iron Production

The iron production process involves the reduction of iron ore and other iron-bearing materials in a blast furnace. The furnace is charged with iron ore, sinter, fluxes and coke. Diemer described that coke fuels the furnace and provides the reducing atmosphere in the blast furnace. Other sources of carbon are also used in modern furnaces, like the injection of pulverised coal or COG. The burden (consisting of iron oxides, coke, fluxes, and coal) reacts with the hot blast air injected through the tuyere belt at the bottom of the furnace into the blast furnace to reduce the burden to molten iron, carbon monoxide (CO), and slag. The iron and slag are tapped from the hearth of the furnace while the blast furnace gas BFG is recovered from the top of the furnace.

### 4. Raw Steel Production

Iron from the blast furnace is transported to the steel plant where the iron, which is contaminated with impurities, is refined to steel. During the raw steel production process a basic oxygen furnace (BOF) is used to remove carbon from the liquid iron. The BOF is an open-mouthed vessel, which is charged with ferrous scrap and iron from the blast furnace, where the carbon is removed by injecting high-purity oxygen into the iron and scrap mixture (Diemer et al., 2004). The carbon is removed in the form of CO and CO<sub>2</sub>. If the BOF is equipped with open hoods, the CO produced by the BOF is converted to CO<sub>2</sub> by combusting it at the BOF mouth. The unconverted CO and CO<sub>2</sub> from the BOF is extracted via the gas-cleaning plant and then flared off to the atmosphere.

### 5. Ladle Metallurgy

Raw steel from the previous process is poured into a ladle where the secondary metallurgy process is initiated. The metallurgical specifications for the client is obtained from this process, which typically includes deslagging and reslagging, electrical heating, chemical heating or cooling with scrap, powder injection or wire feeding alloying materials, and stirring with gas or with electromagnetic fields.

**6. Continuous Casting**

From the secondary metallurgy process, the molten steel is transferred to the continuous caster. Semi-finished shapes, like slabs, blooms, billets and large diameter rounds are cast. Some integrated steel plants allow for the option of hot charging, whereby hot blooms, billets, etc. are loaded directly into the reheating furnaces of the hot rolling mills, which subsequently results in a decreased energy input required to reheat the material before it undergoes hot rolling. If hot charging is not possible, products from the continuous caster must be stored before it can be loaded in the reheating furnaces of the hot rolling mills.

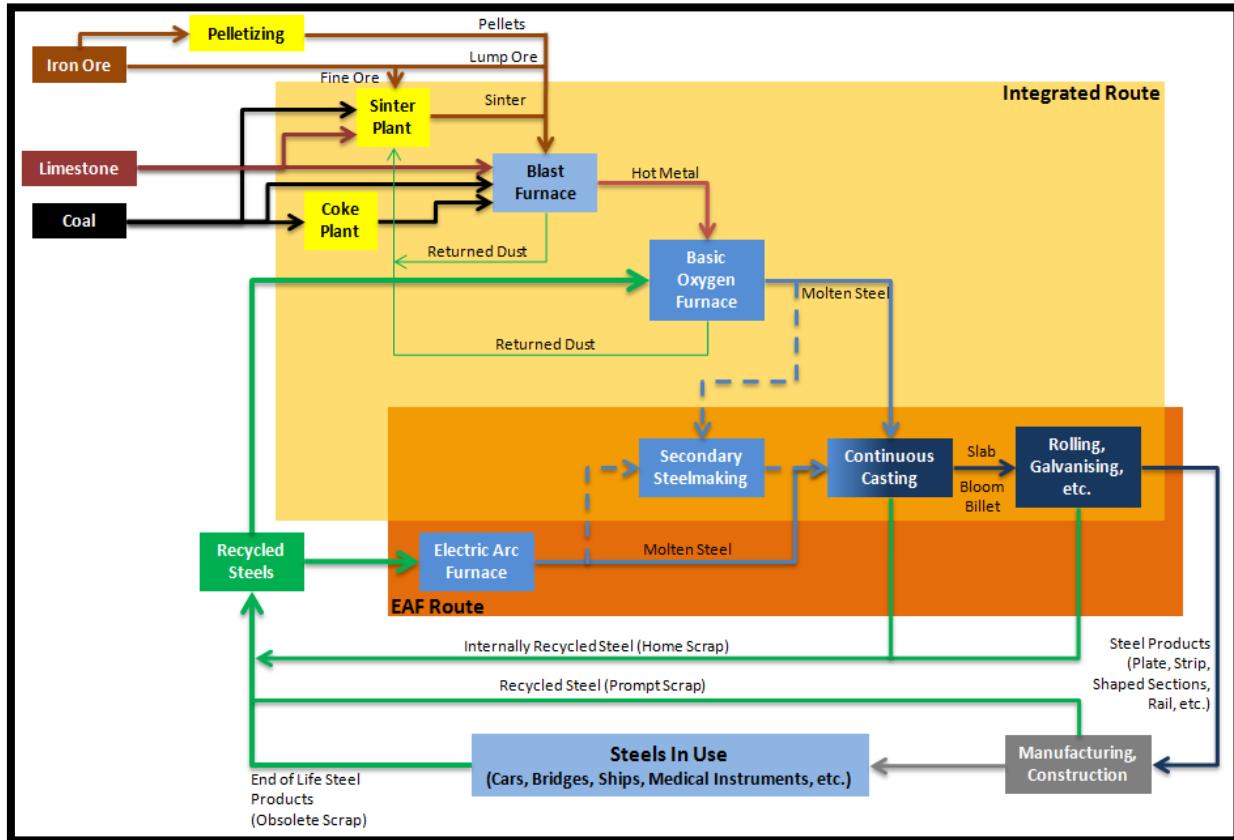
**7. Hot and Cold Rolling**

Products received from the continuous caster are dimensionally too big to undergo cold rolling immediately; consequently, it is necessary to first reduce the dimensions utilising a hot rolling process. Blooms, billets, etc. are loaded into a reheating furnace before it is processed in the hot rolling mill either to final products or to products of the desired dimensions that will allow for cold rolling which will then deliver the final product according to customer specifications.

**8. Finished Product Preparation**

From hot or cold rolling, the semi-finished product may require further processing to meet the customer specifications. Processes may be as simple as cutting products to size or may also include other processes like annealing, heat treating, pickling, galvanising, painting or coating of the products.

The interrelationships of these processes that constitute the integrated steel plant are indicated in Figure 2.1. It is important to comprehend the layout and process flows of the integrated iron and steel industry in order to investigate all possible plants where cogeneration may be lucrative.



**Figure 2.1 - Integrated Steel Plant (Sector Policies and Programs Division Office of Air Quality Planning and Standards, 2010)**

In addition to understanding the operation of the integrated iron and steel industry, one must also take note that the processes constituting this industry is energy intensive, and consequently produces large amounts of GHG emissions. According to the United States Environmental Protection Agency, the GHG emissions generated from the integrated steel plant are categorised as:

1. Process emissions generating CO<sub>2</sub> emissions from raw materials and combustion;
2. Emissions from combustion processes alone;
3. Indirect emissions as a result of the consumption of electricity (Sector Policies and Programs Division Office of Air Quality Planning and Standards, 2010)

These emissions can further be classified as Scope 1 and 2 emissions according to the GHG Protocol (Anon, 2008):

1. Scope 1: All direct GHG emissions related to the iron and steel production activities.
2. Scope 2: Indirect GHG emissions generated from the consumption of purchased electricity and utilities.

As the main objective of this dissertation was to determine a framework for electricity generation opportunities for the integrated iron and steel, it was important to consider the reduction in scope 2 emissions. These emissions were inevitably factored into the economic model concerning each cogeneration technology.

## **2.3 Demand vs. Supply of Electricity in South Africa**

### **2.3.1 The Consumer's Electricity Problems**

During 2007 and 2008 South Africa had to contend with load shedding for the first time in its history due to the demand for electricity exceeding supply. Mitigation actions resulted in Eskom being requested by the Department of Minerals and Energy (DME) to develop a power conservation program (PCP) to assist in relieving the demand for electricity. The PCP required industrial companies to reduce their electricity consumption by approximately 10% in order to accommodate the expansion of generation capacity and to do essential maintenance on current generation plants (Eskom, 2008).

Besides industries being challenged with the reduction of their electricity demand, they also have to contend with the increases in electricity tariffs in order to fund the generation capacity expansion projects. To support the funding for these projects NERSA approved the consecutive tariff increases of 24.8%, 25.8% and 25.9% from 2010/2011 to 2012/2013.

Electricity consumers also have to manage the risk related to the security of supply as a result of the pressure on the electricity supply system, mainly contributed by (Visagie, 2010):

1. The limited new generation capacity, resulting in the power system reserve margin dwindling to unacceptable levels.
2. The availability of generation plants, as they are operated for extended periods over their maximum continuous rating (MCR) and time for essential maintenance is limited.

### **2.3.2 Demand vs. Supply Analysis and the Implications**

According to Visagie's paper, presented at the Association of Municipal Electricity Undertakings (AMEU) conference in 2010, he elaborated on the current to medium term future of the electricity situation in South Africa. A multiyear price determination (MYPD) analysis was done for the demand versus supply projection over the medium term in order to put the challenges related to the country's electricity situation in perspective. The analysis was heavily dependent on a number of assumptions, which can be reviewed in Appendix A.1.

The sales projection is indicated by the shaded areas in Figure 2.2, while the line graphs represents the theoretical annual energy supply availability for the 86% and 84% energy availability factors (EAF), excluding the capacity reserved for Alcan - Alcan refers to the smelter that is planned for the Coega district. The system adequacy metrics (AM) used in this analysis are indicated in Table 2.1.

Capacity Adequacy Metric		Threshold	Detail
AM1: UE GWh	Unserved Energy (UE)	< 20 GWh per annum	The amount of energy in a year that could not be supplied due to system supply shortages.
AM2:GLF (OCGT)	OCGT Load Factor	< 6% per annum	The Gross Load Factor (GLF) of the combined OCGT plant in operation in a year.
AM3:EL1 GWh	Emergency Level 1 Energy	< 400 GWh per annum	The energy supplied in a year by generators operating above their continuous rating under instruction during supply emergencies. Interchangeable with OCGT generation.

AM4:GLF (EBLS)	Expensive Base Load Stations (EBLS) Load Factor	< 50% per annum	The Gross Load Factor (GLF) of the combined expensive Base-load Stations (typically Camden, Grootvlei and Komati) in a year.
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Table 2.1 - Adequacy Metrics (Visagie, 2010)

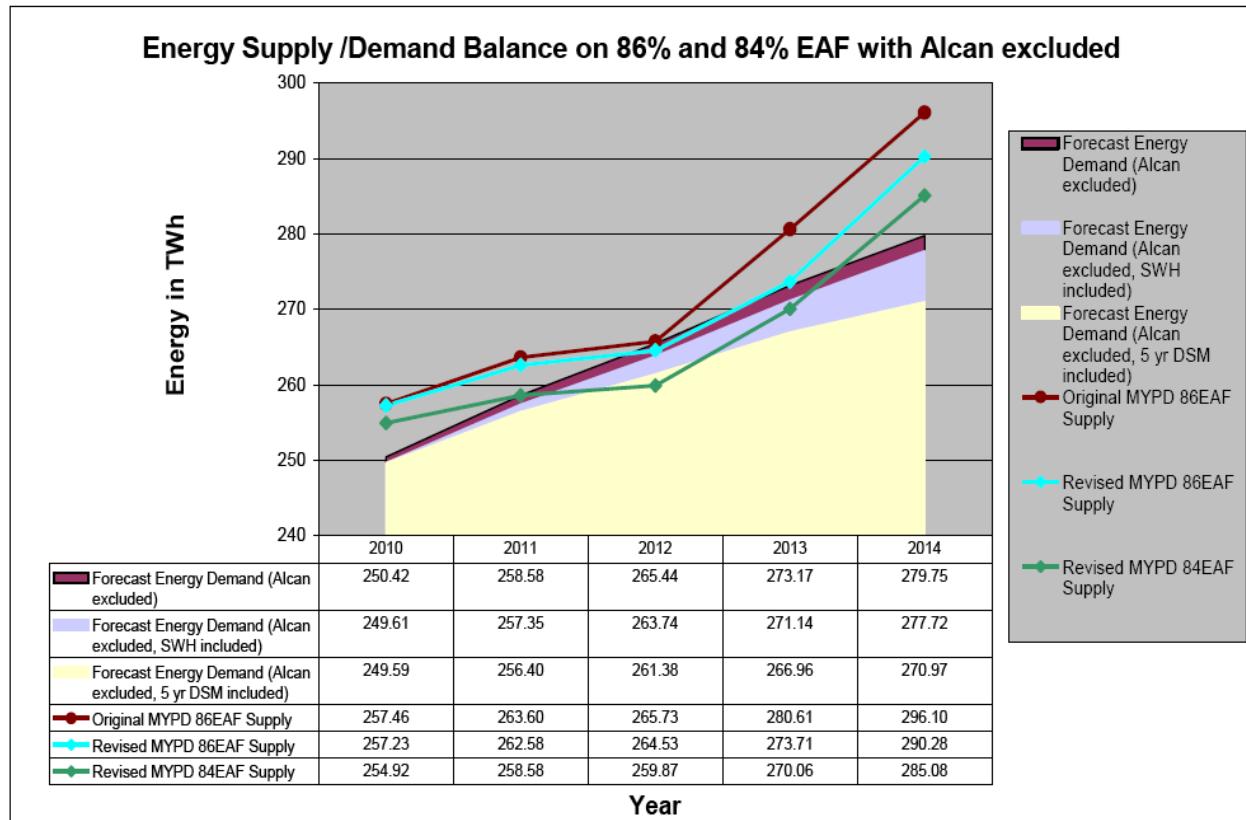
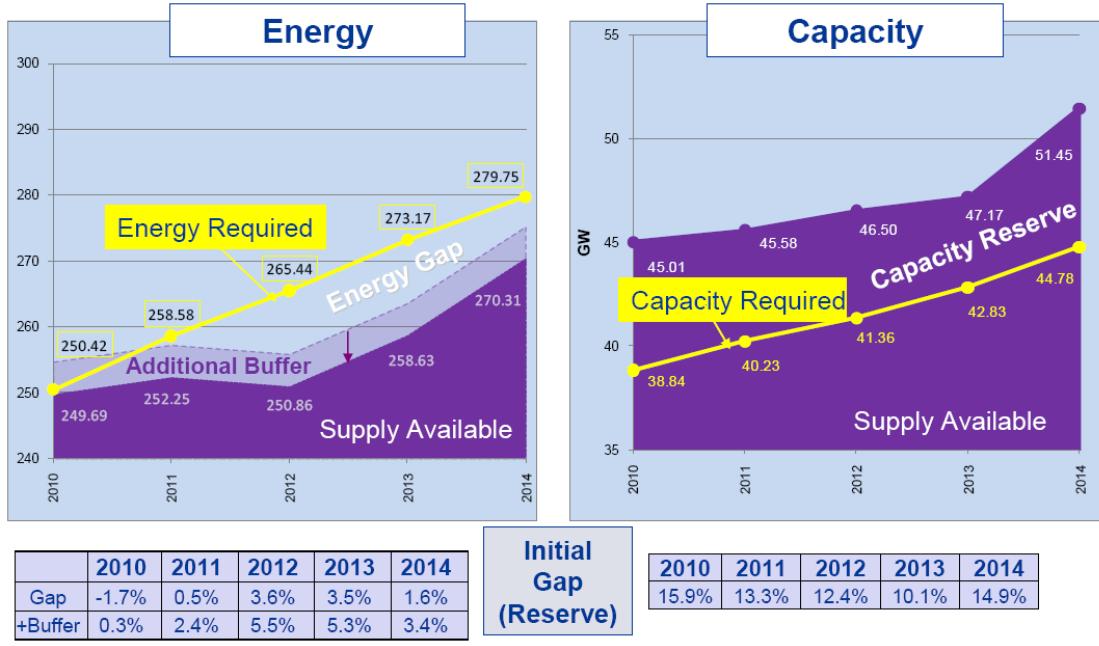


Figure 2.2 – MYPD2 Analysis (Visagie, 2010)

From Figures 2.2 and 2.3 it is clear that the security of supply risk on the national electricity system peaks in 2012. This statement was also based on the assumption that the supply assumptions were all met (with regards to the commissioning of new generation capacity). The MYPD2 analysis was further elaborated by considering a number of contingencies to accommodate additional risks and to make provision for unforeseen circumstances. Refer to Appendix A.2 for the assumptions used in the contingency analysis. Figure 2.3 illustrates the results from the contingency analysis; indicating that electricity availability is a problem in the short term rather than a capacity problem. Even though, capacity is not a direct problem, peak loads can only be managed through additional base load capacity or a reduction in the overall consumption.



**Figure 2.3 - Gap Analysis Based on Contingencies (Visagie, 2010)**

According to Visagie, the implications of not closing the energy gap can be summarised as follow (Visagie, 2010):

1. Security of supply remains a risk, stemming from the severe pressure imposed on the electricity supply system.
2. Price of electricity will be increased if open cycle gas turbines are used to mitigate the risk.
3. Economic development will be affected negatively as the supply pressure will prohibit the connection of large customers.
4. The sustainability, reputation and competitiveness of South Africa will be negatively affected.
5. Reducing supply to neighbouring countries may have negative political implications.
6. Damage may be incurred to the reputation of Government and the electricity supply industry.
7. Opportunities to unlock economic efficiencies through more efficient use of electricity may be lost.

The iron and steel industry in South Africa is dependent on electricity, and more specifically low cost electricity. Thus, the security of electricity is closely interlinked with the sustainability of steel production in South Africa.

## **2.4 IRP 2010**

### **2.4.1 IRP 2010 Introduction**

Long-term planning for the South African electricity supply sector is essential, but the current pace of global change concerning political, economical, social, technological and environmental factors creates a number of challenges. Balancing the desired outcomes and required input or output constraints further complicates the long-term planning process. In view of the above, the IRP 2010 was developed to realise the role as a long-term electricity capacity plan, focusing on the country's electricity demand, supply of demand, and the cost implications. One of the outcomes from the IRP 2010 that was of particular interest to this study was the requirement for 1,253 MW cogenerated electricity. The IRP 2010 was not clear with regards to who will be responsible for this 1,253 MW of cogenerated electricity, but it is for certain that the country's security of supply is dependent on this contribution.

The IRP 2010 was developed from the process of scenario planning, whereby a modelling process was used to observe the effects of interdependent variables from a particular outcome or input to the scenario (Department of Energy, 2010). The balanced scenario was developed from a number of scenarios investigated for the IRP 2010, which ultimately forms the basis for the Government's risk/policy adjustment plan with the main objective being to determine how the demand for electricity will be met. Factors taken into account to determine the type, cost, capacity and timing for generation expansion included planning factors, *inter alia*, economic development, funding, environmental and social policy formulation.

Evaluation of various scenarios realised the "Revised Balanced Scenario" which balanced the following risks and constraints:

1. Affordability
2. Reducing carbon emissions

3. New technology uncertainties (costs, operability, lead time to build etc.)
4. Water usage
5. Job creation
6. Security of supply

The following two outcomes, as quoted from the Draft IRP 2010, were of particular interest pertaining to cogeneration in the iron and steel industry (Department of Energy, 2010):

1. *“Own generation or cogeneration options of 1,253 MW as identified in the Medium Term Risk Assessment study.*
2. *Eskom’s (Demand Side Management) DSM programme as stipulated in the multi-year price determination (MYPD) application has been incorporated.”*

As mentioned in the IRP 2010 introductory paragraph, South Africa’s security of electricity supply is depended on cogeneration from industries. Not only will cogeneration contribute to the country’s electricity plan, but it will also promote self-sufficient operations in industries.

Eskom’s DSM programme aimed to reduce the demand for electricity through energy efficiency or alternatively cogeneration. An insight into the DSM programme follows later in this dissertation in terms of how it can contribute to cogeneration in the industry.

#### **2.4.2 IRP 2010 Development, Modelling and Finalisation**

As the objective of the IRP 2010 was to create a basis for new generation capacity, the development process as set out by the Electricity Regulations had to be followed (Department of Energy, 2010):

1. Adoption of the planning assumptions.
2. Determination of the electricity load forecast.
3. Modelling scenarios based on the planning assumptions.
4. Determination of the base plan derived from a least cost generation investment requirement.
5. Risk adjustment of the base plan, which was based on:

- i. The most probable scenarios; and
  - ii. Government policy objectives for a diverse generation mix, including renewable and alternative energies, demand side management and energy efficiency.
6. Approval and gazetting of the integrated resource plan.

Current policies were used to develop the IRP 2010, but its outcomes are most likely to lead to the redefining of these policies or may lead to the development of new policies.

The scenario modelling delivered a number of generation portfolios subjected to the following evaluation criteria (Department of Energy, 2010):

1. Water usage/dependency
2. Cost
3. Climate change mitigation
4. Portfolio risk or uncertainty
5. Localisation benefit
6. Regional benefit

Based on the evaluation criteria mentioned, a multi-criteria decision-making framework (MCDF) made it possible to numerate the various scenarios, making it possible to select a single portfolio based on the scoring of these portfolios and catalyse the changes or prioritisation of policy choices.

The Revised Balanced Scenario is a refinement of the original Balanced Scenario (based mainly on the Emission 2 scenario) which was developed from the results of the various scenarios and the MCDF analysis. Factors resulting in the refinement of the Balanced Scenario included (Department of Energy, 2010):

- Delays in the start of the wind programme – set to start in 2014
- Construction delays in the new built programme – Medupi by 12 months and Kusile by 24 months
- Costs of future coal was reduced from R300 a tonne to R200 a tonne, while the cost of liquefied natural gas (LNG) increased to R80/GJ and the costs of

imported coal were changed to include flue gas desulphurisation (FGD) with the generic costs of pulverised fuel.

- Furthermore, the emissions resulting from imported coal were excluded from domestic emissions accounting, a solar build program was required to substitute a portion of the wind programme as this was still a relatively new technology, which might not necessarily deliver the initially anticipated results, and the initial solar programme was moved a year later.
- Regional options from the Regional Development Scenario were also included and the capacity from (combined cycle gas turbine) CCGT was increased to allow for domestic contingency for import and renewable energy; thus, providing the opportunity for private investment in electricity generation.

A definite factor concerning the development of an electricity generation framework for the iron and steel industry was that part of the medium term business mitigation strategy required own generation or cogenerated electricity options before 2017. This was required to ensure capacity increase continuity between the various plans that make up the Revised Balanced Scenario. Delays in commissioning Medupi and Kusile should not be excluded from the demand management plan. Delays in these projects would result in the shifting of the available electricity supply curves to a later date (refer to the Gap Analysis in Figure 2.3).

#### **2.4.3 IRP 2010 Conclusions**

The commitments that South African Government made concerning the reduction of GHG emissions will not be met entirely by implementing the IRP 2010. The modelling of the various scenarios proved that governing electricity supply only around a *low carbon future* in South Africa would lead to additional costs of the electricity consumer due to the more expensive capacity. Nevertheless, the Revised Balanced Scenario still provided for a significant reduction in GHG emissions at a marginal increase in electricity tariffs (Department of Energy, 2010). This increase in tariffs was considered during the development of the electricity generation framework for the iron and steel industry.

The IRP 2010 did provide guidance concerning the expected electricity tariff trajectory, but this would have to be negotiated and finalised by the electricity supply entity,

Eskom and NERSA. However, the Revised Balanced Scenario established a framework for a stable programme of capacity increase from renewable energy technologies in the medium term through localisation. A key driver for the development of an electricity generation framework in the iron and steel industry was the 1,253 MW of cogeneration capacity that is required for the success of the IRP 2010 in the next seven years.

While great emphasis was placed on mitigating GHG emissions, Professor Philip Lloyd from the Cape Peninsula University of Technology (Lloyd, 2011) indicated that South Africa's contribution to GHG emission reduction would go unnoticed unless large GHG emitters like India and China also actively partake in reducing their GHG emissions. Thus, GHG emission reduction should carry less weight in the IRP 2010, and South Africa should rather focus on its resource constraints. Nonetheless, until South Africa succumbs to the easing the reduction of GHG emissions; its industries would have to pursue technologies that would contribute to these emission reductions.

Although the IRP 2010 planned to guide South Africa's electricity capacity increase and address climate change by aiming to reduce GHG emissions, it should be realised that the IRP 2010 is a twenty-year plan, which relies on a number of assumptions. Practically, this is a plan that would not go unrevised in the near future. Climate change, especially the mitigation of GHG emissions requires careful consideration, possibly re-evaluating its weighting in the IRP 2010, as global participation is required before any significant changes are noticed. South Africa's intensive efforts to this cause come at a cost, which would propagate into all sectors of its economy.

## **2.5 Available Electricity Generation Technologies for the Iron and Steel Industry**

### **2.5.1 Introduction**

The integrated steel making process allows for the recovery of both chemical potential energy – by means of combusting process waste gases – and the recovery of mechanical energy in the forms of heat and pressure. Akashi et al. identified the following available technologies for the generation of electricity applicable to the integrated steel making process (Akashi et al., 2010):

Coke Ovens:	Coke oven gas (COG) recovery COG latent heat recovery Coke dry type quenching
Sinter Furnace:	Waste heat recovery from the sinter machine strand and the sinter-cooling strand
Blast Furnace:	BFG recovery Top pressure recovery turbine
Basic Oxygen Furnace (BOF):	Oxygen steel furnace gas recovery Oxygen steel furnace gas latent heat recovery

However, Akashi *et al.* neglected to identify the electricity generation technologies for the final steps of the integrated steel making process (namely the rolling of the steel blooms to produce the final steel products) and other processes (for example industrial boilers). Advances in waste heat recovery by means of utilising Organic Rankin Cycles (ORC) (Turboden, 2011) enables the industry to recover waste heat at far lower temperatures compared to conventional recovery of heat energy by transferring it to water and in the process generating steam. For the reasons mentioned above, the following two plants and the related technologies should also be considered when developing a comprehensive cogeneration frame for the iron and steel industry:

Rolling Mills:	Waste heat recovery from reheating furnace exhaust stacks
Process Steam Generation:	Backpressure turbine instead of steam attemperation

The last available technology that was considered is the utilisation of backpressure turbines in preference to steam attemperation. Steam attemperation is the process where the pressure and temperature of steam is reduced by way of water injection into the steam stream in order to achieve a lower energy condition (The Instrumentation, Systems, and Automation Society, 2005).

The literature relating to the identification of the electricity generation technologies was specific to only a few fields, namely generation capacity, possible emission reductions, capital expenditure, etc. However, there was no framework available in which all of the

mentioned technologies were evaluated for feasible application in the integrated iron and steel industry.

The succeeding paragraphs investigated the mentioned electricity generation technologies (per plant) and formed the technical basis from which the framework for electricity generation technologies in the iron and steel industry was developed.

### **2.5.2 Coke Ovens**

COG is a by-product of the coke making process; however, there are modern processes, namely non-recovery coke ovens, which use all the by-products to sustain the process; thus eliminating the opportunity to recover COG. On average, the by-product recovery process produces 300-350 m<sup>3</sup> COG per tonne of coke, but as mentioned before, the coke oven battery consumes approximately 30% of the COG to sustain the coke making process. The calorific value of the COG is approximately 17.4 MJ/m<sup>3</sup> (Diemer et al., 2004) but this value may vary depending on the plant specific specifications and the quality of the coal being used. Due to the energy value of the COG, it is common to find that COG is used in various combustion processes, like reheating furnaces, OCGTs or CCGTs, and for the production of process steam that is among other applications used for electricity generation purposes.

Recovery coke ovens utilise the latent heat from the COG, which is approximately 1,400 °C. However, there is no indication that recovery coke ovens are used in the South African iron and steel industry. Coke is produced in South Africa by means of non-recovery coke ovens, where COG is a by-product of the coke making process. The COG produced by the non-recovery process exits the coke oven battery at approximately 649 °C to 982 °C, but it is then cooled and the by-products are recovered (Johnson & Choate, March). Flushing liquor and liquor from the primary coolers contain tar and are sent to the tar decanter, where ammonia is separated from the tar decanter and recovered at the waste treatment plant. Further cooling promotes the separation of naphthalene in the separator on the final cooler, while benzene, toluene and xylene are fractionated from the light oils in the COG. Limited heat recovery from COG is possible by means of a low-pressure heat transfer medium as demonstrated by Japan (Johnson & Choate, March). Heat is recovered from the COG

exit temperature to a minimum temperature of 450 °C, after which tar condenses, resulting in soot formation of the heat exchanger.

Another area where heat can be recovered from the coke oven battery is from the exhaust gases that exit the heating flue, which is adjacent to the oven chamber in the coke oven battery. The hot exhaust gases are produced from the combustion of COG in the heating flue. It leaves the heating flue and passes through a regenerator to transfer heat to the incoming combustion air and/or fuel. The exit temperature of the exhaust gases that leave the regenerator average approximately 200 °C (Johnson & Choate, March). Some plants utilise the heat from the exhaust gases that leaves the regenerator for other purposes like for preheating coal charge and reducing its moisture content, resulting in a further decrease of temperature to approximately 60 °C. If the regenerator heat is not used, it provides an opportunity for low temperature heat recovery that may be utilised for electricity generation.

After the coke has been baked for cycles of between 14 to 36 hours (Anon, 1998), the coke must be cooled from approximately 1,000 °C to room temperature (JP Steel Plantech Co, 2010). The conventional method of discharging the heat energy from the coke is to quench the red-hot coke with water. Large quantities of steam is generated which is vented to the atmosphere; thereby, transferring the energy to the environment. Coke dry quenching (CDQ) can be used to recover the sensible heat that would otherwise be lost. This heat energy is transferred to water to generate steam in waste heat recovery boilers after which the steam is used in turbine driven generators to generate electricity. Figure 2.4 is a schematic illustration of the CDQ process:

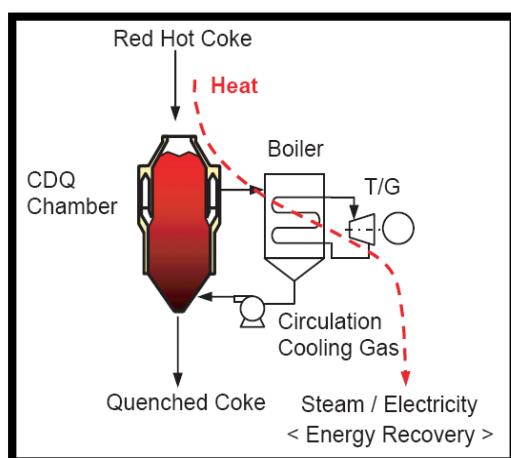


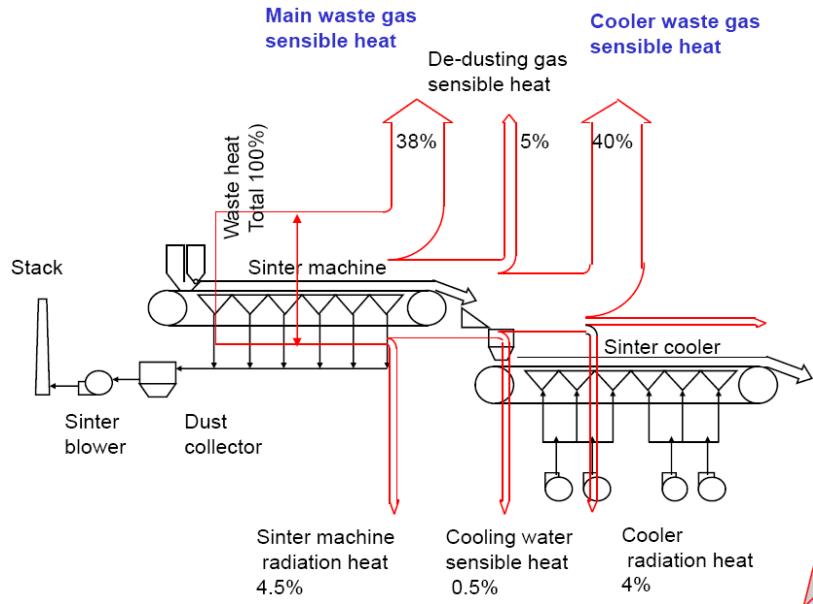
Figure 2.4 - Coke Dry Quenching Process (JP Steel Plantech Co, 2010)

Hot coke is charged into the CDQ chamber, where the coke will be cooled. An inactive gas is then circulated through the CDQ chamber, via a dust catcher to the waste heat boiler, where steam is generated to power a generator. A gas blower sustains the circulation of the cooling gas. In the coke quenching process, the temperature of the coke is reduced to approximately 200 °C; coke is removed from the CDQ chamber where after the process then repeats itself. It is estimated that the steam recovery rate is 0.55 GJ/tonne of coke. According to the United States Environmental Protection Agency the installation cost of the CDQ is approximately \$109.5/tonne of coke. Retrofitting costs depend on the facility layout and is estimated to be \$112-144/GJ saved (Sector Policies and Programs Division Office of Air Quality Planning and Standards, 2010). According to the literature, CDQ technologies realised intensive financial requirements and it was challenged by researching commissioned CDQ plants during the development of the framework.

### **2.5.3 Sinter Furnace**

The United States Environmental Protection Agency identified the sinter plant as a prime plant to generate electricity from recovered waste heat (Sector Policies and Programs Division Office of Air Quality Planning and Standards, 2010). According to Worrel, *et al* waste heat recovery does not only have to be incorporated in new plants, but existing plants can also be retrofitted to enable waste heat recovery (Worrell et al., 1999), thus, opening cogeneration avenues for current sinter plants in South Africa.

The following diagram (Figure 2.5) illustrates the waste heat balance of the sintering process:



**Figure 2.5 – Waste Heat Balance for the Sintering Process (JP Steel Plantech Co., 2008)**

According to Figure 2.5, 78% of the total heat generated from the sintering process is transferred to the environment via the sinter machine and sinter cooler stack. Heat can be recovered at an efficiency of 60% from the sinter cooler and 34% efficiency from the sinter machine proper (JP Steel Plantech Co., 2009).

The high temperature heat is recovered from the two exhaust stacks as steam that can be used for electricity generation. Figure 2.6 illustrates the heat recovery processes from the two exhaust stacks. In order to realise higher efficiency recovery, a high-temperature exhaust section and low-temperature exhaust section are separated. The waste heat from the high-temperature and low-temperature recovery systems are circulated to the back to the sintering machine and sinter cooler respectively. Table 2.2 indicates the realised steam and electricity generated per tonne of sinter produced – assuming steam is generated at 20 bar. Implementing these recovery technologies also contributes to a reduction in dust dispersed into the atmosphere as indicated in Table 2.3.

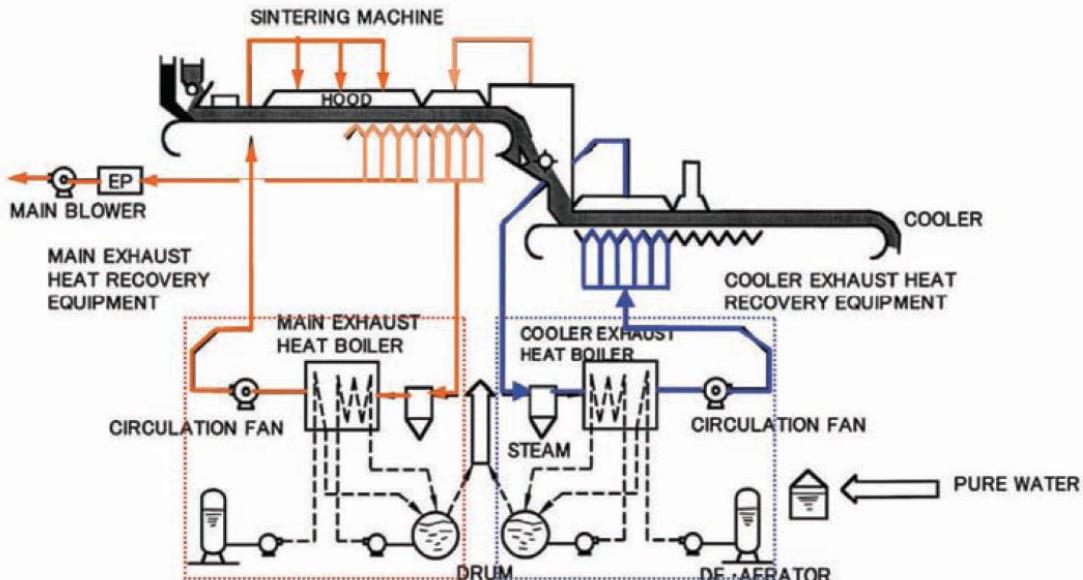


Figure 2.6 – Sinter Plant Heat Recovery System (JP Steel Plantech Co., 2009)

No.	Waste heat recovery system	Steam recovery volume (kg/t-sinter)	Power recovery volume (converted value) (kWh/t-sinter)
1	No system	0	25
2	Cooler recovery system (circulating type)	120	20 26
3	Cooler recovery system (circulating type) and sintering machine recovery system (circulating type)	170	30 26

Recovered power  
 Consumed power

Table 2.2 - Steam and Power Recovery (JP Steel Plantech Co., 2009)

No.	Waste heat recovery system	Dust dispersion volume (kg/t-sinter)
1	No system	0.92
2	Cooler recovery system	0.29
3	Cooler recovery system and sintering machine recovery system (circulating type)	0.19

Sintering machine proper  
 Cooler  
 Others

Table 2.3 - Dust Dispersion (JP Steel Plantech Co., 2009)

#### 2.5.4 Blast Furnace

BFG is the by-product of the iron making process in the blast furnace, where iron ore is reduced with coke to metallic iron ("hot metal"). BFG has a very low calorific value,

ranging between 2.7 to 4 MJ/m<sup>3</sup>, where carbon monoxide (20 – 28%) is the energy carrier in the gas (Energy Technology Systems Analysis Programme, 2010) and the production is approximately 1,200 to 2,000 Nm<sup>3</sup>/tonne hot metal. As the BFG exits the blast furnace, it is channelled via a series of cleaning plants before it is reticulated throughout the steel works. There are two common means of BFG cleaning, namely wet-type or dry-type cleaning. The wet-type cleaning system typically consists of a dust catcher, a venturi scrubber system and a demister; as opposed to the dry-type cleaning system that largely consists only of a filter cleaning system. The dry-type cleaning system results in a higher BFG temperature after the gas has been cleaned, which is an advantage when a top pressure recovery turbine (TRT) is to be installed (ASEAN Centre for Energy, 2008). Cleaned BFG can be used to sustain the combustion processes throughout the integrated steel plant. In terms of electricity generation, BFG is used in boilers or can even be combusted in gas turbines, but the latter technology still not mature.

The TRT is used to recover the top pressure in the furnace. The differential pressure between the furnace and the BFG distribution pressure is relatively small, but the high volume of BFG produced allows for the recovery of enough energy to make it economically viable at several plants. The higher differential pressure is expanded via a turbine and in turn generates electricity. It is estimated that the TRT can produce approximately 36 kWh/tonne (0.054-0.14 GJ/tonne) of hot metal. The large investment required for this technology is approximately \$28.4/tonne of hot metal (Sector Policies and Programs Division Office of Air Quality Planning and Standards, 2010). As mentioned in paragraph 2.5.2, the framework was developed from data of installed systems. This data was then also used to scrutinise the literature presented by the United States Environmental Protection Agency.

Waste heat can also be recovered from the hot stoves at the blast furnace; however, the technology lends itself more to the recuperation of waste heat in order to preheat combustion air rather than towards electricity generation (Sector Policies and Programs Division Office of Air Quality Planning and Standards, 2010). Therefore, the heat from the hot stoves was not considered for cogeneration as it is used for recuperation purposes.

### **2.5.5 Basic Oxygen Furnace**

Crude steel is produced by charging the BOF with molten iron, scrap and other additives, and then lancing oxygen into the BOF; resulting in an exothermic reaction and in the process producing BOF gas at temperatures ranging between 1,650 to 1,900 °C. This heat can be recovered by either open combustion or suppressed combustion systems (Johnson & Choate, March). In the open combustion system, the CO produced in the BOF blowing process is converted to CO<sub>2</sub> by introducing air into the BOF gas duct. The generated heat is recovered with a waste heat boiler. In the suppressed combustion system, air leakage into the BOF gas duct is minimised by equipping the converter (BOF) with a special skirt. This prevents the combustion of CO which is collected after being cleaned and then used as fuel. Heat is still generated when using the suppressed combustion system; thus, waste heat can be recovered in a waste boiler while the BOF gas is recovered and combusted for electricity generation purposes. It is estimated that the capital cost of the recovery system is approximately \$ 66 Mil (2010 value) for an average BOF with a production rate of 3 million tonnes per annum, but as with the previous technologies, these costs was verified by comparing it with the real investment costs of recent projects.

### **2.5.6 Rolling Mills**

Semi-finished products from the casting operations are further processed to produce the final steel products, usually heating the castings in reheating furnaces and manipulating the size and shape through a series of mill rolls. The flue gas temperature of these reheating furnaces ranges between 450 to 550 °C, thereby realising an opportunity for heat recovery. It is a standard practice to recover waste heat from reheating furnaces by means of recuperators, but even utilising a recuperator, flue gas temperatures of these furnaces are over 200 °C. The introductory paragraph to this chapter indicated that the advances in ORC technologies now provide the opportunity to recover heat at much lower temperatures as opposed to conventional waste heat boilers. The flue gas volume and the economic viability would dictate the possibility of implementing ORC technologies at mills' reheating furnaces.

### **2.5.7 Process Steam Generation**

It is a common occurrence that not all of the steam consumers at an integrated iron and steel facility require steam at the same pressure; thus, steam is usually generated at a pressure dictated by the highest-pressure consumers. If the lower-pressure steam consumers' demands do not justify their own steam generators, steam is then attemperated from the higher pressure to the lower pressure required. The process of steam attemperation allows for the opportunity of replacing the attemperation system with a backpressure turbine that can harness the energy embodied in the pressure drop from the high-pressure to the low-pressure steam. Like with the rolling mills, the feasibility was determined by reviewing the installation capacity and installation costs of previous projects (Bailey & Worrell, 2005).

## **2.6 CDM Funding for Electricity Generation**

### **2.6.1 Introduction**

The Clean Development Mechanism (CDM) allows developing countries to earn certified emission reduction (CER) credits from emission reduction projects (United Nations Framework Convention on Climate Change, 2010). A CER is equivalent to a tonne of CO<sub>2</sub> and can be traded and sold to industrialised countries to meet their emission reduction targets. The mechanism was established under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) in order to stimulate sustainable development and emission reductions (Winkler & van Es, 2007).

The implementation of electricity generation projects in the iron and steel industry would realise a reduction in electricity purchased from Eskom – with the assumption made that electricity consumption stayed constant. Thus, substituting purchased electricity with cogenerated electricity will result in a reduction of CO<sub>2</sub> emissions from the generation of electricity from coal-fired power stations. These reductions can be claimed as CERs and consequently traded; resulting in an additional income to fund the project that will realise the CERs. However, additionality is a prerequisite – meaning, CERs shall only be awarded to the project if, under normal circumstances, the project would not be economically viable.

### **2.6.2 The CDM Project Cycle and Project Flow**

Stakeholders may vary in range and type per project, but every project has a generic set of participants in order to complete the CDM process (United Nations Development Programme, 2003). In addition to the explanation of the CDM process, one must consider the fact that the CDM is a time-bound and that the continuation of this mechanism is periodically reviewed. Prior to the 17<sup>th</sup> Conference of the Parties (COP17) the CDM would only be valid until the end of 2012; however, COP 17 realised a second commitment period under the Kyoto Protocol, commencing on 1 January 2013 and ending on 31 December 2017 or 31 December 2020 (UNFCCC, 2012). Figure 2.7 illustrates the simplified process flow for a CDM project as well as the participants for every stage of the CDM process.

By referring to Figure 2.7 as guide to the CDM process, each stage/milestone of the process was elaborated in this paragraph.

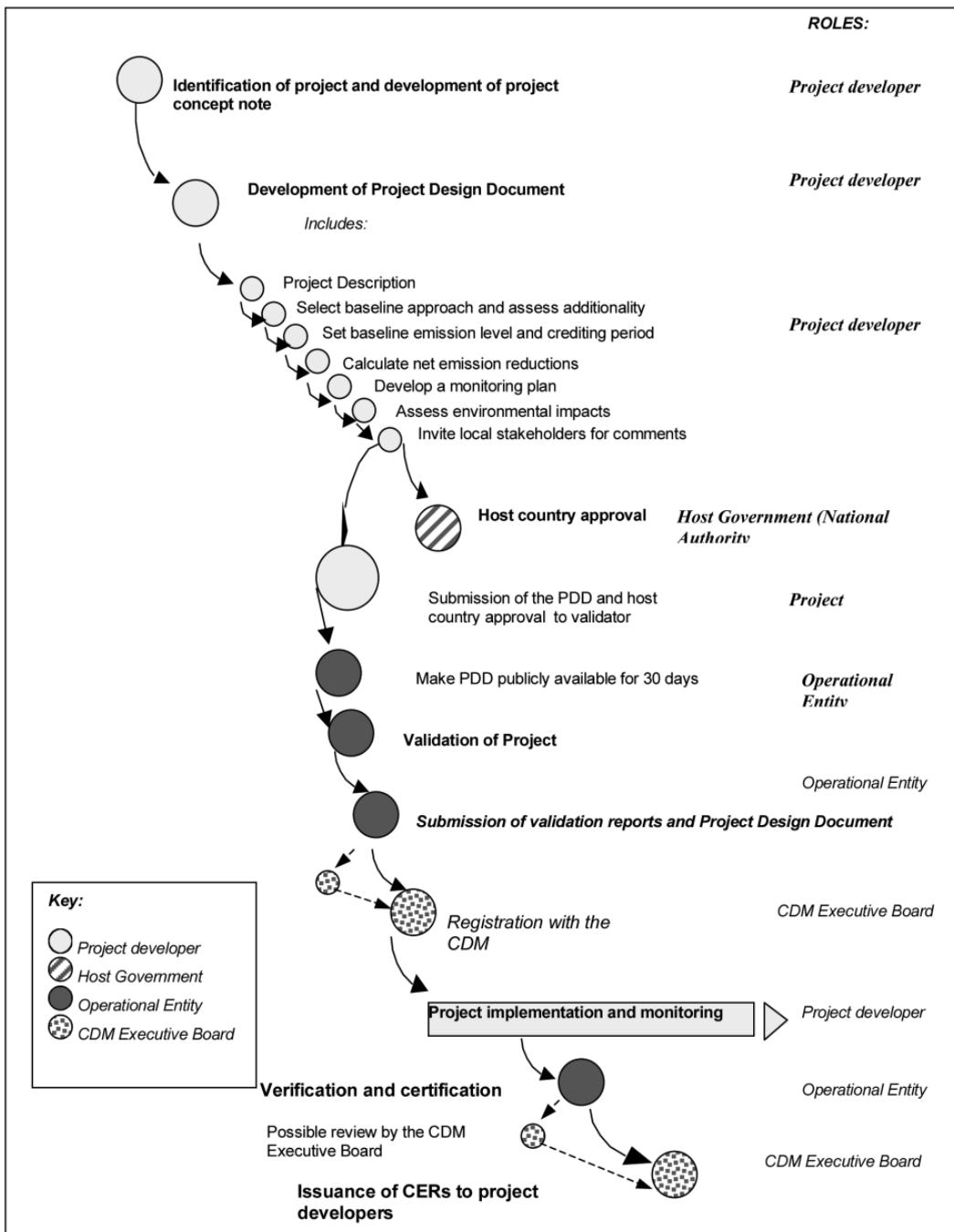


Figure 2.7 – CDM Process Flow (United Nations Development Programme, 2003)

### Project Identification

The project developers or operators of the host country can identify a possible CDM project. The developers may include private companies, non-governmental organisation (NGOs), governments, international organisations or international investors. The developer must ascertain that the identified project will have the required

support from the host country and ensure that the project is eligible under the CDM (United Nations Development Programme, 2003). The host country must be a party to the Kyoto protocol; of which South Africa is indeed a party member.

***Project Idea Note***

If the project proves to be eligible under the CDM, the project developer and its advisors must develop and submit a project idea note (PIN) to a number of possible carbon credit buyers in order to evaluate the interest in the marketplace. The PIN recipients will investigate the project in order to ensure conformance with the CDM rules and investment criteria.

Even though the PIN is not a prerequisite under the CDM, it allows the developer to test the interest of potential buyers and can be regarded as a market-evaluating tool. The PIN is a brief document that includes the following information:

- Project type and size
- Location
- Anticipated total amount of GHG reduction compared to the ‘business-as-usual’ scenario
- Suggested crediting life time
- Suggested CER price in US\$/tCO<sub>2</sub> equivalent reduced
- Financial structuring
- Socioeconomic or environmental effects/benefits

The PIN can also be submitted to the Designated National Authority (DNA) – which is the South African designated national authority for CDM projects (de Swardt, 2010) – for voluntary screening. The developer may request from the DNA:

- A letter of no objection
- Comments on the project
- Assistance in the project development

If the project proves to be eligible under the CDM, the project developer and its advisors must develop and submit a project idea note (PIN) to a number of possible

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carbon credit buyers in order to evaluate the interest in the marketplace. The PIN recipients will investigate the project in order to ensure conformance with the CDM rules and investment criteria.

## **2.7 Conclusion**

This chapter defined what constitutes the integrated iron and steel industry; as this was the base for specific technologies that can possibly be implemented in this industry. The motivational factors for pursuing electricity generation were also highlighted, specifically focussing on the country's electricity supply situation and the requirements set out in the IRP 2010. Upon clarification of the need for electricity generation in this industry, avenues where technologies can be implemented were identified. Lastly, an overview of the CDM process was also given. The research specifically highlighted how industries must go about implementing the CDM in order to generate additional revenue for the projects.

Although each element was researched in isolation, it was important that the development of an electricity generation framework required a holistic approach. Thus, evaluating Chapter 2 on this basis, it surpassed the outcome of isolative investigation necessary for the development of the electricity generation framework for South Africa's integrated iron and steel industry.

Chapter 3 used the preceding information and the researcher's experience in the South African iron and steel industry as a departure point to develop the electricity generation framework.

## **Chapter 3**

### **Development of the Framework**

*Expanding on the literature review, this chapter develops the framework for electricity generating opportunities in the South African integrated iron and steel industry. The objective is to provide industry with an all-encompassing framework in which cogeneration should be pursued in this industry.*

## **Chapter 3 : The Framework Development**

### **3.1 Introduction**

The development of the *framework for electricity generation opportunities for the South African iron and steel industry* (hereafter simply referred to as the *framework*) is intended to address the current driving factors concerning electricity generation in the industry, quantify the available electricity generation technologies and its implementation areas, and consider the economic factors related to pursuing these technologies.

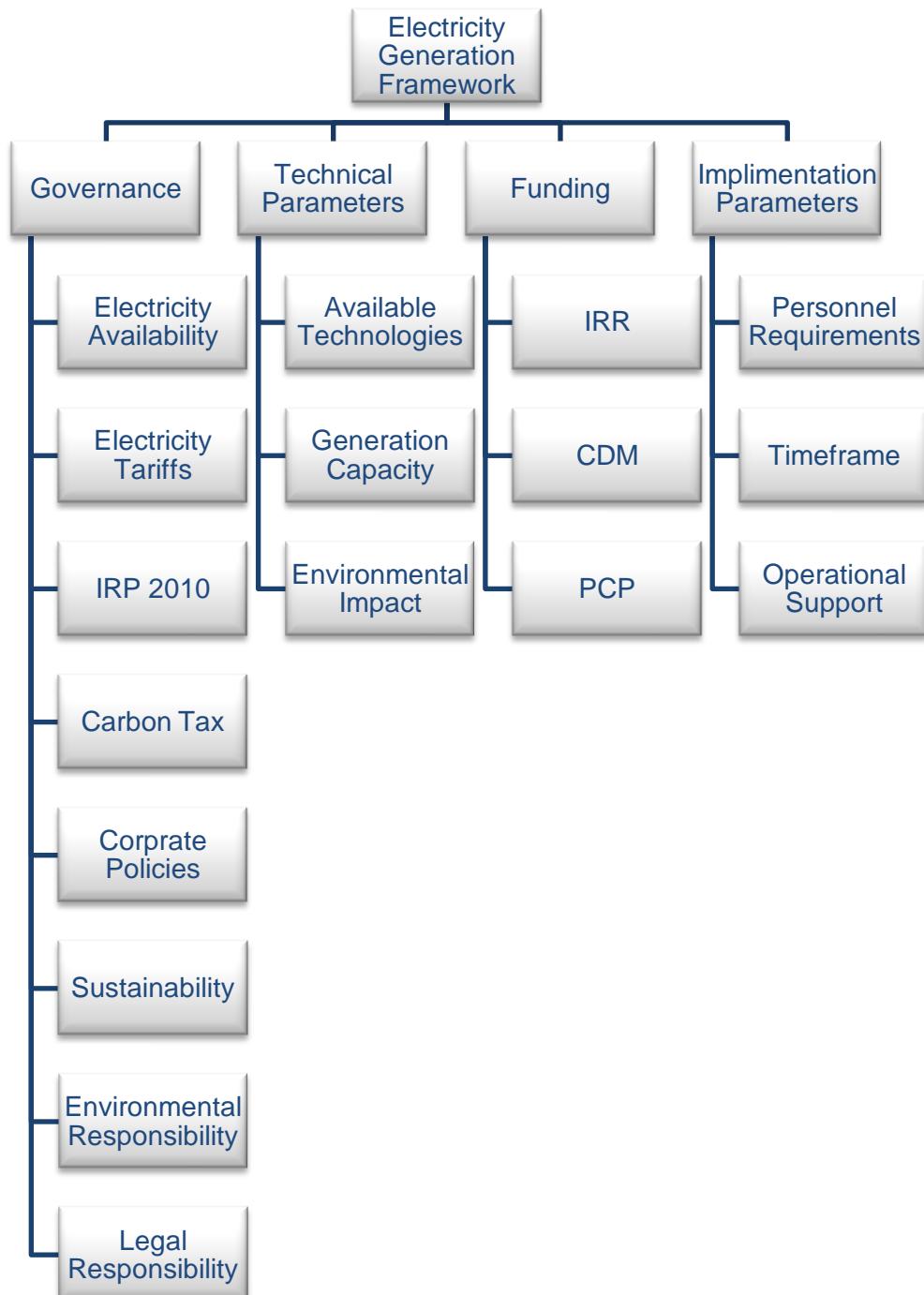
Referring to the definition of a framework (Google Dictionary, 2011), it is important to realise that it is only the basic structure of an underlying concept, and that the uniqueness of each plant/operation and its operating environment should be considered when the framework is implemented. Thus, the framework forms the basis as to what factors are contributing to why a company should pursue cogeneration, what technologies are available and what is the economic incentive.

This chapter represents the following factors that constitute the electricity generation framework under the following main building blocks:

1. Governance
2. Technical Parameters
3. Funding
4. Implementation Parameters

The four building blocks differentiate between the driving factors for cogeneration; what technologies are available for this industry; remuneration of cogeneration projects and lastly, what is required to pursue cogeneration, which are combined into a single framework. Wilson developed a similar framework for zero effluent discharge (ZED), which was implemented in the South African integrated iron and steel industry (Wilson, 2008). Many of the subsets embodied in Wilson's framework was adopted for the development of the electricity generation framework for the integrated iron and steel industry in South Africa.

The abovementioned building blocks are embodied by a compilation of subsets, which are progressively elaborated throughout this chapter. Figure 3.1 is a graphical representation of the framework and gives an overview of its structure and contents.



**Figure 3.1 - Structure of the electricity generation opportunities framework for the South African iron and steel industry**

## 3.2 Governance

The governing factors concerning the electricity generation framework are what drive cogeneration in the iron and steel industry. It answers the question, *why the iron and steel industry has to pursue electricity generation.*

Strong emphasis was placed on economical driving factors, such as electricity availability, electricity tariffs and carbon taxing. Other factors, like the IRP 2010, environmental responsibility, legal responsibility and corporate responsibility, all relate to commitments to either governmental compliance or internal company policies.

### 3.2.1 Electricity Availability

Stemming from the paper presented by Visagie at the AMEU Conference in 2010 and referring to Figure 2.3, it is clear that electricity availability is a definite problem in South Africa. Figure 2.3 illustrates that the energy required outweighs the available supply from 2011 onwards, but the gap between the available supply and the required energy peaks in 2012. Unfortunately, 2012 is in the too near future and industries would not be able to develop and commission electricity generation plants within such a limited timeframe. This is due to a number of factors, like long lead times on project proposals and feasibility studies, funding approvals, EIAs to be completed, equipment procurement, construction, etc. According to Figure 2.3 the demand will not meet the supply by 2014. Currently it is unclear what demand versus supply projections dictate after 2014, but it can be assumed with reasonable certainty that electricity supply will remain under pressure for a number of years beyond 2014.

Visagie's report failed to mention if the PCP target imposed on industries was abolished in the projection, considering that the targets were implemented in 2008 based on a 10% reduction from the 2007 electricity demand. Thus, assuming that the PCP was valid for the entire projection period in Figure 2.3, then abolishing the PCP, when the electricity demand and supply curves meet, would once again place the system under pressure unless the PCP was gradually phased out. Nevertheless, the electricity supply system will remain under pressure well into the near future.

Thus, electricity availability will remain a risk to industries as there is no guarantee when the electricity supply will be able to meet the demand. Furthermore, intentions of

increasing plants' capacity will also be limited as a capacity increase relates to an electricity demand increase. Because the iron and steel industry is heavily depended on electricity and is not able to instantly reduce load due to the nature of these operations, industries have to either accept the risk of losing electricity supply or should become self-sufficient by generating their own electricity.

### **3.2.2 Electricity Tariffs**

According to a paper that was submitted to the NER, it is indicated that the real price of electricity for the industrial sector decreased by 25% over the period 1970-2005, with the real price in 2005 being 11.28 c/kWh (van Heerden et al., 2008). Tariff increases for most of this period were below inflation; thus, a correction by Eskom was unavoidable. Realising this correction is evident from the current electricity increases of 24.8%, 25.8% and 25.9% over the period 2010 to 2013 (Creamer, 2010). However, Eskom requested a 35% tariff increase for this period in order to fund the R385 billion power expansion programme (NewsTime, 2010). Thus, the realised increases are well below what is required, and though there is not a tariff forecasting available beyond 2013, it can be expected that there will be further price increases beyond 2013. This statement was based on the following three assumptions:

1. The NERSA approved tariff increase was below the Eskom requested tariff increase; thus, the shortfall should still be equalised.
2. The referred expansion programme mentioned earlier in this paragraph was related to the Medupi and Kusile power stations. However, referring to the IRP 2010, more tariff increases would be inevitable to fund the IRP 2010 capacity expansion programme.
3. The IRP 2010 stated that the plan would be implemented with a marginal increase in electricity tariffs (Department of Energy, 2010).

It is evident that the framework should consider the currently imposed electricity tariff increases until 2013 and then expect electricity tariff increases greater than inflation beyond 2013. However, suggesting a tariff increase greater than inflation would only be based on assumption, which would jeopardise the accurateness of the economic viability study. In addition, to use inflation for the tariff increase beyond 2013 proved to

be a more conservative approach, as higher tariff increases would only strengthen the economic incentive of these projects.

### **3.2.3 IRP 2010**

The purpose of this paragraph is to determine how the IRP 2010 would affect the South African iron and steel industry, and suggest mitigating actions that can be taken by industry.

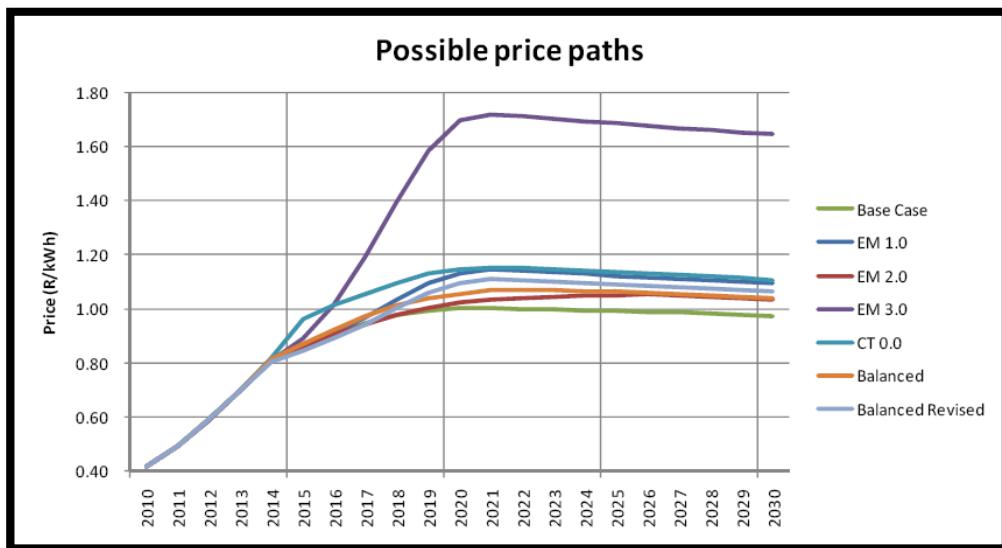
As part of the *medium term business mitigation strategy*, it is required that 1,253 MW of cogenerated electricity is contributed to the total electricity supply of South Africa by 2017 (Department of Energy, 2010). The intention of the IRP 2010 is not to dictate which industries are expected to contribute to this 1,253 MW target; this will be the responsibility of the Department of Energy minister. Nevertheless, this target must still be achieved by industries. Industries that can cogenerate will probably be probed to pursue cogeneration. Referring to paragraph 2.5, integrated iron and steel plants lend themselves toward multiple possibilities for cogeneration; therefore, they can contribute to the target set in the IRP 2010.

The IRP 2010 further relies on the DSM programme, and industries pursuing the DSM route can benefit from Eskom funding by reducing the electricity demand. Cogeneration projects will most likely be larger than 1 MW in capacity; thus, it will be required that industry utilises an Energy Services Company (ESCO) or registers itself as an ESCO in order to be able to receive funding from the DSM programme (Nicosia, 2011). The rebate from the DSM programme will be based on an individual project calculation and will either be refunded based on R/MW or c/kWh to the maximum value of:

1. Actual costs (Customer to provide proof of costs)
2. 85% X Technology benchmark
3. Technology Payment Factor (TPF) X Technology benchmark

The IRP 2010 also supports the previous paragraph concerning electricity tariffs by factoring an increase in electricity tariffs concerning the implementation of the plan. Figure 3.2 represents the electricity increases related to the IRP 2010. The prices may

not be 100% correct, but the general trend is more important for planning purposes, as suggested by the IRP 2010 (Department of Energy, 2010).



**Figure 3.2 – Electricity Tariff Forecasting (Department of Energy, 2010)**

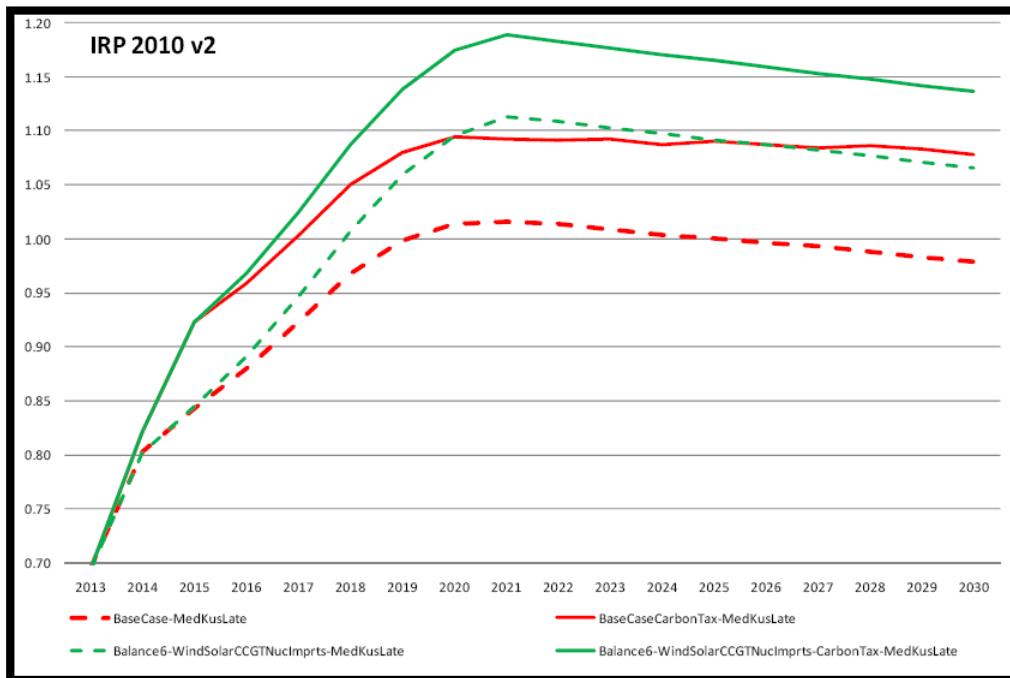
In summary, the following factors contributed to the framework and were accounted for in evaluating cogeneration possibilities for the South African iron and steel industry:

1. Contributing to the national benchmark of 1,253 MW of cogenerated electricity.
2. The IRP 2010 relies on DSM and can also contribute as revenue for the funding of cogeneration projects.
3. The pricing model must be taken into account for financial planning.

### 3.2.4 Carbon Tax

The 2007 Long-Term Mitigation Scenarios report and the 2010 National Climate Change Response Green Paper for South Africa recommend the implementation of carbon taxes to induce behavioural changes that will contribute to lower GHG emissions (National Treasury, 2010). Moreover, although the carbon tax has not yet been implemented in South Africa, the possibility of implementation still exists; it is for this reason the IRP 2010 considers it for the 2010 to 2030 capacity-building programme.

Figure 3.3 illustrates the effect of the carbon tax on the electricity path as derived from the IRP 2010, with the taxation starting in 2010 at R150/tonne CO<sub>2</sub> and increasing with inflation.



**Figure 3.3 – Pricing Path with Impact of Carbon Tax (Department of Energy, 2010)**

Figure 3.3 only illustrates the effect on electricity tariffs directly resulting from CO<sub>2</sub> produced from electricity generation. The possible technologies investigated for the cogeneration in the iron and steel industry will only result in a reduction in Scope 2 emissions; thus, the saving can only be realised if the tax is imposed on the purchase of electricity.

### 3.2.5 Corporate Policies

Besides external factors (like, electricity tariffs and carbon taxing) companies also adhere to corporate policies that govern the manner in which business is conducted. Wilson suggests that (Wilson, 2008):

“Companies should have policies in place to govern their business and to optimise the value of their processes by applying sound commercial judgement

whilst endeavouring to realise maintained long-term business sustainability in a manner that respects the environment and the health of all stakeholders.”

Therefore, the framework embodies the fact that companies should internally promote the sustainability of energy sources and the environment. Furthermore, when reviewing the corporate policies, it is important to take into account the commitments made by companies, and realising that they must be held accountable to realise these commitments.

### **3.2.6 Sustainability**

According to Sustainability South Africa, rapid globalisation will result in the demand for electricity growing faster than the demand for any other energy source over the next few decades, which may affect electricity sustainability. The underpinning factors related to energy sustainability in South Africa is the future generation capacity and the implications electricity generation has on global warming (Sustainability South Africa, 2010). Heun et al. also support this statement. According to Heun et al., the National Framework for Sustainable Development acknowledges the growing stress on environmental systems and natural resources from economic growth and development (Heun et al., 2010). Thus, realising that electricity will have an effect on economic growth, companies should be proactive in mitigating the risk related to the availability of electricity and minimising their GHG emissions in order to sustain growth.

### **3.2.7 Environmental Responsibility**

According to Earthlife Africa Johannesburg, South Africa has deployed the following national policies and strategies related to climate change (Earthlife Africa Johannesburg, 2009):

1. White Paper on Energy Policy (1998)
2. The National Waste Management Strategy (1999)
3. The NEMA Air Quality Act (2004)
4. South African National Climate Change Strategy 2004
5. Renewable Energy Policy of South Africa White Paper 2004
6. Electricity Regulation Act (2006)

## 7. Long Term Mitigation Scenario Planning study (2008)

Without delving into all of these documents, the outcomes of these policies and strategies refer to the accumulative goal of GHG emission reductions, as set out in the Kyoto Protocol. However, as mentioned in paragraph 2.4.3 the total reduction commitment made during the acceptance of the Kyoto Protocol will not be realised with implementation of the IRP 2010, but a significant reduction in GHG emissions is still incorporated in the IRP 2010.

When embarking on any new plant development in the industry, an Environmental Impact Assessment (EIA) must be conducted in order to ensure that the new developments will not affect the environment negatively. However, this is known to be lengthy process that can easily propagate into project delays, which can generally not be afforded. According to the Energy Security Master Plan, an EIA strategy would be developed and implemented that will:

- Reduce the time to undertake EIAs
- Reduce the time required to obtain EIA authorisation
- Minimise the risk of appeals and legal challenges to project EIAs

In conclusion, the integrated iron and steel industry is obligated to mitigate its GHG emissions. This also coincides with the sustainability prospectus of the industry, as highlighted in paragraph 3.2.6, that in order for industries in South Africa to sustain growth, it is the industry's responsibility to address climate change. The time constraints related to EIAs was also be factored into the feasibility studies of the relevant cogeneration projects.

### **3.2.8 Legal Responsibility**

According to Wilson, there are substantial and complicated legal requirements related to any industry, and the impact of legislation affects the sustainability of the industry (Wilson, 2008). Wilson's study, among other things, investigated the environmental legislative requirements related to the South African industry. Wilson highlights the following acts and regulations that must be considered when considering environmental legal requirements:

- National Environment Management Act (108 of 1998)
- Environment Conservation Act (73 of 1989)
- Occupational Health and Safety Act (Act 85 of 1993)
- Health Act (63 of 1977)
- National Environment Management: Air Quality Act No. 39: 2004
- Hazardous Substances Act (15 of 1973)
- Atmospheric Pollution Prevention Act (45 of 1965)
- National Building Regulations

However, Wilson highlights that the aforementioned acts and regulations are not the only legislative requirements to be considered when evaluating possible new technologies or driving motives to change current processes for better environmental conditions, increased efficiencies or sustainable electricity generation. Furthermore, Wilson explains that a list with relevant acts and regulations should be compiled when considering the legislative requirements for a cogeneration project.

Wilson's study concerning the legal aspects related to environmental projects could also be adopted when considering generation expansion projects. It is clear that all projects have unique legal requirements; thus, making it impractical to address all the legal requirements concerning any particular project, whether the project is primarily driven from an environmental perspective or for other reasons, like sustainable electricity supply.

Relating the legal responsibility aspects to the framework, industries must ensure that the pursuit of these cogeneration projects is done within the relevant legal boundaries. This can be achieved either by utilising the internal legal service of a particular company, or legal subject experts must be included in these cogeneration projects to ensure compliance with legislative requirements.

### **3.3 Technical Parameters**

During Chapter 2 (literature study), different electricity generation technologies were identified but not properly quantified. The purpose of this paragraph was to develop the framework of available electricity generation technologies and properly quantify all

relevant parameters related to these technologies. The technical parameters are based on the information acquired during the literature study and data collected from implemented projects. The UNFCCC has made a database of project design documents (PDD) available. The PDDs are related to all projects registered under the CDM and contain the basic project information that is relevant to the framework development. Furthermore, subject matter experts (SMEs) review the PDDs, and the CERs are then issued to projects based on the information from the PDDs; thus, the information is scrutinised and can be accepted as accurate.

### **3.3.1 Available Technologies**

Table 3.1 provides a summary of the various electricity generation technologies related to the particular plant that constitute the integrated iron and steel factory. The required investment per technology was adjusted to 2011 values based on annual inflation rates, and currencies were converted to South African Rand. The information presented in Table 3.1 is based on parameters derived from the literature review as well as information from a number of PDDs. Furthermore, in order to develop the summary shown above, the following assumptions were made:

1. The overall electricity generation efficiency, following the implementation of conventional steam boilers, is 33%.
2. The overall electricity generation efficiency, following the implementation of OCGT, is 38%.
3. The overall electricity generation efficiency, following the implementation of CCGT, is 57%.
4. Latent heat recovery from COG is not a widespread practice, as highlighted in the literature review; therefore, it was not possible to obtain sufficient data for a statistical approach to summarise the data in Table 3.1. Consequently, information from waste heat recovery units and sponge iron kilns could be used to quantify the generation capacity and investment costs related to latent heat recovery from COG.
5. The same methodology, as used in point 4, was used for the quantification of latent heat recovery from BOF gas.
6. The electricity generation capacity of backpressure turbines was not indicated in Table 3.1 as the it is heavily dependent on the steam operating

parameters. Thus, factors to be considered include the steam inlet pressure and temperature, and the steam exit pressure and temperature. These parameters are determined by the boilers' steam supply specifications and the low-pressure consumers' steam specifications.

Although the parameters indicated in Table 3.1 are a good departure point for the quantification of electricity generation opportunities at a particular integrated iron and steel industry, it must be noted that the values cannot be considered as absolute parameters pertaining to any particular plant, as all plants have unique conditions that may require adjustments to the framework parameters to meet the specific plant requirements.

Appendix B.1 contains the information derived from all the researched PDDs. Apart from the information in Table 3.1, Appendix B.1 gives more plant specific parameters that allows for a refinement in the quantification of the electricity generation opportunities for a plant subject to investigation. Thus, Table 3.1 can only be used to approximate a plant's generation capacity and potential investment cost, where after the Appendix data must be used to benchmark against specific plants. Need be, the plants mentioned in Appendix B.1 can be consulted directly for further technical assistance.

Summary of Available Electricity Generation Technologies in the Integrated Iron and Steel Industry				
Plant	Energy Recovery	Technology	Electricity Generation	Capital Investment
Coke Plant	COG Recovery	Combustion in conventional steam boilers	1.8662 GJ/ton	R 5,449/kW
		Combustion in OCGT	2.1489 GJ/ton	R 6,122/kW
		Combustion in CCGT	3.2236 GJ/ton	R 7,483/kW
Sinter Furnace	COG Latent Heat Recovery	Latent heat steam boiler	1 MW per 11333Nm <sup>3</sup> /hr flue gas flow rating	R 6,355/kW
	Coke Dry Quenching	Latent heat steam boiler	0.55 GJ/ton	R 8,185/kW
Sinter Furnace	Waste Heat Recovery from Sinter Machine and Cooler	Latent heat steam boiler	0.108 GJ/ton	R 7,758/kW
Blast Furnace	BFG Recovery	Combustion in conventional steam boilers	1.7688 GJ/ton	R 5,449/kW
		Combustion in OCGT	2.0368 GJ/ton	R 6,122/kW
Basic Oxygen Furnace		Combustion in CCGT	3.0552 GJ/ton	R 7,483/kW
Top Pressure Recovery Turbine	TRT Technology		4.8835kW per 1m <sup>3</sup> Blast Furnace Volume	
	Latent heat steam boiler	1 MW per 11333Nm <sup>3</sup> /hr flue gas flow rating	R 5,757/kW	
Rolling Mills	Waste Heat Recovery	ORC Technology	0.03456 GJ/ton	R 17,837/kW
Process Steam Generation	Backpressure Turbines	Non condensing steam turbines	Heavily dependent on steam pressure and temperature	R 5,714/kW for a 50 kW installation to R 1,632/kW for a 2000 kW installation

**Table 3.1 – Summary of Technical Parameters Related to Electricity Generation Technologies for the Integrated Iron & Steel Industry**

### 3.3.2 Generation Capacity

The following aspects collectively add to the topic of generation capacity:

1. Specifying the electricity generation capacity of the plant with regards to the plant's production capacity.
2. Capital investment required to fund the electricity generation project.

According to Table 3.1 the electricity generation capacities are indicated as GJ/tonne, kW/m<sup>3</sup> or as MW/flue gas volume flow rate. It is important that these relations be well defined in order to specify the electricity generation capacity of the plant correctly.

GJ/tonne refers to the amount of energy (electrical energy) generated per tonne of product (example 1 tonne sinter). The sinter plant will be the subject for explanation (values derived from Table 3.1). If the plant has a production capacity of 6,000 tonnes/day, the amount of electricity generated is calculated to be:

$$\begin{aligned} \text{Electrical Energy} &= 0.108 \frac{\text{GJ}}{\text{ton}} \times 6000 \frac{\text{ton}}{\text{day}} \\ &= 648 \frac{\text{GJ}}{\text{day}} \end{aligned}$$

With Watt being defined as  $W = \frac{J}{s}$  and  $\text{day} = 60 \times 60 \times 24 \text{ s}$

$$\begin{aligned} \text{Electricity Generation Capacity} &= 648000 \frac{\text{MJ}}{\text{day}} \\ &= 648000 \times \frac{\text{MJ}}{86400 \text{ s}} \\ &= 7.5 \text{ MW} \end{aligned}$$

Thus, the typical installation capacity of the electricity generation unit will be 7.5 MW. Consequently, the typical capital expenditure for a 7.5 MW unit is R 58,185,000, based on the average capital investment per installed MW.

Specifying the generation capacity for a TRT or a latent heat recovery system is even simpler as it is only a derivative between the generation capacity and the blast furnace volume; or hourly flue gas volume flow rate for a latent heat recovery system.

If the capital investment is based solely on the information in Table 3.1, the relation between electricity generation capacity and the capital investment is linear. It is generally accepted that the capital investment per MW increases as the installed capacity decreases due to fixed costs that remain almost unchanged for a range of installation capacities. Thus, if a plant's electricity generation capacity is outside of the norm, then the investment requirements will have to be adjusted. In order to address the abovementioned problem, it was required that all feasibility studies, derived from the framework information be subject to a sensitivity analysis with regards to variable investments costs.

In conclusion, the framework allows for a definitive comparison to be drawn between the plant's technical parameters and those of cogeneration technology.

### **3.3.3 Environmental Impact**

Although the objective of this study is to quantify the reduction in CO<sub>2</sub> through the implementation of cogeneration technologies, it should still be noted that all proposed technologies will be subjected to an Environmental Impact Assessment (EIA), but the details of EIAs are beyond the scope of this research. Nonetheless, the time constraints related to an EIA must be considered as an average EIA duration is between 380 and 400 days (Mandl, 2010).

On average South Africa produces 963 kg/MWh of CO<sub>2</sub> during electricity generation (Mwakasonda et al., 2009). Thus, for every MWh of electricity generated through cogeneration, 963 kg of CO<sub>2</sub> is prevented from entering the atmosphere, and this reduction in GHG emissions can be accounted for as CERs if the project is classified as a CDM project. Furthermore, the emission reductions are classified as Scope 2 reductions. This reduction in Scope 2 emissions can be accounted for as revenue to the project when CERs are traded under the CDM. Revenue from CERs was dealt with in paragraph 3.4.2.

### **3.3.4 Technical Parameters Costs Discussion**

In comparison with the capital requirements concerning the current Build Programme in South Africa, namely Medupi and Kusile that are being built at a cost of R15,705.07/kW

and R16,865.67 respectively (Eskom, 2011), one must acknowledge that it is considerably higher than the framework's capital investment requirements. The deviation from the norm (new generation capacity costs) can be explained as follow:

1. China and India form the greater part of the countries benchmarked for the study, and based on industry experience, the mentioned countries are renowned for realising projects at far lower costs compared to the other countries. Thus, in order for companies who want to pursue these cogeneration technologies at capital investment requirements – well underneath the industry norm – will have to procure the equipment and contract the labour and skills associated with the projects from the benchmarked countries.
2. The cost associated with cogeneration (per kilowatt installed) is generally much lower (The Texas Center for Policy Studies, 1995) compared to the costs associated with new power plants; reason being that much of the infrastructure (distribution grid, heat sources, etc) is usually already available, generation is localised to the production facility, generation capacity is much smaller than that of power plants, hence, it requires smaller infrastructure and is more convenient (Chambers & Potter, 2002).

In view of the above, the costs associated with cogeneration and new power plants cannot necessarily be compared due to the relatively large difference in scope/scale of these technologies. In addition, to fully reap the benefits of low-cost cogeneration companies pursuing cogeneration should outsource equipment, labour and skills to countries like China and India.

### **3.4 Funding**

There can be a number of very valid driving factors to promote electricity generation in the iron and steel industry; therefore, the subsequent paragraphs describe the financial mechanisms to which electricity generation projects should be subject during the project feasibility stages.

#### **3.4.1 Internal Rate of Return (IRR)**

According to MoneyTerms the internal rate of return (IRR) is a rate of return on an investment. It can further be explained as the discount rate that will give a project a net present value (NPV) of zero (Pietersz, 2011). The IRR of a project/investment is one of

the most important decisive factors that determines the attractiveness of a project from a financial point of view. In some cases investors prefer to evaluate the NPV of a project in conjunction with the IRR, as a larger investment with a lower IRR can realise a higher total gain compared to a small investment with a high IRR.

However, experience in the iron and steel industry has shown that the financial feasibility of a project is based greatly on its IRR. Thus, the higher the IRR the more attractive the project is to execute. The IRR is directly related to the revenue that the project can generate. In summary, the following factors will influence the project's IRR that, in turn, will determine whether the project is financially attractive:

1. Capital investment required to execute the project.
2. Savings generated. In the case of cogeneration projects, this will equate to the reduction in electricity purchased from the electricity supplying entity.
3. Carbon tax savings. If carbon tax is implemented in South Africa, the savings on carbon tax due to a reduction in Scope 2 emissions can contribute to revenue of the project.
4. CERs. From the literature review, it was highlighted that a project will only be granted CERs if the project is financially not feasible without the revenue generated from the CERs. Thus, the addition of CERs to a project will increase its IRR.
5. DSM funding. This funding initiative may reduce the capital expenditure required by a company for a specific project. However, as mentioned earlier in this chapter, the terms of cogeneration funding from Eskom must be negotiated between the ESCO and Eskom; DSM funding for cogeneration projects is not guaranteed.

In conclusion, when a project is subject to financial scrutiny, a minimum IRR baseline will determine if a project is economically viable; this baseline is company specific. If a project's IRR does not meet this baseline, then only can CERs be considered in order to attempt to reach the IRR baseline. Thus, from an investment point of view, the IRR of a project is critical to determine the feasibility of a project.

### 3.4.2 CDM Funding

As mentioned in the previous paragraph, a project is eligible for CDM funding if the project is not able to sustain itself from its own generated revenues. The revenue generated from the trading of CERs can increase the IRR of the project. For the past two years the price of CERs have been in a trading range of 11 – 15 €/tonne CO<sub>2</sub> (World Bank, 2011).



**Figure 3.4 – CER Trading Prices**

Thus, for every MWh generated by means of cogeneration, revenue of approximately R 109.56 can be realised (based on July 2011 currency and CER trade values). For forecasting purposes, the CER value trends should be used as Figure 3.4 suggests that the cost of CERs do not follow a steady increase that is proportional to inflation.

### 3.4.3 Power Conservation Program (PCP)

The effect of PCP on the production output of an industry is only noticeable if the industry's electricity consumption exceeds the PCP target. For example, AMSA exceeds its PCP target from 2011 onwards, as indicated in Figure 4.4, which will result in a reduction in forecasted production in order to comply with the PCP limits. Furthermore, Visagie also highlighted that South Africa's energy demand will exceed its supply beyond 2014. This is also taking into account that Eskom's new build program is

on schedule, but realistically assuming delays of 18 months, it will result in the PCP being effective into 2016/2017.

Therefore, the electricity requirement per tonne of final product will determine if it is lucrative to pursue cogeneration in order reap benefits from the increased production. It must be noted that this evaluation is unique to a particular iron and steel industry's electricity input per tonne of final product produced and its production forecasting.

### **3.5 Implementation Parameters**

The implementation parameters also form a critical part of the feasibility studies. From the start of a project, the implementation parameters play a significant role in the execution and success of a project; for instance, a team must be appointed to manage a project and all additionalities, like capital procurements, project contracts, engineering studies, etc. After implementation, the investment must also be managed in terms of maintenance, service support, and skill requirements to operate and maintain the equipment, etc.

Thus, the implementation parameters provides the framework with an outline of the required activities to ensure that the project is implemented successfully and maintained accordingly.

#### **3.5.1 Personnel Requirements**

Up to this stage of the research, the focus was placed only on the technical aspects of the project. However, if the project is identified to be lucrative, then the necessary human resources (HR) must be coupled to the project.

Based on the literature review and the researcher's project experience in the iron and steel industry, the HR requirements for this project are generally categorised as *Project* and *Environmental Support*.

### **Project Support**

1. Project Manager: The project manager fulfils the role of coordinating all project related activities on behalf of the operational entity (relevant iron and steel industry).
2. Capital Procurement: They are responsible for the capital purchasing requirements of a project. Their responsibilities typically include the contractual agreements between the operational entity and the project contractors and coordinating financial activities within the project boundary.
3. Plant Support: The identified cogeneration projects will inevitably be installed on some or other plant at the operational entity. Thus, inputs and coordination from plant level is required.
4. Project Contractors: The operational entity will award contracts to a number of project contractors who will be responsible to realise the project. Typically, the operational entity will follow a turnkey approach to a project of this nature; therefore, the project contractors are responsible for the detail project implementation. Furthermore, the main project contractors are also responsible for the equipment suppliers and installers.

### **Environmental Support**

1. EIA: A cogeneration project will also be subject to an EIA. As with most project activities, the operational entity will outsource the responsibility for the EIA to an environmental consulting company, who is responsible for the registration of the EIA and who coordinates all activities required for EIA approval.
2. CDM: Again, the operational entity will appoint a CDM consultant to oversee the project CDM registration process. The CDM consultant fulfils the role as project developer (as derived from the literature study). Other parties involved in the CDM process include the host government, the operational entity and the CDM Executive Board.

In conclusion, the aforementioned form the minimum personnel requirements. The actual size of the workforce related to the personnel requirements could not be defined in this research as it was dependent on the real project size. In addition, the objective of the implementation parameters of the framework is only to provide an outline for possible personnel resources. It may be that the operational entity is required to extend

its personnel requirements, but that will be based on externalities imposed on the project.

### 3.5.2 Timeframe

Among other factors, the success of project implementation is based on meeting the project completion date. For this reason, it is important to ensure that the time planning is thorough in order to commit the project to a realistic completion date.

Figure 3.5 illustrates elements which constitute the system engineering process, forming a critical part of the project development. Thus, time schedules are allocated to each element.

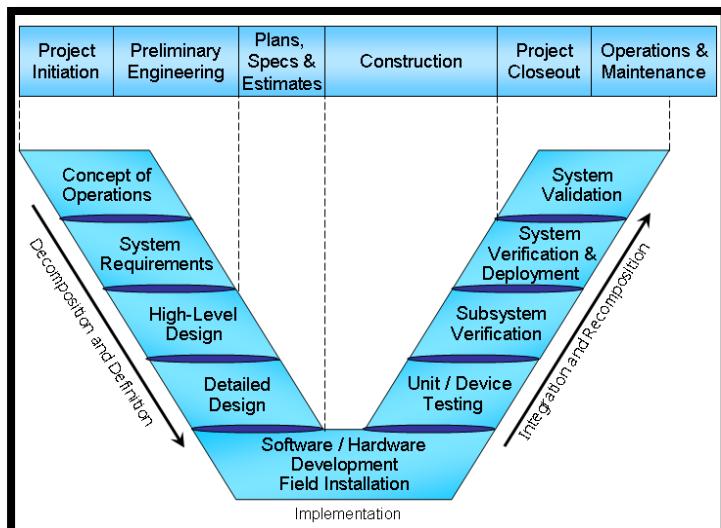


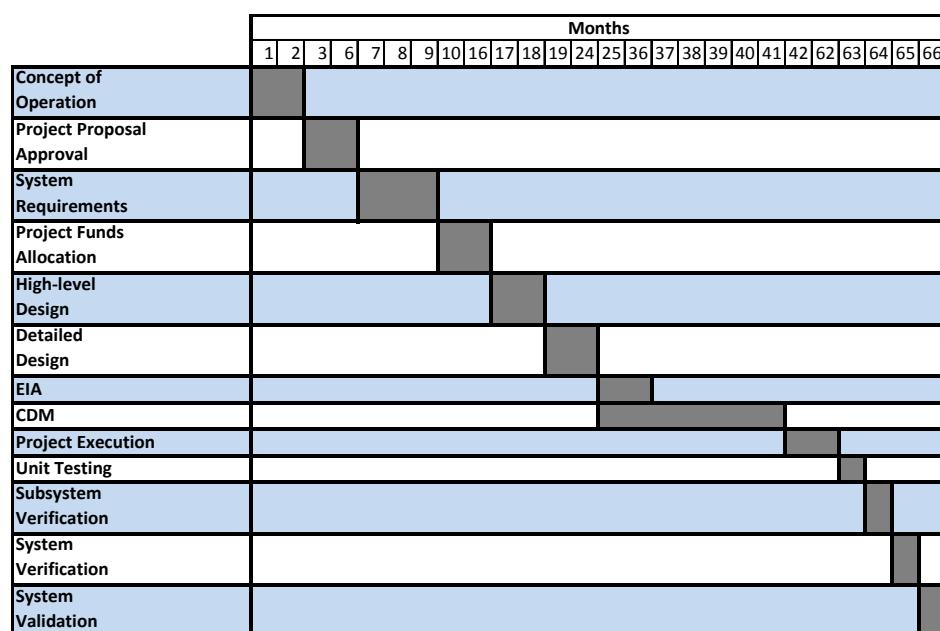
Figure 3.5 – System Engineering Process (Federal Highway Administration, 2009)

For the purpose of this study, Figure 3.5 is only applicable to the technical aspects of the project. Over and above this, there are other project factors to be included, like the CDM project process (indicated in Figure 3.6), EIAs, internal project approvals, etc.



**Figure 3.6 – Average CDM Timeline (Gilder & Sa, 2011)**

Every project has unique specifications, complications, constraints, size, etc. Thus, from start to finish, all these factors influence the time schedule of a project. As illustrated in Figure 3.6, the average CDM timeline is 536 days. Consequently, if the project is only executable with the addition of CERs to its revenue, then these 536 days will be considered in the project time schedule. Figure 3.7 illustrates the estimated time schedule of a cogeneration project in the iron and steel industry.



**Figure 3.7 – Approximate Project Time Schedule**

If the project can be executed without CDM funding, then the project time schedule can be decreased by approximately 1.5 years, consequently reducing the project time schedule to approximately 4 years. It is important to note that the time schedule is only an approximation, and that the actual time schedule for a project of this nature is dependent on project specific details and requirements.

### **3.5.3 Operational Support**

As important as the investment itself, is the support thereof, particularly from a maintenance and operational support viewpoint. For this reason, the following aspects must be considered when evaluating various equipment suppliers and planning operational costs of the project:

1. Mature support base in South Africa: This includes technical support skills, like trained support personnel who will be able to assist the plant in the event of problems experienced. Furthermore, the availability of spare parts must be readily available.
2. Maintenance personnel: Current plant maintenance personnel must be taken into consideration regarding their time availability to perform maintenance on the new plant equipment as well their knowledge and skills to support the proposed investments.
3. Service contracts: In the event where periodic specialised intervention is required on the proposed equipment, it may be necessary to obtain a service contract from a service provider. The alternative is to invest in the plant's own personnel to provide these specialised services.
4. Maintenance costs: According to data from the reviewed PDDs, the maintenance costs of an investment can be as low as 1 % of the total investment cost per annum (typically TRT installations when only routine maintenance is required). However, the maintenance costs can be as high as 13 % of the total investment cost per annum during periods where the proposed investment is subject to statutory refurbishments.

## **3.6 Conclusion**

In view of evaluating the framework, it addresses all the factors related to the research objectives. Thus, this framework will provide industry with the necessary guidance that collectively addresses the relevant factors concerning cogeneration in the South African integrated iron and steel industry. The tailoring of the framework will enable industry to steer the factors related to cogeneration that are specific to their operational requirements. The developments stemming from this framework (that may include procedures or manuals concerning cogeneration in a particular industry) must be

considered as live documents and must be updated as the framework's building blocks are altered or updated in terms of:

1. Changes in South Africa's electricity and carbon emission situations;
2. New and improved cogeneration technologies;
3. Lessons learned and practices applied by industry (Wilson, 2008).

Chapter 4 is a case study pertaining to ArcelorMittal Newcastle with the objective of drawing similarities between the framework and the practices followed by industry in order to validate the framework in Chapter 5. Chapter 4 applies the available cogeneration technologies to ArcelorMittal Newcastle to investigate the effects of including funding from carbon tax savings and the CDM in the economic feasibility study. The economic sensitivity of these technologies is also investigated by increasing the investment requirements, as suggested by the framework.

## **Chapter 4**

### **The ArcelorMittal Newcastle Case**

*This chapter represents a case study pertaining to ArcelorMittal Newcastle, and aims to highlight the similarities between the framework the practices followed by industry. In addition, this chapter applies the available cogeneration technologies to ArcelorMittal Newcastle to investigate the economic viability of these projects.*

## Chapter 4 : The ArcelorMittal Newcastle Case

### 4.1 Introduction

ArcelorMittal Newcastle was subjected to a critical evaluation concerning the identification of possible electricity generation projects. The evaluation was executed in accordance with the developed framework and the relevant literature. By placing this chapter into context with the research process, one can argue that the purpose of this case study was to validate the framework (or the experimental subject in the context of the research process). Chapter 5 elaborates further on the validation of the framework.

A brief overview of ArcelorMittal Newcastle is given in order to determine the extent of the technical implementation on the Newcastle Works. Furthermore, ArcelorMittal Newcastle was investigating the re-commissioning of the Coke Oven Battery 1 (only three of the four installed coke oven batteries at ArcelorMittal Newcastle is currently in operation). The demand for market coke was the main driving factor for the re-commissioning of Battery 1. Thus, the operation of an additional coke battery implies excess process gas, gas that can potentially be used for electricity generation. To ensure that the study is fully comprehensive, the possibility of electricity generation from Battery 1 was also investigated.

Paragraphs 4.2 to 4.7 subjected each plant to an individual investigation, but plants that produce process gas were also subjected to a combined investigation in paragraph 4.8; excess process gases from the various plants were combined to explore different possibilities to generate electricity at a greater yield.

The production history of ArcelorMittal Newcastle was of great importance to this study as the framework, developed in Chapter 3, correlates the potential electricity generated with the production of the facilities. Thus, the average stable production of each plant was calculated from the production history of ArcelorMittal Newcastle, which ultimately governed the specification of the electricity generation facilities. The production history is graphically indicated in Appendix C.1. The periods where the production deviated from the norm were due to the following events:

1. The Blast Furnace and Sinter Furnace Reline in 2008;

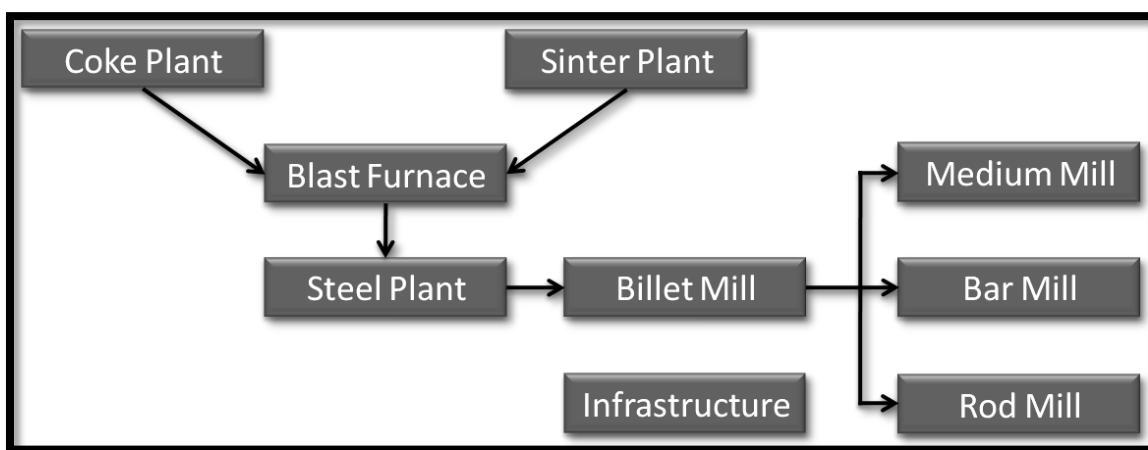
2. The recession of 2008/2009 that resulted in a very poor market; consequently, the production was reduced (the blast furnace was shut down for a period);
3. The blast furnace experienced a cold furnace condition in December 2010 and January 2011; thus, no iron production for that period.

The information derived from this evaluation was also subject to a sensitivity analysis in paragraph 4.10. This analysis investigated the effects of changing investment costs.

To ensure that the applicability of the other building blocks that constitute the framework were also validated, the AMSA 2010 annual report was reviewed, in addition to certain outcomes of the AMSA's environmental, energy and projects department. These entities maintains issues especially relevant to the framework building blocks, *governance* and *implementation parameters*.

#### 4.1.1 Overview of the Newcastle Works

ArcelorMittal Newcastle dates back to 1974 when the first profiles were produced. Eighteen months later, the facility was in full production. Figure 4.1 graphically illustrates the process flow for ArcelorMittal Newcastle.



**Figure 4.1 – Newcastle Works Process Flow**

The information used for each plant description is courtesy of information supplied by ArcelorMittal Newcastle. Although the information related to ArcelorMittal Newcastle considers very in-depth technical information, it should be considered as supplementary information that can be used for benchmarking purposes, when referencing from this dissertation.

#### **4.1.1.1 Coke Plant**

ArcelorMittal Newcastle has four 6.2 m *Dr Otto* twin flue underjet-type batteries of which three (Battery 2, 3 & 4) are in operation and one (Battery 1) was cooled down under controlled conditions as a standby. Furthermore, the gas purification and by-product plant produces crude tar, crude benzole, ammonium sulphate and sulphuric acid.

A coal blend, consisting of 20% imported coal and 80% local coal, is charged at an average design capacity of 150 ovens per day. However, it is common to see figures of around 170 – 185 ovens per day. Furthermore, the calculated average yield per oven is approximately 14.5 tonnes per oven, but occasionally the yield can be as high as 19.7 tonnes per oven.

#### **4.1.1.2 Sinter Plant**

Sinter for use in ArcelorMittal Newcastle's blast furnace, N5, is produced in a single sinter plant. The sinter machine is a *Delattre-Levivier* design and was commissioned in 1976. The sintering strand has a total surface area of 400 m<sup>2</sup>.

Sintering is achieved on the first 220 m<sup>2</sup> of sinter strand by suction delivered by two 4.5 MW sintering fans, and cooling is achieved on the remaining 180 m<sup>2</sup> by two 3.3 MW cooling fans. The sinter product is crushed and screened and the products measuring 6 - 40 mm in size is used in the blast furnace.

The designed average production rate is 300 tonnes/hour, or 7,150 tonnes/day; however, since January 2006 to June 2011 (excluding the isolated events that resulted in reduced production) the average production was only 5,562 tonnes per day. The equipment is capable of much higher production figures - as indicated by the daily and monthly production records of 8,188 tonnes per day and 202,625 tonnes per month respectively. Unlike the coke plant that produces market coke, which is sold to outside companies, the sinter plant produces sinter for use at ArcelorMittal Newcastle only; thus, the sinter plant production is dependent on the sinter demand from the blast furnace.

#### **4.1.1.3 Blast Furnace**

ArcelorMittal Newcastle operates only one iron making unit, Blast Furnace N5, that provides hot metal for the steel plant. Constructed in 1974, this GMBH-designed unit has a 10.14 m diameter hearth and a 2,017 m<sup>3</sup> working volume after the last reline in 2008.

A conveyor-fed *Paul Wurth*, bell-less top is used for charging. Three *Krupp-Koppers* external combustion chamber stoves preheat the blast air, which is enriched by up to 3.5% oxygen. A PCI injection practice is used and casts are rotated continuously over the three tap holes.

The average hot metal production from January 2006 to June 2011 (excluding the isolated events that resulted in reduced production) is 4,530.1 tonnes of hot metal per day. The maximum production capacity of the blast furnace is currently 5,600 tonnes of hot metal per day.

#### **4.1.1.4 Steel Plant**

The steel plant, or commonly referred to as the BOF throughout the study, actually consists of four subunits, namely the BOF, Ladle Furnace, Vacuum Degasser and the Continuous Caster.

##### **Basic Oxygen Furnace**

Approximately 160 tonnes of the hot metal (together with about 12 % scrap) is charged into the basic oxygen furnace. The injection of oxygen and the addition of lime initiate oxidation reactions raise the temperature from 1,300 °C to 1,600 °C in a process typically lasting 20 minutes. During subsequent tapping into a ladle, alloying elements are added to achieve the specific properties of the required end product. This liquid can be processed further in the secondary metallurgical units or delivered directly to the casting plant.

The average monthly production rate is approximately 165,000 tonnes, but a record of 192,000 tonnes has been achieved.

### **Ladle Furnace (Secondary Steelmaking)**

The ladle furnace, designed and built by *Nippon Steel Corporation*, was commissioned in 1989. It has three electrodes of 450 mm diameter arranged in a pitch circle of 1.2 m. One 25 megavolt ampere (MVA) transformer provides a heating rate of 3.5 °C/min, which allows tap temperatures at the BOF to be reduced significantly.

The ladle furnace is fitted with a water-cooled hood. Flux and alloy additions are made from specially designed bunkers by a conveyor feed system. A wire feeder allows alloying elements to be injected directly into the steel. Precise slag compositions are designed to give low sulphur and phosphorous concentrations and cleaner steel. The furnace normally processes about 30 % of the total liquid steel production and on average treats 24 heats per day.

### **Vacuum Degasser**

The vacuum degasser, designed by *Vacmetal* and erected by *Dorbyl Structural Engineering*, has a rocker arm mounted one-piece vacuum vessel which allows the nozzles to be immersed 1.5 m into the steel. The electrical preheating capacity for the vessel is 1.4 MVA. Four steam ejectors, operating in three stages to produce a vacuum of 0.07 kPa. Argon injection at 1,500 litres per minute create a steel circulation rate of 85 tonnes per minute. A vacuum alloy feed system allows micro-alloy adjustments to give a narrow chemical analysis, while the circulation results in thermal and chemical homogenisation.

The vacuum degasser was commissioned in 1991 to produce low hydrogen [ $< 1.5$  parts per million (ppm)] and ultra low carbon steels ( $< 50$  ppm). Approximately 15,000 tonnes of liquid steel is treated each month.

### **Continuous Caster**

The continuous casting plant comprises of three similar machines, each designed to convert liquid steel into solid blooms at a rate of 175 tonnes per hour. The cross-section of the bloom differs from machine to machine, but is either 315 x 315 mm or 315 x 210 mm. When a machine is in operation, six strands are cast simultaneously from which blooms with lengths of between 5 m and 14 m are cut, each weighing typically between 4 and 10 tonnes.

The capacity of the caster is matched to that of the BOF vessels and consequently it typically processes 165,000 tonnes of liquid steel per month.

#### **4.1.1.5 Billet Mill**

The billet mill can be regarded as a primary mill that processes cast blooms received from the continuous caster into blooms and billets for the secondary mills (medium, bar and rod mill). Round bar of various sizes are also produced for the local and export markets, as well as blooms.

Two 150 tonne per hour pusher furnaces reheat the blooms to rolling temperature. The fuel used in these furnaces is mainly coke-oven gas or a combination of coke-oven gas and SASOL gas.

A breakdown or reversing mill is used to form the cast blooms into blooms for dispatch, or for the continuous mill, where two vertical and two horizontal stands are used for further rolling into billets or round bar, after which a flying shear cuts the products to ordered lengths.

#### **4.1.1.6 Medium Mill**

The medium mill comprises three areas: the mill, finishing and the roll preparation area. Production varies between 30,000 and 50,000 tonnes per month depending on the product mix.

The mill consists of a walking beam reheating furnace, two reversing breakdown mill stands, a hot saw for cropping, six horizontal and three vertical/horizontal mills. The material from the mill is cut into cooling bed lengths with a shear. The cooling bed is 130 metres long.

From the cooling bed the material goes through the strengtheners into the finishing area where the material is cut to the ordered lengths by five cold saws and then piled and bundled on two piling machines. There the material is weighed and marked for dispatch to various customers.

#### **4.1.1.7 Bar Mill**

The bar mill is referred to as a multi-line hot profile mill as different mill set-ups or paths are used to roll reheated intermediate billets into finished profile products.

Final products are produced from billets that are reheated in the furnace and passed through the eight-stand roughing train where the billet cross-section is reduced. Further reduction and profiling takes place through the five-stand intermediate trains and the four-stand finishing train. The final products include angles, flat bars, squares, round bars and some special sections.

The final product is then either coiled or run out onto the cooling beds as straight bar after which it is cut into lengths (as per customer order) and bundled before being loaded for transport, either by rail or by road.

#### **4.1.1.8 Rod Mill**

This mill produces rod in sizes from 5.5 mm up to 14 mm in various steel grades ranging from low carbon steel to high carbon and alloy steels.

The plant was upgraded in November 1995 with the addition of a four-stand reducing/sizing block per strand allowing rolling speeds up to 100 m/s on the smaller diameter rod. The finished product is coiled, compacted and tied with four steel straps before being dispatched to customers.

#### **4.1.1.9 Infrastructure**

Infrastructure is responsible for the generation of electricity for both the emergency grid and for cogeneration purposes, the distribution and management of electricity, process gas, water, atmospheric gases and the generation of steam to meet the demands of the Newcastle Works.

Steam is generated via four boilers, with the following specifications:

1.     2 x 50 t/hr ICAL Boilers
2.     2 x 150 t/hr Babcock and Wilcox Boilers
3.     Process Parameters:
  - a.     Pressure: 42 Bar

- b. Temperature: 427 °C

The large steam consumers include the blowers, which generate the cold blast air that is used at the blast furnace; the alternators, which can generate a maximum of 18 MW; the exhausters, which are responsible for the extraction of COG from the coke batteries; and the remainder of the steam is used for process applications.

Thus, if the cogeneration projects are realised, Infrastructure will play a significant role in the entire process as it will be responsible for the management of these assets, the generated electricity and integration with the current network.

#### **4.1.2 Commission of Coke Oven Battery 1**

Coke Battery 1 was cooled under controlled conditions during a period where the demand for market coke did not justify the operation of the battery. However, in recent years the demand for this commodity has increased to the extent that AMSA was investigating the re-commissioning of the coke battery. The design production capacity of the coke battery is the same as that of Batteries 2, 3 and 4, namely 50 ovens per day. However, referring to the production history of the coke plant (refer to Appendix C.1), it is noted that a coke battery is capable of pushing more than 50 ovens per day, but for this study, the assumption was made that only 50 ovens are pushed per day.

As ArcelorMittal Newcastle's gas requirements were already met with the use of three coke batteries, a fourth battery would realise excess gas. The assumption was made that the excess gas would only be used for cogeneration (COG required to sustain the coke battery is already accounted for).

#### **4.1.3 Combined Gas Combustion**

Apart from each gas producing plant being evaluated on its own, the option to combine the process gases from all the plants was also evaluated. However, the framework does not accommodate this option and a gas balance had to be conducted, from which the generation capacity was derived, based on the assumptions made in paragraph 3.3.1.

#### **4.1.4 Technical Investigation Methodology**

During the investigation, the following assumptions were made which largely govern the technical and financial parameters of the investigation:

1. The current boilers and generation configuration will not be changed. Additional generation units can be added, but the current system remains unchanged.
2. An inflation rate of 5 % was used for all calculations. The inflation rate was based on the current inflation rate, as on June 2011 (Trading Economics, 2011).
3. Based on the framework that was developed in the previous chapter, it was assumed that a project cash flow commences over a period of 37 months, with the cash flow distribution as follow:
  - a. Month 1: 20 % of investment
  - b. Month 10: 10 % of investment
  - c. Month 20: 20 % of investment
  - d. Month 30: 20 % of investment
  - e. Month 37: 30 % of investment

The payment over the specified period was also subject to inflation.

4. The average costs of electricity for the Newcastle Works in 2011/2012 (after tariff increase), according to the Megaflex tariffs are as follow:
  - a. Summer tariff: R 286.68
  - b. Winter tariff: R 549.69
  - c. The tariff increase for 2012/2013 was calculated at 25.9 % (as derived from the literature study)
  - d. The tariff increases after 2013 is based on inflation of 5 %
5. The cost per CER in 2011 is R 109.56 (as derived from the framework in chapter 3). The cost per CER has been escalated for future years based on an inflation rate of 5 %; although the framework suggested that a cost trend be used for the value of CERs. Referring to Figure 3.4, one notes that the average cost per CER only varied marginally over the past two years and for the end of the two year period indicated in Figure 3.4, the cost of CERs was on a positive trend. Thus, as the cash flow projection for the project was over such an extended period of time, the assumption was made that the cost of CERs would increase with inflation.
6. 90 % cogeneration availability was applied to all technologies.

## 4.2 Coke Plant Investigation

### 4.2.1 Introduction

The following production information was used for the investigation of cogeneration possibilities at the coke plant. The average stable production of coke per day was calculated to be 171.9 ovens pushed, resulting in a daily average production of coke of 2,489 tonnes. The corresponding energy produced (available in the COG) was calculated to be 833,610 GJ per month of which the coke ovens use 25.32 % to sustain the coke making process. The total COG consumed was calculated to be 93.88 % of the energy produced. The difference is lost during flaring of excess gas.

The current practice is to optimise the use of COG throughout ArcelorMittal Newcastle, and COG is only flared once a consumer cannot use the available energy. Therefore, it will not be possible to use the 6.12 % of COG energy continuously for cogeneration.

### 4.2.2 COG Recovery

The option of recovering COG exists only if Coke Oven Battery 1 is commissioned. The designed production capacity of Battery 1 is 50 ovens per day. Based on the same yield per oven as Batteries 2, 3 and 4, the coke production capacity of Battery 1 is expected to be 724.35 tonnes per day. At the calculated coke production rate and assuming a plant availability of 90 %, the following generation capacities and investments can be expected (Table 4.1):

Daily Production [ton/day]	724					
Electricity Generation Technology	Generation Potential [GJ/ton]	Daily Generation [GJ] (including 90 % availability)	Generation [MW]		Overnight Investment	
Boilers	1.87	1,217	14.08	R	76,727,700	
OCGT	2.15	1,401	16.21	R	99,262,900	
CCGT	3.22	2,102	24.32	R	182,009,500	

Table 4.1 - Cogeneration from COG Recovery

From Table 4.1, the IRR, NPV and payback years could be calculated for each proposed technology and for the scenarios of including and excluding CERs and carbon taxing. Table 4.2 indicates the relevant information.

Excluding Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Boilers	39%	16.03	5.80	46%	22.12	5.20
OCGT	36%	17.39	6.10	42%	24.40	5.50
CCGT	31%	22.80	6.90	37%	33.33	6.00
Including carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Boilers	49%	24.79	5.00	55%	30.89	4.70
OCGT	45%	27.40	5.30	51%	34.49	4.90
CCGT	39%	37.94	5.80	44%	48.47	5.30

**Table 4.2 - COG Recovery Results**

#### 4.2.3 COG Latent Heat Recovery

The average amount of gas (as per energy unit) per month produced by Batteries 2, 3 and 4 is 833,610 GJ, thus, the approximate daily COG production is 27,787 GJ. As the CV of COG is considered to be 17.4 MJ/Nm<sup>3</sup> (normal m<sup>3</sup>), the daily volume of COG is consequently 1,596,954 Nm<sup>3</sup> or 66,540 Nm<sup>3</sup>/hr.

If Battery 1 (50 additional ovens per day) is included in the calculations, then the production of COG will increase to 2,063,899 Nm<sup>3</sup> per day or 85,996 Nm<sup>3</sup>/hr. At the calculated coke production rate and assuming a plant availability of 90 %, the following generation capacities and investments can be expected (Table 4.3):

Production (Excluding Batt 1) [Nm <sup>3</sup> /hr]	66,540		
Production (Including Batt 1) [Nm <sup>3</sup> /hr]	85,996		
Electricity Generation Technology	Generation Potential	Generation [MW] (90 % Availability)	Overnight Investment
Waste Heat Boilers (Excluding Batt 1)	1 MW per 11,333 Nm <sup>3</sup> /hr	5.28	R 33,581,000
Waste Heat Boilers (Including)	1 MW per 11,333 Nm <sup>3</sup> /hr	6.83	R 43,400,100

**Table 4.3 - Cogeneration from COG Latent Heat Recovery**

Similar to paragraph 4.2.2, the financial results for the possible projects are indicated in Table 4.4.

Excluding Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Waste Heat Boilers (Excluding Batt 1)	35%	5.54	6.30	41%	7.83	5.60
Waste Heat Boilers (Including Batt 1)	35%	7.16	6.30	41%	10.12	5.60
Including Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Waste Heat Boilers (Excluding Batt 1)	44%	8.83	5.40	49%	11.12	5.00
Waste Heat Boilers (Including Batt 1)	44%	11.41	5.40	49%	14.37	5.00

**Table 4.4 - COG Latent Heat Recovery Results**

#### 4.2.4 Coke Dry Quenching (CDQ)

Generating electricity from CDQ exists with both options, namely including or excluding the additional coke production from Battery 1. Again, as with the other coke plant related cogeneration possibilities, the additional amount of ovens used for the calculations are 50 ovens per day. The coke production was already discussed in paragraph 4.2.2.

Production (Excluding Batt 1) [Ton/day]	2,489					
Production (Including Batt 1) [Ton/day]	3,214					
Electricity Generation Technology	Generation Potential [GJ/ton]	Daily Generation [GJ] (including 90 % availability)	Generation [MW]	Overnight Investment		
Waste Heat Boilers (Excluding Batt 1)	0.55	1,232	14.26	R	116,737,200	
Waste Heat Boilers (Including Batt 1)	0.55	1,591	18.41	R	150,699,600	

**Table 4.5 - Cogeneration from CDQ Technology**

Excluding Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Waste Heat Boilers (Excluding Batt 1)	29%	12.38	7.40	34%	18.56	6.40
Waste Heat Boilers (Including Batt 1)	29%	15.98	7.40	34%	23.96	6.40
Including Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Waste Heat Boilers (Excluding Batt 1)	37%	21.26	6.10	41%	27.41	5.60
Waste Heat Boilers (Including Batt 1)	37%	27.44	6.10	41%	35.41	5.60

**Table 4.6 - CDQ Results**

## 4.3 Sinter Plant Investigation

### 4.3.1 Introduction

The following production information was used for the investigation of cogeneration possibilities at the sinter plant. The average stable production of sinter per day was calculated to be 5,562 tonnes per day. There was also a close correlation between the production of the sinter plant and the blast furnace, as the sinter plant production was based on the blast furnace demand.

### 4.3.2 Sinter Furnace Waste Heat Recovery

For this investigation, the average sinter production was used to govern the cogeneration parameters. Furthermore, the waste heat recovered from both the sintering machine and the sinter cooler were considered. Tables 4.7 and 4.8 indicate the parameters related to this cogeneration technology.

Production [Ton/day]	5,562				
Electricity Generation Technology	Generation Potential [GJ/ton]	Daily Generation [GJ] (including 90 % availability)	Generation [MW]	Overnight Investment	
Waste Heat Boilers (Sinter-	0.11	541	6.26	R	48,543,700

Table 4.7 - Cogeneration from Sinter Latent Heat Recovery

Excluding Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Waste Heat Boilers (Sinter- and Cooling Strands)	30%	5.70	7.10	36%	8.41	6.20
Including Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Waste Heat Boilers (Sinter- and Cooling Strands)	38%	9.59	5.90	43%	12.30	5.40

Table 4.8 - Sinter Latent Heat Recovery Results

## 4.4 Blast Furnace Investigation

### 4.4.1 Introduction

The following production information was used for the investigation of cogeneration possibilities at the blast furnace. The framework based the generation capacity on the inner volume of the blast furnace. The technology relevant to the N5 Blast Furnace is that of recovering the top gas pressure. ArcelorMittal Newcastle utilises a wet scrubbing method to clean the gas, which results in lower gas temperatures entering the TRT. If a dry scrubbing system can be used, the generation capacity can be increased by approximately 60%. However, ArcelorMittal Newcastle is in the process of sourcing a new scrubber, again proposing a wet type system; thus, the increased generation will not be achieved.

### 4.4.2 TRT

The investigation concerning the generation capacity of the blast furnace was based on an inner volume of 2,017 m<sup>3</sup> and a wet scrubbing method. The outcome of the investigation is indicated in Tables 4.9 and 4.10.

Blast Furnace Volume [m <sup>3</sup> ]	2,017		
Electricity Generation Technology	Generation Potential [kW/m <sup>3</sup> ]	Generation Capacity [MW] (90% Availability)	Overnight Investment
TRT	4.88	8.87	R 51,036,200

Table 4.9 - Cogeneration for Blast Furnace, using a TRT

Excluding Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
TRT	38%	9.82	5.90	44%	13.66	5.30
Including Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
TRT	47%	15.34	5.10	53%	19.18	4.80

Table 4.10 - TRT Results

## 4.5 Steel Plant (BOF) Investigation

### 4.5.1 Introduction

During the literature study, three means of electricity generation technologies concerning the BOF were identified: BOF gas recovery, BOF gas and latent heat recovery (by means of suppressed combustion), and latent heat recovery from open combustion in the BOF hood. The latter could not be applied at ArcelorMittal Newcastle, mainly because only one BOF vessel is blowing at a time and there are long periods between blowing where no heat can be recovered. Thus, cogeneration will not be sustainable by means of open combustion. If ArcelorMittal Newcastle had two or more BOF vessels blowing in sequence in order to eliminate the periods of no heat generation, then this option could be investigated. Thus, only BOF gas recovery or combined BOF gas and heat recovery were viable options applicable to ArcelorMittal Newcastle.

### 4.5.2 BOF Gas Recovery

The cogeneration capacity by means of combusting the recovered BOF gas was based on the average daily production of the Steel Plant (BOF). Tables 4.11 and 4.12 represent the outcome of the BOF gas recovery analysis.

Daily Production [ton/day]	4,668			
Electricity Generation Technology	Generation Potential [GJ/ton]	Daily Generation [GJ] (including 90 % availability)	Generation [MW]	Overnight Investment
Boilers	0.22	943	10.91	R 63,308,200
OCGT	0.26	1,086	12.56	R 76,921,100
CCGT	0.39	1,628	18.85	R 141,032,500

Table 4.11 - Cogeneration from BOF Gas Recovery

Excluding Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Boilers	37%	12.04	6.00	44%	16.76	5.30
OCGT	36%	13.47	6.10	42%	18.91	5.50
CCGT	31%	17.67	6.90	37%	25.83	6.00
Including Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Boilers	47%	18.83	5.10	53%	23.55	4.80
OCGT	45%	21.29	5.30	51%	26.73	4.90
CCGT	39%	29.40	5.80	44%	37.56	5.30

Table 4.12 - BOF Gas Recovery Results

#### 4.5.3 BOF Gas – and Latent Heat Recovery

The framework derived the cogeneration capacity from the volume of BOF gas produced. Thus, the relation between daily production (tonne/day) and volume of gas produced had to be determined. According to literature, 80 Nm<sup>3</sup> BOF gas is produced on average for every tonne of liquid steel produced. By combining the energy from combustion of the BOF gas and the latent heat recovered, the average cogeneration for this configuration could be calculated. Another important factor to note is that the open cycle gas turbine (OCGT) technology was excluded from this evaluation as it was technically not possible or practical to recover the BOF gas latent heat and use it in an OCGT. Tables 4.13 and 4.14 indicate the results from this investigation.

Daily Production [ton/day]	4,668			
Electricity Generation Technology	Generation Potential [GJ/ton]	Daily Generation [GJ] (including 90 % availability)	Generation [MW]	Overnight Investment
Boilers	0.25	1,039	12.02	R 69,796,800
CCGT	0.41	1,724	19.96	R 149,354,400

**Table 4.13 - Cogeneration from BOF Gas - and Latent Heat Recovery**

Excluding Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Boilers	37%	13.26	6.00	44%	18.47	5.30
CCGT	31%	18.71	6.90	37%	27.35	6.00
Including Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Boilers	47%	20.75	5.10	53%	25.95	4.80
CCGT	39%	31.13	5.80	44%	39.77	5.30

**Table 4.14 - BOF Gas - and Latent Heat Recovery Results**

## 4.6 Rolling Mills Investigation

### 4.6.1 Introduction

There are a total of four rolling mills, each with a reheating furnace (except the billet mill which has two reheating furnaces), at ArcelorMittal Newcastle. Two-furnace operation at the billet mill is not continuous and is dependent on the demand and profile of billets. Logically, periods when the billet mill is on two-furnace operation, the cogeneration capacity of the mill will increase, but for this evaluation the average production output of the mills was used. The average production output is inclusive of single- and two-furnace operation.

The temperatures of the mills' exhausts is approximately 200 °C. Due to the relatively low heat source, conventional steam boilers will not be able to recover the heat and convert the energy to electricity. Organic Rankine Cycles utilise flow mediums that vaporise at far lower temperatures, making ORC technology preferable for this application.

#### 4.6.2 ORC Technology for Waste Heat Recovery

The framework related the cogeneration capacity with the mills production. Tables 4.15 and 4.16 indicate the average daily production of each mill and assign a generation capacity to each. For the base case (scenario that excluded CDM funding and the savings from carbon tax), the payback exceeds the life expectancy of the plant; consequently, the NPV for this scenario is negative.

Billet Mill Daily Production [ton/day]	3,602				
Medium Mill Daily Production [ton/day]	892				
Bar Mill Daily Production [ton/day]	1,067				
Rod Mill Daily Production [ton/day]	1,834				
Electricity Generation Technology (ORC)		Generation Potential [GJ/ton]	Daily Generation [GJ] (including 90 % availability)	Generation [MW]	Overnight Investment
Billet Mill		0.035	112	1.30	R 23,128,000
Medium Mill		0.035	28	0.32	R 5,725,500
Bar Mill		0.035	33	0.38	R 6,854,000
Rod Mill		0.035	57	0.66	R 11,780,200

Table 4.15 - Mills Waste Heat Recovery

Excluding Carbon Tax						
Plant	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Billet Mill	14%	-0.11	20.00	18%	0.45	13.51
Medium Mill	14%	-0.03	20.00	18%	0.11	13.51
Bar Mill	14%	-0.03	20.00	18%	0.13	13.51
Rod Mill	14%	-0.06	20.00	18%	0.23	13.51
Including Carbon Tax						
Plant	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Billet Mill	19%	0.70	11.87	23%	1.26	9.63
Medium Mill	19%	0.17	11.87	23%	0.31	9.63
Bar Mill	19%	0.21	11.87	23%	0.37	9.63
Rod Mill	19%	0.36	11.87	23%	0.64	9.63

Table 4.16 - ORC Technology Results

## 4.7 Process Steam Generation Investigation

### 4.7.1 Introduction

Four steam boilers supply ArcelorMittal Newcastle with steam. Steam is produced at 42 bar and 427 °C. 30 to 48 tonnes/hour of the steam produced is supplied as low pressure (LP) steam, at 16 bar and 362 °C. The LP-steam is produced by the attemperation of the high pressure (HP) steam. This process can be substituted by replacing the PRS with a backpressure turbine that is connected to a generator.

### 4.7.2 Backpressure Turbine

The generation capacity of the boiler plant had been calculated during an independent boiler survey that was conducted at ArcelorMittal Newcastle. According to the survey, the average generation capacity of the plant is 1 MW. Based on the information from the framework, the following findings were made:

Boiler	Replacing PRS with BPT		
Electricity Generation Technology	Generation Potential	Generation Capacity [MW] (90% Availability)	Overnight Investment
Backpressure Turbine	Based on Boiler Expert Survey	1.00	R 3,725,000

Table 4.17 - Boiler Plant Cogeneration

Excluding Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Backpressure Turbine	51%	1.31	4.90	59%	1.74	4.50
Including Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Backpressure Turbine	63%	1.93	4.40	70%	2.36	4.20

Table 4.18 - Backpressure Turbine Results

## 4.8 Combined Gas Analysis Investigation

### 4.8.1 Introduction

As mentioned at the beginning of the chapter, the option of combining all process gas was also explored. The merit behind this option was to substitute all the smaller gas recovery options with one large cogeneration unit, utilising all of the recovered process

gas. The financial practicality may be in question as it will require extensive capital at once to initiate one large cogeneration project.

It was not possible to simply make use of the framework parameters to determine the capital outlay required for this cogeneration unit. Rather, an energy balance ascertained the available energy for the cogeneration unit. The technologies that were considered for this unit included: Conventional steam boilers, OCGTs and CCGTs. Again, the technology was subject to evaluation regarding the inclusion and exclusion of CERs.

#### **4.8.2 Combined Gas Recovery Investigation**

The daily available energy was calculated from the gas balances and the production figures of ArcelorMittal Newcastle. The calculation incorporated the energy from the excess gas due to the commissioning of Coke Oven Battery 1, the excess BFG and the energy from the BOF gas. Table 4.19 represents the data for the energy availability of ArcelorMittal Newcastle.

Gas	Available Energy (After Consumer Reductions)
BFG [GJ/day]	1898.17
COG (Batt1 Incl.) [GJ/day]	8680.86
BOF Gas [GJ/day]	402.85
<b>Total Energy per Day [GJ/day]</b>	<b>10981.88</b>

**Table 4.19 - Combined Energy Available from the Newcastle Works**

As with the development of the framework, the efficiencies of the technologies in this exercise were as follows:

1. Conventional Steam Boilers: 33%
2. OCGT: 38%
3. CCGT: 57%

The generation availability of the plants was considered to be 90%. With these parameters, the generation capacity and financial evaluation of the combined gas recovery option are as follows:

<b>Daily Production [GJ/day]</b>	<b>17,773</b>		
<b>Electricity Generation Technology</b>	<b>Daily Generation [GJ] (including 90 % availability)</b>	<b>Generation [MW]</b>	<b>Overnight Investment</b>
Boilers	5,279	61.09	R 354,466,800
OCGT	6,078	70.35	R 430,686,100
CCGT	9,117	105.53	R 789,649,800

**Table 4.20 – Cogeneration through Combined Gas Recovery**

Excluding Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Boilers	37%	67.41	6.00	44%	93.86	5.30
OCGT	36%	75.40	6.10	42%	105.86	5.50
CCGT	31%	98.92	6.90	37%	144.61	6.00
Including Carbon Tax						
Technology	Excluding CERs			Including CERs		
	IRR	NPV [Million]	Payback Years	IRR	NPV [Million]	Payback Years
Boilers	47%	105.43	5.10	53%	131.88	4.80
OCGT	45%	119.18	5.30	51%	149.64	4.90
CCGT	39%	164.60	5.80	44%	210.28	5.30

**Table 4.21 - Combined Gas Recovery Results**

## 4.9 Interpretation of Economic Analyses

This paragraph aims to give feedback on the preceding results for each plant's respective cogeneration technology in terms of generation capacity, investment cost, IRR, NPV and payback. The life expectancy of each cogeneration plant was assumed to be 20 years, and the discount rate that was used for the calculations was 15%. However, the mills' cogeneration projects have produced payback periods in the excess of the plants' operating life of 20 years. The tables related to the mills cogeneration information indicate a payback of 20 years; which is actually supposed to be in excess of 20 years.

For the base case scenario, an average increase of 5 - 7% in the IRR of the projects can be expected if the projects generate revenue from CERs. Moreover, if carbon taxing is imposed in South Africa an average increase of 9% can be expected in the projects' IRR.

The average IRR and payback for each of the following categories in the base case scenario were considered and is represented in the table below:

Funding Categories	IRR	Payback
No CERs or Carbon Tax Savings	35%	6.382
Only CER Funding	41%	5.645
Only Carbon Tax Saving	44%	5.416
CERs Funding and Carbon Tax Savings	49%	5.027

**Table 4.22 - Average IRR and Payback for Base Case Scenario**

The data generated from the mills' cogeneration projects were excluded from the table above as the payback periods for these projects were in excess of the plants' life expectancy. The revenue generated from CERs reduced the payback period by 13.1%. The effect of carbon taxing was greater as it reduced the payback period by approximately 17.83%. However, when both CER funding and carbon taxing was applicable, these effects could be superimposed and IRR increased by 14% and the payback period reduced by 27%. Although these projects realised relatively good IRRs, the payback periods remained in the excess of 5 years (for the base case scenario).

Although the payback of these cogeneration projects is over extended periods, one cannot escape the effects of not pursuing these projects. As indicated in paragraph 4.11, it is clear that ArcelorMittal Newcastle has reached its production capacity based on the availability of electricity, and there is still another 17.82% in production capacity available. Unless ArcelorMittal Newcastle is able to reduce its electricity consumption per tonne of steel produced, it has no other alternative than to pursue cogeneration in order to increase its steel production.

## 4.10 Sensitivity Analyses

### 4.10.1 Introduction

The base case scenario was confined to one set of variables over which the project executors do not have much control. Thus, the purpose of the sensitivity analysis was to investigate the effects of changing these variables. The changes in IRR, NPV and payback were monitored. The base case scenario facilitated the departure point of the sensitivity analyses and was characterised as follow:

1. The investment cost per cogeneration technology was derived from the framework costs.
2. The inflation rate used was equal to 5%.
3. The investment cost and generation capacity of the cogeneration technology was applied in a linear fashion.

The sensitivity analyses that were conducted focused on the effects of increasing investment costs. The objective of the sensitivity analyses was to determine how attractive a project may be with incremental increases in the investment costs (keeping in mind that AMSA has a minimum IRR limit of 20% before a project is considered). In addition to the aforementioned, the sensitivity analyses also aimed to absorb variances in factors like the costs of CERs. The following set of input values governed the sensitivity analyses:

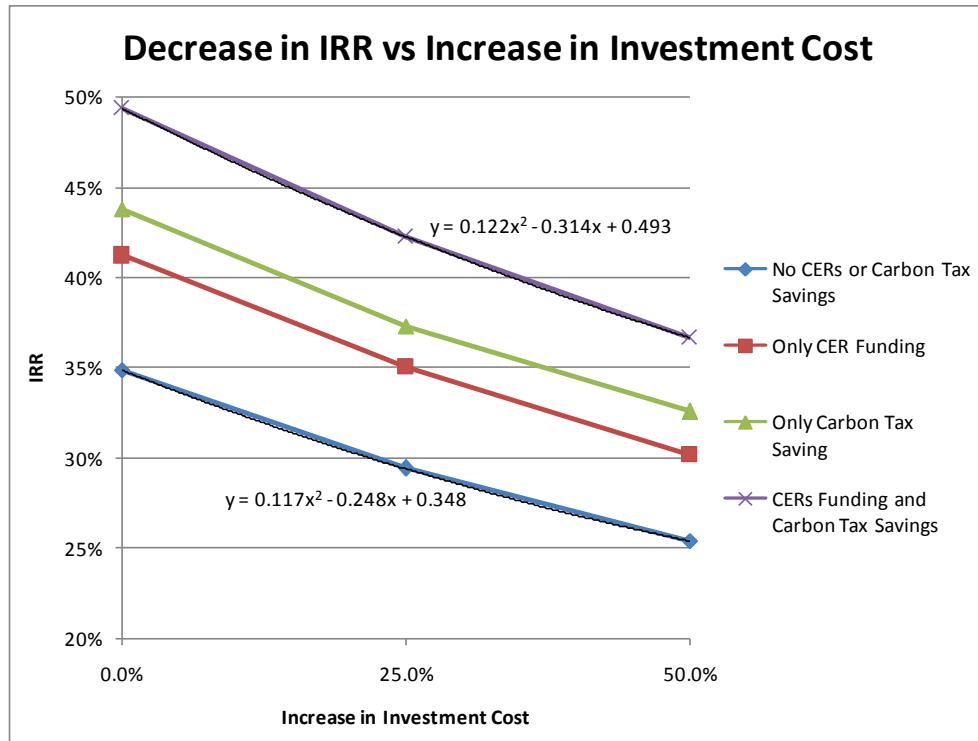
#### **Increase in Investment Cost**

As mentioned above, the base case scenario formed the basis from which the sensitivity analysis was conducted. The effects of increasing the investment costs up to 50% (in 25% increments) were investigated. The results are presented graphically in paragraph 4.10.2 and Appendix C.2.

#### **4.10.2 Effects of Increasing Investment Costs**

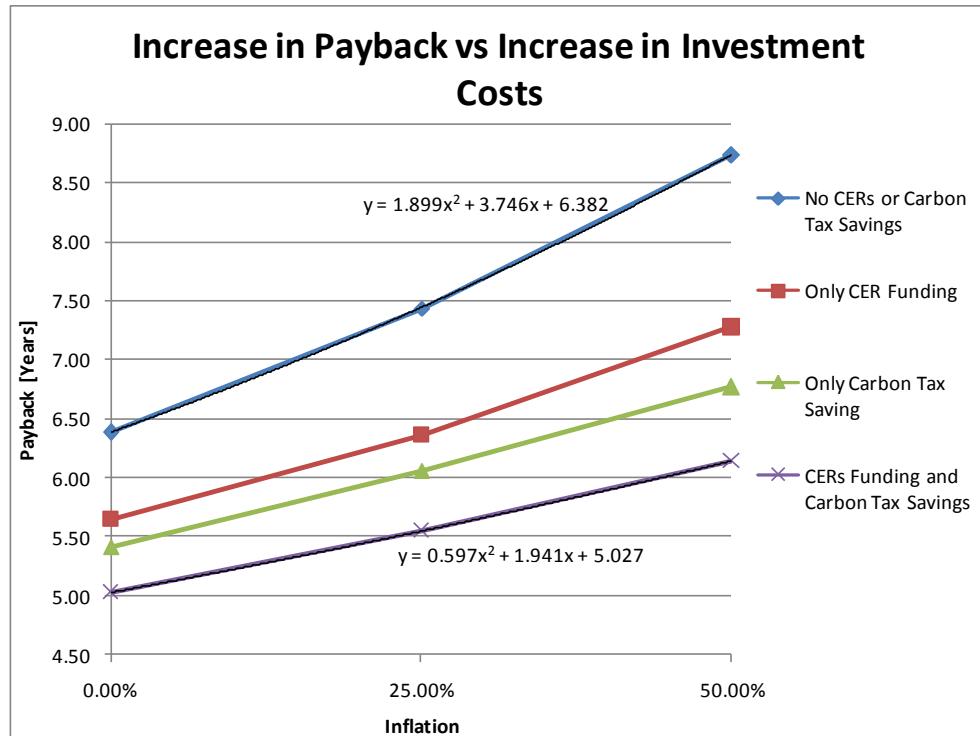
When investigating the effects on the IRR by increasing the investment costs of the projects, a tendency emerged where the rate of change is greater when the base case IRR is greatest. Thus, for a larger initial IRR, the effects of increasing the investment cost of the project are more noticeable and the rate at which the IRR decreases lessens when the initial IRR of the project decreases. Nonetheless, even with a 50% increase in the investment costs, a project can still be considered lucrative when savings from carbon tax and CER revenues are achieved.

Figures 4.2 and 4.3 graphically represent the averaged data related to the investment cost sensitivity analysis.



**Figure 4.2 - Averaged Effect of Investment Costs Increase on IRR**

Figure 4.3 illustrates how the payback periods diverge with an increase in investment costs. The scenario that had the lowest IRR during the base case investigation was affected the most as the investment costs increase.



**Figure 4.3 - Averaged Effect of Investment Cost Increase on Payback**

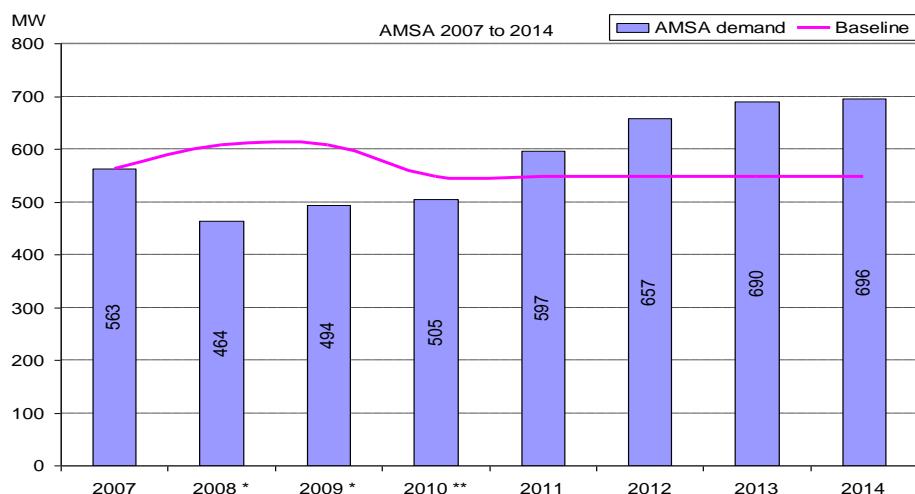
#### 4.10.3 Sensitivity Analyses Conclusion

As mentioned previously, AMSA requires that a project can realise an IRR of at least 20% before it is considered for the CAPEX budget. The sensitivity analyses maintain that the IRR of a project will decrease by approximately 10 – 13% if the investment costs are increased by 50%. In addition, the payback period of the projects are prolonged by approximately 19 – 26% for the same increase in investment costs.

The sensitivity analyses highlighted that even with a 50% increase in the anticipated investment costs (as provided by the framework); projects are still economically viable, if the IRR is the only deciding criteria. However, payback periods ranging from approximately 6.1 to 8.7 years, may hinder the initiation of these projects, as suggested by ArcelorMittal Newcastle management. Thus, it may be possible that investors, who can absorb a long payback on their investments, be included as a capital venture for projects of this nature.

## 4.11 Effects of PCP on Steel Production

Figure 4.4 and Table 4.23 indicate the registered base load of electricity consumption for AMSA as well as the allocated PCP targets for the various business units that constitute the AMSA Group. The applied baseline was based on the actual electricity demand for the AMSA Group over the period October 2006 to September 2007.



**Figure 4.4 - AMSA Electricity Demand and Baseline**

	2007	Applied Baseline	PCP allocation	2008	2009	2010	2011	2012	2013	2014
Vanderbijlpark main	183	210.4	189	169	187	173	238	232	241	240
Vanderbijlpark EAF	108	112.3	101	77	111	87	114	118	125	130
Vanderbijlpark Total	291	322.7	290	246	297	259	352	350	366	371
Saldanha	159	160.5	144	116	121	154	137	168	177	177
NewCastle	68	72.0	65	63	66	80	81	81	85	85
Vereeëniging	45	53.0	48	40	24	25	42	44	46	46
ArcelorMittal SA	563	608.2	547.4	464.2	507.6	518.5	611.5	643.6	673.9	678.6

**Table 4.23 - AMSA Business Units PCP Allocation**

It must also be noted that currently, the PCP allocation was collectively assigned to the AMSA Group, making it possible for one business unit to reduce its electricity consumption by more than 10 % in order to account for another business unit that is unable meet its PCP target. According to Figure 4.4, it is expected that AMSA's electricity demand will exceed its electricity allocation from 2011 onwards. Based on this figure, AMSA would have to contend with this threat to its steel production due to

the shortage of electricity until the Department of Energy (DOE) allocates AMSA with a higher PCP target.

However, the current downturn in the steel market and the delays in expansion projects at ArcelorMittal Newcastle resulted in a deviation from the electricity consumption forecasting, as suggested in Figure 4.4. Consequently, ArcelorMittal Newcastle is able to maintain the PCP allocation. Based on the relationship between electricity consumption and steel production, it can be assumed that the production of steel cannot be increased any further without exceeding the PCP allocation. According to production history, the average steel production is 4,668 tonnes per day and the daily electricity consumption is 1,774 MWh. Thus, the average steel production per MW equates to 63.1 tonnes per MW.

Based on the steel plant's design specifications, the plant is capable of a production rate of 5,500 tonnes per day, which realises a 17.82% increase in steel production over the 4,668 tonnes per day. Therefore, in order to achieve the plant's maximum capacity, an additional 13.185 MW is required, which constitutes a 20.28% increase in the current electricity demand. These conditions exclude the commissioning of future plans related to the ZED plant and the commissioning of Coke Battery 1. Thus, these additions will increase the shortfall even more.

In summary, with the current PCP allocation, ArcelorMittal Newcastle has reached a plateau, and the full potential of the plant will only be realised once ArcelorMittal Newcastle is able to increase its cogeneration capacity, or when the PCP allocation is abolished. The significance of the PCP allocation would only truly be experienced once the ArcelorMittal Newcastle attempts to increase its steel production.

## **4.12 Governance and ArcelorMittal Newcastle**

The purpose of this paragraph is to discuss the building blocks that constitute the governing factors of AMSA. According to the AMSA 2010 annual report (ArcelorMittal South Africa, 2011), the principles of the King Report (King II and King III), current legislation and JSE Limited Listings Requirements govern the business. Honouring the mentioned requirements, the AMSA board's policies and procedures are continually

updated. Furthermore, during the review period, the Audit and Risk Committee identifies among other, electricity supply and carbon taxes as the most significant risk exposures.

The annual report maintains that climate change is of material importance to their corporate citizenship, but it also represents a potential risk to the business. These risks are related to the meteorological changes that climate change brings about, like scarcity of water. As AMSA is mindful of its contribution to global warming, it also acknowledges the responsibility that they have to minimise its carbon emissions and manage its energy usage more efficiently. AMSA also plays a significant role in striving to obtain the global group target concerning emission reductions:

“At a global group level, the company’s goal is to reduce CO<sub>2</sub> emissions by 8% (170kg/tonne of steel produced) by 2020. While we do not believe that it is possible for the South African industry and business to achieve our government’s target, outlined in the 2009 Copenhagen Climate Change Summit, to reduce CO<sub>2</sub> emissions by 34% by 2020, we remain fully committed to engaging with key stakeholders to set realistic targets.”

In addition to the abovementioned, the following quotations are drawn from the AMSA 2010 annual report that further highlights the need to drive cogeneration (ArcelorMittal South Africa, 2011):

“In South Africa, a company’s carbon footprint is inextricably linked to electricity usage because the national electricity supply is derived from coal... Reducing our reliance on the national electricity grid and investigating cleaner forms of energy provide the most significant possibilities for reducing indirect carbon emissions. As a signatory to the national energy accord, ArcelorMittal has already committed itself to reducing its electricity consumption by 12% by 2014. In addition, proposed electricity tariff increases over the next three years will strengthen the business case for alternative energy projects. The company’s annual electricity cost has increased from R700 million in 2007 to R1.7 billion in 2010. In the past, low electricity tariffs meant that the return on investment made most energy efficiency projects unfeasible.”

Apart from only addressing the current problems and problems in the near future concerning energy in the AMSA context, AMSA also ensures that operations are maintained under strict company policies, which regulates the operations according to sound practices as identified on a global scale. The following paragraph highlights the policies applicable to this study.

#### **4.12.1 Corporate Policies**

Stemming from the preceding paragraph, corporate policies provide guidelines as to how the operations are to be managed and maintained. ArcelorMittal has also put the following energy policy in place in order to regulate the operations according to sound energy practices (ArcelorMittal, 2011):

1. “Competitiveness: By reducing our energy costs;
2. Efficiency: By establishing and implementing effective energy management programmes to reduce the specific energy consumption in our processes. We will also support manufacturing capabilities by internal benchmarking of energy efficiency and transforming our best practices into standards;
3. Technology: By investing in innovative, energy efficient technologies that are both environmentally and economically effective;
4. Social Responsibility: Through energy efficiency measures by harnessing any source, including waste gases, to reduce our carbon footprint;
5. Partnering: With our suppliers and customers to maximise the inherent energy efficient properties of steel and steel products;
6. Employees Engagement: By supporting and encouraging continuous energy conservation by employees in their work and personal activities;
7. Continuous Improvement: By establishing and maintaining a framework for setting, reviewing and reporting our corporate energy target and objectives;
8. Supporting: National governmental energy efficiency policies;
9. Leadership: By being a reference in the industrial world through our energy approach.”

In view of the ArcelorMittal energy policy; investing in innovative technologies, like that used for cogeneration should be pursued, as long as it can be justified from an

economical and environmental perspective. Thus, it highlights the internal drive of the business to make progress in technological arena concerning energy.

In addition to the energy policy, ArcelorMittal's environmental policy is also of interest to this study, as the link between energy and the environment was already noted in paragraph 4.12. ArcelorMittal's policy concerning its commitments to the environment is as follow (ArcelorMittal, 2011):

1. "Implementation of environmental management systems including ISO 14001 certification for all production facilities;
2. Compliance with all environmental laws and regulations, and other company commitments;
3. Continuous improvement in environmental performance, taking advantage of systematic monitoring and aiming at pollution prevention;
4. Development, improvement and application of low impact, environmental production methods taking benefit of locally available raw materials;
5. Development and manufacture environmentally friendly products focussing on their use and subsequent recycling;
6. Efficient use of natural resources, energy and land;
7. Management and reduction where technically and economically feasible of the CO<sub>2</sub> footprint of steel production;
8. Employee commitment and responsibility in environmental performance;
9. Supplier and contractor awareness and respect for ArcelorMittal's environmental policy;
10. Open communication and dialogue with all stakeholders affected by ArcelorMittal's operations."

ArcelorMittal commits itself to the voluntary environmental management system, ISO 14001. According to the ISO (International Organisation for Standardisation, 2011), this standard enables management to identify and control the environmental impact of its operations and to improve its environmental performance on a continuous basis. Thus, putting this into perspective with GHG emissions, the iron and steel industry is obligated to continually reduce its GHG emissions in order to retain its ISO 14001 accreditation. This requirement coincides with ArcelorMittal's seventh goal in its

environmental policy, namely, that it will strive to reduce its CO<sub>2</sub> footprint in steel production as far as technically and economically possible.

In conclusion, the Global Management Board (GMB) of ArcelorMittal signed and committed to two corporate policies that are of particular interest when investigating cogeneration projects. With that said, accountability with regards to these policies must not be neglected, especially when referring to the corporate governance principles, as highlighted in the King II report. Thus, besides being prompted by external governing factors related to cogeneration in this industry, this is also an internally driven matter in the interest of ArcelorMittal.

#### **4.12.2 Sustainability**

This paragraph must be related to the effects of the PCP. As it was noted in paragraph 4.11, based on the current Eskom electricity demand, ArcelorMittal Newcastle has reached its steel production plateau. Currently, ArcelorMittal Newcastle is maintaining the PCP target, but with the commissioning of future plants, the electricity demand for the Newcastle Works will increase. Thus, to remain within the current PCP target when the electricity demand increases, ArcelorMittal Newcastle will not be able to sustain its current steel production nor will it be able to sustain growth. For these reasons, ArcelorMittal Newcastle will have to consider pursuing cogeneration or it must decrease its electricity demand per tonne of steel product produced.

#### **4.12.3 Environmental Responsibility**

By pursuing cogeneration technologies, environmental responsibilities, such as reducing the company's carbon emission footprint, are inherently addressed. Apart from just focusing on emission reductions, ArcelorMittal Newcastle's ISO 14001 accreditation must be taken into account. Referring to paragraph 3.2.7, compliance to this standard obligates ArcelorMittal Newcastle to actively pursue the reduction of its carbon emissions. The emission reductions (Scope 2 emissions) obtained through reduced dependence on purchased electricity can account for the emission reductions required by ISO 14001.

In addition to paragraph 4.12, the AMSA 2010 annual report acknowledges that the impact of its operations constitutes one of their most significant business and reputational risks. The annual report further maintains that the environmental footprint of this industry derives from its need for natural resources, electricity and coal. Thus, the environmental impact is therefore unavoidable, and the business owns the responsibility to manage and reduce this impact as far as possible (ArcelorMittal South Africa, 2011).

#### **4.12.4 Legal Responsibility**

ArcelorMittal Newcastle's legal aspects are steered by AMSA's Corporate Legal Services (CLS). Together with the inputs from the AMSA's Energy and Environmental departments, legal compliance is constantly maintained. In honouring of the AMSA's environmental responsibility, the following legislative framework is applicable (ArcelorMittal South Africa, 2011):

1. National Environmental
2. Management Act 107 of 1998;
3. Atmospheric Pollution Prevention Act 45 of 1965 (repealed on 1 April 2010);
4. National Environmental Management: Air Quality Management Act 39 of 2004;
5. National Water Act 36 of 1998;
6. Protected Areas Act 57 of 2003;
7. National Environmental Management: Waste Act 59 of 2008;
8. Bill of Rights – Chapter 2 of the Constitution of the Republic of South Africa, 1996

Apart from the environmental legal framework, all other operations are managed within the required legislative frameworks. This is also applicable to new projects, for example a possible cogeneration project. Due to the size of the investment required for a project of this nature, it has to be reviewed and approved by ArcelorMittal's Investment Approval Committee (IAC). Projects qualifying for IAC approval have an investment value larger than \$7.5 million, and all projects are subject for approval of the same topics, of which relevant legal obligations is one of them. Only once the IAC has approved the legal framework in which the project will be executed may a project commence to ensure that during any part of a project lifecycle (including the motives for the project) it is managed in the correct legal frameworks.

#### **4.13 Technical Parameters and ArcelorMittal Newcastle**

The purpose of this particular paragraph is to discuss two cogeneration studies concerning ArcelorMittal Newcastle. These studies were conducted prior to the research pertaining to the framework under discussion. The first study was applicable to the blast furnace and the second concerned the power plant to utilise the excess gas as a result from the commissioning of Coke Battery 1. These studies did unfortunately not continue to the stage of realising the execution of projects; however, it did provide valuable information concerning the cogeneration technologies to pursue and the generation capacities of these two technologies in the ArcelorMittal Newcastle context.

The study related to the blast furnace, recommended a TRT as the cogeneration technology. This study was conducted in 2008 by the ArcelorMittal Newcastle expansion project team, when it was planned to commission a second blast furnace and increase the production of the ArcelorMittal Newcastle. The preliminary study suggested an average generation capacity of 7.5 MW. Take note that if the generation capacity was only specified according to a preliminary study and a detailed investigation was still required to define the generation capacity more accurately. However, the project was halted when ArcelorMittal experienced the effects from the economic recession of 2008; thus, detailed costing and a refinement of the generation capacity could not be obtained. Nonetheless, it still sets a benchmark against which the technical parameters of the framework can be validated in terms of generation capacities.

ArcelorMittal Design Engineering Centre (AMDEC) conducted the second study in 2010, which concerned the commissioning of the Coke Battery 1. The study progressed to the stages where the various cogeneration concepts were identified and the enquiries were sent to possible vendors for the project. Like with the preceding example, this project was also halted due to a sudden decrease in the demand for market coke. The study did however suggest similar technologies as mentioned in the framework. The generation capacity that can be used in context of the validation of the framework, is that of the combined gas recovery, as suggested in paragraph 4.8.2. The study suggested that with the combined gas recovery and the utilisation of the CCGTs, a generation capacity of 103 MW. Again no, investment requirements could be obtained, as the project was halted prior to the issuing of the enquiries.

The environmental impact of the two mentioned cogeneration studies was calculated similarly to that of the framework. In both cases, a reduction of Scope 2 emissions could be realised. As none of the mentioned studies led to the realisation of projects, the emission reductions were only calculated based on a reduction in Eskom's carbon emissions, similar to what was suggested by the framework.

#### **4.14 Funding and ArcelorMittal Newcastle**

As with any new investment, ArcelorMittal subjects these projects to an economic feasibility study, especially focussing on the IRR of these projects. AMSA requires a minimum IRR of 20 %, before a project will be included in the CAPEX budget. However, discussions with ArcelorMittal Newcastle management contradicts the aforementioned statement; they suggested that although cogeneration projects can realise IRRs of in the excess of 30 %, it is still not in favour of AMSA's current financial situation, as the payback of most cogeneration projects are in the excess of 5 years, and they would most likely at present not pursue it. Nonetheless, if market conditions return to pre-recession conditions and AMSA regains the ability to invest in large CAPEX projects, then the minimum IRR of 20 % ruling will probably be re-enforced.

Thus, in order to decrease the payback of the investigated projects, revenues from CERs were included in both studies. AMSA has recently appointed an internal CDM consultant to administrate and facilitate the CDM processes related to energy efficiency and cogeneration projects. Thus, it is evident that AMSA acknowledge that the CDM is a valuable revenue stream for projects.

#### **4.15 Implementation and ArcelorMittal Newcastle**

The purpose of this paragraph is to discuss how ArcelorMittal Newcastle manages projects in terms of implementation parameters. In honouring the validation of the framework, it was important that the framework be benchmarked against the current implementation procedures followed at ArcelorMittal Newcastle.

As none of the two studies realised any tangible projects, other procedures within AMSA were used to illustrate the implementation parameters.

The IAC framework highlights important implementation factors that should be addressed when projects larger than \$7.5 million are pursued. The IAC suggests the following implementation parameters:

1. Resource requirements:
  - a. This includes internal and external resources for a project.
  - b. Full time ArcelorMittal project manager and an assistant project manager.
  - c. Subject matter experts (SMEs) will be called upon for inputs at different stages of the project.
  - d. Other staff that needs to be contracted, some directly to ArcelorMittal and some via the engineering contractors.
- The IAC also requires that the proportion of the time that each project resource will spend on a project be specified in order to ensure that resources are not strained or underutilised.
2. Project team:
  - a. The responsibility of each project team member (ArcelorMittal personnel) shall be clearly defined.
  - b. The minimum requirements for the project team are as follow: Project manager, assistant project manager, document controller, financial accountant, environmental management, SMEs, capital buyer and commercial consultant.
3. Project schedule:
  - a. The project schedule has a great influence on the economic investigation of a project, as it governs when the cash flow occurs in the project. The ArcelorMittal Newcastle cogeneration studies, mentioned earlier, suggest that capital will flow of a 4-year period.
  - b. Although the IAC highlights the time requirement for an EIA, it does not give a clear timeline in which an EIA must be completed.
4. Project risk management:
  - a. Factors included in the risk management structure include: timeline, cost, project management (strain on the resources), operational and possible future scenarios.

#### **4.16 ArcelorMittal Newcastle Case Conclusion**

AMSA recognises that the electricity status and its related issues pose a risk to the business operations. The applicable governing factors, practices and details of project execution in the cogeneration environment that were highlighted by ArcelorMittal Newcastle provided a sound basis for the researcher to develop a framework that holistically addresses all the factors pertaining to cogeneration in this industry. Chapter 5 validates the framework developed in Chapter 3 against the case study from this chapter.

## **Chapter 5**

### **Framework Validation**

*This chapter elaborates on the validation of the framework by scrutinising it and establishing similarities between the framework and the case studies from Chapter 4.*

## Chapter 5 : Framework Validation

### 5.1 Introduction

Wilson, who did a similar study in the iron and steel industry, made the comment that there are various arguments against and criticism concerning the validation of a framework through a case study research because of potential investigator subjectivity (Wilson, 2008). He further highlighted remedies, as suggested by Yin, to mitigate this potential phenomenon, which may include (Yin, 1993):

1. Utilising multiple sources of evidence
2. Establishing a chain of evidence

For the purpose of the validating the framework, the case study from Chapter 4 was used to establish the chain of evidence supporting the validity of the framework. The case study investigated the effects that the inclusion of CERs and the savings from carbon taxing had on the IRR of a project. In addition, the case study also proved to consider the economic sensitivity of the various cogeneration technologies due to increases in investment costs and inflation.

The validation is headed under the four building blocks of the framework, namely:

1. Governance
2. Technical Parameters
3. Funding
4. Implementation Parameters

### 5.2 Governance Validation

In the view of providing guidance to the South African iron and steel industry concerning cogeneration, the framework includes eight factors that should be considered. In addition, the framework highlights the stakeholders involved in the pursuing cogeneration in this industry, like government, Eskom, regulatory bodies and internal corporate stakeholders. These factors collectively motivates the cogeneration in the industry, especially honouring South Africa's current energy and environmental situation.

With reference to paragraph 4.12, AMSA highlights global warming as one of their business risks and from that stems the necessity of becoming more self-sufficient with regards to electricity generation, due to the interlinking of global warming and electricity generation in South Africa. Furthermore, AMSA acknowledges that cleaner electricity generation means should be pursued in attempt to minimise its effects on global warming and reducing their reliance from the national electricity grid as electricity supply and carbon taxes have been identified as among other to be their most significant business risks. AMSA's signatory to the national energy accord for reduction of their electricity consumption furthers the need to becoming more self-sufficient.

The abovementioned factors, electricity supply, carbon taxes and global warming were addressed in the case study and are in line with the framework recommendations. With regards to electricity availability, the framework suggests an immediate 10% reduction in electricity consumption, as advocated by the PCP. However, excluding the PCP requirements, AMSA has committed to a reduction of 12 % in their electricity consumption by 2020; thus emphasising AMSA's effort to reduce its dependence on the national electricity grid. In addition, the drastic increase in electricity tariffs, which was quantified by AMSA, now strengthens the need to cogenerate, as was also suggested by the framework.

Although the framework does not make it clear whether carbon tax will be implemented nor the means of how it will be implemented, but if it does realise in South Africa, it does address it as a significant business risk.

The IRP 2010, maintains and elaborate on the electricity tariff forecasting of South Africa, and must therefore be used as a mitigation tool if electricity tariffs are identified as a motivation to becoming more self-sufficient. The IRP 2010 also gives some guidance concerning carbon tax. Again, the IRP 2010 fulfils the role of a mitigation tool, specifically for business risk mitigation. The last comment that can be made concerning the IRP 2010, and which was not highlighted by the ArcelorMittal Newcastle case study, is the fact that the IRP 2010 provides guidance about what is expected from industry concerning cogeneration and DSM. Even though the case study did not directly address these two factors, it must still be included in the framework, as the framework development highlighted the relevance of these factors.

The framework further maintains that corporate policies should provide guidance on how the business must be managed and operated. The case study also supports this factor by honouring AMSA's own corporate policies that support cogeneration from an energy and environmental point of view. One can also link the corporate policies to AMSA's environmental and legal responsibilities, as there is an interlinking between these factors. Although the framework addresses these factors individually, one must follow a holistic approach to the implementation of the mentioned factors to ensure that the interlinking characteristic be maintained.

Lastly, the case study did not highlight many dominant sustainability concerns, one can however link the risks highlighted in the case study with the sustainability of the business. Furthermore, the framework only expresses the risks related to PCP and the sustainability of the business, but the case study did highlight factors like water scarcity, as a result of global warming. Thus, when the framework is implemented, one must ensure that other factors, besides PCP, are considered in view of the sustainability of the business. These factors can typically be derived from identified business risks.

### **5.3 Technical Parameters Validation**

In honouring the remedies proposed by Yin, namely utilising multiple sources of evidence, the validation of the available technologies and generation capacities that constitute the technical parameters building block of the framework, was addressed during the development of the framework. As this particular part of the framework was developed by empirical data derived from previous projects, one can accept that the constituents of this building block are valid. In addition, South Africa's renewable energy policy roadmap suggests capital requirements for CCGT and OCGT technologies of R 9,580.21/kW and R 6,255.62/kW respectively, which realise correlations with the framework of 78% and 98% (Edkins et al., 2010). This correlation suggests that the framework is aligned with current cogeneration capital investment requirements. However, in honouring the similarity recognition of Yin's remedies, the ArcelorMittal Newcastle case study corresponds with the framework suggestions. The two studies that were conducted by the ArcelorMittal Newcastle expansion project team and AMDEC (refer to paragraph 4.13), suggested the same technologies as was

proposed in paragraphs 4.4 and 4.8 respectively. Furthermore, the correlations between the ArcelorMittal Newcastle case study and what was proposed in paragraphs 4.4 and 4.8 were respectively 84.6% and 97.6%. This proves that the framework is accurate in terms of quantifying the generation capacities and identifying the applicable cogeneration technologies.

Although the case study in paragraph 4.13 did not directly address the environmental impact, specifically the reduction in Scope 2 emissions, it does mention that the trading of CERs was considered. Thus, the trading of CERs will constitute a reduction in Scope 2 emissions; thereby, suggesting that there would have been a noticeable impact on the environment. This aligns the case study practice with what is proposed by the framework.

## **5.4 Funding Validation**

The framework suggests three avenues when considering the funding aspects of cogeneration projects. The first of these is the IRR of projects. This is an obvious factor to consider when investments are pursued. However, the framework elaborates on factors that may benefit the IRR of these projects, namely:

1. Savings generated from the reduction in electricity purchased.
2. Savings from possible carbon tax in South Africa.
3. Trading of CERs.
4. DSM funding.

The case study in paragraph 4.13 only focused on the savings from reduced electricity purchases and the revenue from the trading of CERs. However, the effects of including the savings from the possible carbon tax in South Africa can realise an increase in the IRR of approximately 9 %, as proven in paragraph 4.9. Thus, it is valid to include this factor into the funding building block of the framework.

A factor that was not investigated in the ArcelorMittal Newcastle case study, was that of DSM funding. Although paragraph 3.2.3 provided some guidelines as to how the DSM rebate can be accommodated in a cogeneration project's rebate; the rebate agreement must be negotiated between Eskom and the business pursuing the cogeneration

project. Although, the case study did not investigate the effects of the DSM rebate, the framework does make provision for this revenue source as it can only benefit the economic viability of the project.

Paragraph 4.11 maintains the relevance of PCP in the funding model of the framework. As highlighted in the study, a potential increase of 17.82% can be realised if the electricity capacity can be made available. For this reason, it was included in the funding model as the additional production income can only be realised once the electricity capacity is available. In terms of motivating a cogeneration project, the additional income from the increased production can be included in the IRR calculation of the project which will consequently greatly benefit the return on the investment.

## **5.5 Implementation Parameters Validation**

The case study indicated that there is a distinct correlation between the personnel requirements that were specified in the framework. AMSA's IAC guidelines provided significant evidence that supported the inclusion of the personnel requirements, as specified in the framework. The case study did however highlight a factor that can be included in the framework, namely accounting SMEs in the project resources as they will provide the necessary technical expertise to the project. The entity pursuing the project should have their own SMEs, alternatively, external SMEs should be contracted to provide the relevant service.

With regards to the timeframe of the projects, the case study in paragraphs 4.15 also suggested a cash flow period of 4 years. This corresponds with the timeframe suggested by the framework and consequently, the same timeframe was used for the economic feasibility study pertaining to ArcelorMittal Newcastle. To prevent possible contradiction of the framework where it suggests a project time schedule over a period of 66 months, it must be noted that the framework does not imply that cash flow will be over the entire 66 months. In relation to the framework, cash flow will only commence from month 17, when the funds are allocated to a particular project.

An additional factor that was included in the framework, which was not evident in the case study, is that of the operational support. Inevitably, if a cogeneration technology is

pursued, it is critical that the local knowledge base and support for the technology is mature and sound. This should prevail in the maintenance aspects as well as the technical support of the technology. For this reason, this factor was included in the framework.

## **5.6 Conclusion**

The case study concerning ArcelorMittal Newcastle, as summarised in Chapter 4, realise frequent similarities with the outline of the framework pertaining to cogeneration in the iron and steel industry. ArcelorMittal Newcastle cannot represent all the challenging factors that industries face concerning cogeneration, as ArcelorMittal has not concluded any of the pursued cogeneration technologies in recent years; however, the interconnection between ArcelorMittal Newcastle, the electricity situation in South Africa and mediating actions that AMSA has applied in response to the electricity situation makes ArcelorMittal Newcastle a commendable reference study.

Many of the building blocks, and its constituents, of the framework compares to the practices and responses of AMSA. Therefore, it may be confirmed that the framework for cogeneration in the iron and steel industry is consistent with the current practices applied by AMSA, and more specifically ArcelorMittal Newcastle. In conclusion, the framework will benefit industries as a tool to address their cogeneration requirements.

## **Chapter 6**

### **Conclusion and Recommendations**

*This chapter provides a summary of the dissertation and concludes that the framework addresses the relevant factors concerning cogeneration in the South African integrated iron and steel industry.*

## Chapter 6 : Conclusion and Recommendations

### 6.1 Conclusion

A literature study was completed to research the building blocks for the development of an electricity generation framework for the South African integrated iron and steel industry. The literature revealed that the most significant drivers to pursue cogeneration in the iron and steel industry were the security of electricity supply, increases in electricity tariffs, increased pressure to reduce carbon emissions and consequently becoming more self-sufficient in terms of electricity generation. The literature study highlighted the role that each stakeholder plays in the context of cogeneration in the South African integrated iron and steel industry. These stakeholders include government, Eskom, regulatory authorities and corporate stakeholders. Collectively, these stakeholders contribute to the governing factors that constitute one of the building blocks of the framework, and greatly influence the sustainability of the South African iron and steel industry. The literature study identified the possible cogeneration technologies available for each plant that constitute the iron and steel industry. In addition, further literature reviews during the development of the framework enabled the researcher to quantify each cogeneration technology in terms of generation capacities and investment requirements.

A framework was developed through the application of the literature review findings and the researcher's experience in the iron and steel industry with the objective of providing industry with an all-encompassing framework in which cogeneration should be pursued in this industry. The framework embodies four building blocks into a single framework to be followed by South African industries, which provides the necessary governing factors that quantifies the potential need to pursue cogeneration, the technical and economical implications and inevitably, the implementation requirements and guidelines. The framework will enable industries to expand and adapt their own procedures to be specific to their operational requirements. Thus, industries should follow a holistic approach towards the implementation of the framework and tailor it to address their specific needs for cogeneration in this industry.

The framework was validated against case studies pertaining to ArcelorMittal Newcastle. AMSA demonstrated its commitment to reduce its dependency from the

national electricity grid through signatory to the national accord to reduce their electricity consumption by 12% by 2014 in efforts to reduce indirect carbon emissions. The validation of the framework also concluded that the available cogeneration technologies and its generation capacities are accurate. Sensitivity analyses maintained that the validity of the investment requirements of these cogeneration projects were acceptable as even with a 50% increase in the proposed investment costs, these projects still realised IRRs in the excess of 20%. This finding contradicts the comment made by Sector Policies and Programs Division of Air Quality and Standards, suggesting that the cogeneration projects realise very low IRRs. The validation of the framework against the AMSA and specifically ArcelorMittal Newcastle investigations concludes that there is parallel between the framework and the current practices.

**Thus, it may be concluded that the framework provide the necessary guidance and collectively address the relevant factors concerning cogeneration in the South African integrated iron and steel industry.**

## **6.2 Recommendations**

The South African integrated iron and steel industry, facing the challenges related to the current electricity situation and who considers cogeneration as a possible remedy, must utilise the framework to mitigate the risks related to the South African electricity situation. The framework provides the governing factors that should highlight the need to pursue cogeneration and identifies the necessary stakeholder involvements. Furthermore, the framework can be tailored to meet the specific requirements of industries in South Africa. Therefore, it is recommended that each iron and steel industry incorporate the framework into their operations as a tool to develop and steer the factors related to cogeneration.

## **6.3 Recommendations for further Research**

The framework does not address the factors concerning the acquiring of capital to pursue these technologies as projects. Although, the cogeneration technology may achieve the set minimum limit on the IRR, as described by an industry, it is not

## Chapter 6: Conclusion and Recommendations

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necessarily that the industry will be able to fund these investments. Thus, it is recommended that a study be launched to investigate avenues outside of the iron and steel industry to acquire the capital for these investments.

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## **Appendix A**

### **Literature Study Appendixes**

## Appendix A.1

1. Key Assumptions – Demand (Peak demand and energy consumption) (Visagie, 2010)
  - The demand projection excludes the effects of:
    - Demand Side Management
    - Cogeneration
    - Solar Water Heating
  - Price elasticity will have a delayed impact which will not significantly reduce demand over the critical next 3 years
  - Demand is based on a GDP ranging from 3 to 5% for the period 2010 to 2014
  - There is an additional recovery of demand in 2010 due to smelters ramping up to full capacity after the economic recession
  - Unconstrained growth is allowed for new connections  $\geq 20$  MVA

### 2. Key Assumptions – Supply

The table below shows the planned timing of supply capacity additions.

	ESKOM Build						Country Options										Total New Build	System Capacity
	Grootvlei	Komati	Medupi	Kusile	Ingula	Sere	MSBLP	Nuclear	Regional	DoE OCGT	OCGT	MTPP1	REFITT Wind	REFITT Other	Other			
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	
2009	570	202	0	0	0	0	0	0	0	0	0	0	0	0	0	0	772	44157
2010	380	303	0	0	0	0	0	0	0	0	0	0	168	0	175	30	1056	45213
2011	0	404	0	0	0	0	0	0	0	0	0	0	168	200	150	55	977	46190
2012	0	0	738	0	0	100	0	0	0	1020	0	84	200	0	0	0	2142	48332
2013	0	0	738	0	666	0	0	0	0	0	0	0	0	0	0	0	1404	49736
2014	0	0	1476	723	666	0	0	0	1858	0	0	0	0	0	0	0	4723	54459

Table A.1 - Generation Supply Options

Further assumptions on the above are:

- Base Load Coal Energy Availability Factor on the big ten coal fired stations: Scenario's of 86% and 84%
- Expensive Base Load Station (Grootvlei, Camden, Komati) Load Factor: 50%
- Open Cycle Gas Turbines Gross Load Factor: 6%
- Energy Utilisation Factor: 95%

## Appendix A.2

- The following supply and demand assumptions are made to ensure sufficient contingency (Visagie, 2010):
  - Allow for extended delivery dates of Eskom base load stations : assume delivery dates of 2013 and 2015 for Medupi and Kusile respectively
  - Plan for an energy availability factor of 84% (rather than 86%) to allow for sufficient space for maintenance
  - Apart from MTPPP, exclude all other non-Eskom generation options in the period until 2014
  - Postponement of the 1020MW DoE OCGT from 2012 to 2014
  - The MYPD2 sales assumptions allow for sufficient contingency and remains as-is
  - Maintaining the current 5TWh annual energy buffer into the future
- Demand Management solutions need to provide sufficient contingency in the supply / demand forecast to mitigate risk associated with:
  - Reduced performance levels of current generation plant
  - Possible delays in the delivery of the new large power stations (Medupi & Kusile)
  - Higher than anticipated demand
  - Possible delays in the delivery of non-Eskom generation options
- In addition, the contingency will ensure opportunities for:
  - Additional space for maintenance of generation plant
  - Minimising the overall cost to the consumer by avoiding excessive usage of OCGT's
  - Growth in electricity consumption, including large new projects
- Although there is a 5TWh energy surplus in the current year, the system nevertheless remains extremely "tight". It will therefore be appropriate to ensure that this "buffer" be maintained and planned for into the future

**Appendix B**  
**Electricity Generation Framework Development**

## Appendix B.1

TRT Installation Data from the Clean Development Mechanism Project Design Documents															
Plant Name	Country	Year	Blast Furnace Volume	Top Pressure [kPa]	TRT Inlet Pressure [kPa]	TRT Inlet Temperature [C]	TRT Outlet Pressure [kPa]	Generation [GWh/Yr]	Generation [MW]	Installation Capacity [MW]	CO2 Reduction [T/Yr]	Capital Investment	Investment per MW	Reference	
Tata Steel at Jamshedpur	India	2008	2300m3	150.00	120.00	61.00	10.79	64.68	7.70	8.10	60811.00	R 70,257,333.46	R 8,673,744.87	(UNFCCC, 2009)	
ESSAR Steel Hazira Limited (ESHL)	India	2010	2200m3	186.00	150.00	55.00	9.00	71.40	8.50	10.00	65154.00			(UNFCCC, 2009)	
Jiangsu Shagang Blast Furnace	China	2007	5800m3	162.50	128.50	72.00	9.00	160.00	19.05	36.00	421968.00	R 169,083,416.29	R 4,696,761.56	(UNFCCC, 2006)	
Laigang	China	2008	2000m3	200.00	160.00	62.67	15.00	49.40	5.88	16.00	46150.00	R 102,301,523.39	R 6,393,845.21	(UNFCCC, 2007)	
Bhilai Steel Plant	India	2010	2000m3	176.52						7.00	48825.00			(UNFCCC, 2008)	
Bhilai Steel Plant	India	2010	4060m3	294.20						14.00	97650.00			(UNFCCC, 2008)	
Rourkela Steel Plant	India	2010	4060m3	225.55						14.00	97650.00			(UNFCCC, 2008)	
Bokaro Steel Plant	India	2010	2250m3	107.87						5.60	39060.00			(UNFCCC, 2008)	
IISCO	India	2010	4060m3	245.17						14.00	97650.00			(UNFCCC, 2008)	
Qian'an City	China	2004	2650m3	300.00	196.00	120.00	11.00	80.00	9.52	15.00	76242.00			(UNFCCC, 2008)	
Qian'an City	China	2007	2650m3	300.00	196.00	120.00	11.00	80.00	9.52	15.00	76242.00			(UNFCCC, 2008)	
No. 7 Blast Furnace Wugang	China	2008	3200m3	250.00	158.42	81.78	10.00	100.00	11.90	20.00	94445.00	R 65,247,152.78	R 3,262,357.64	(UNFCCC, 2007)	
Baoshan Steel Corporation	China	2003	2500m3							12.00				(UNFCCC, 2008)	
Tanggang	China	2000	2560m3							10.00					
Taigang	China	2001	1650m3							12.00					
Jigang	China	2003	1750m3							8.00					
Jiugang	China	2003	1800m3							6.00					
Shaogang	China	2005	2500m3							10.00					
Ma'an Shan Steel Corporation	China	2000	2500m3							10.00					
Liugang	China	2005	1250m3							8.00					
Pangang	China	1998	1350m3							6.00					
Anyang Iron & Steel Company	China	2005	2200m3							15.00					
Shagang	China	2005	2500m3							10.00					
Laiwu Steel (Group) Co., Ltd	China	2005	3760m3							30.00					
Wugang	China	2005	1516m3							6.00					

Table B.1 - TRT Installation Data from the Clean Development Mechanism Project Design Documents

UNFCCC, 2006. *Jiangsu Shagang Blast Furnace Top Gas Pressure Recovery Turbine (TRT) for Power Generation*. CDM PPD. Zhangjiagang City: UNFCCC Clean Development Mechanism.

UNFCCC, 2007. *1000 m3 Blast Furnace Top Gas Pressure Recovery Turbine (TRT) for Power Generation of Laigang*. CDM PPD. Laiwu City: UNFCCC Clean Development Mechanism.

## Appendix B

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UNFCCC, 2007. *7# Blast Furnace Top Gas Pressure Recovery Turbine (TRT) for Power Generation of Wugang*. CDM PPD. Wuhan City: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *Installation of Top Gas Recovery Turbines (TRT) at Blast Furnaces of SAIL*. CDM PPD. Bhilai, Rourkela, Bokaro, Burnpur: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *Installation of waste pressure recovery system in a steel plant in Qian'an City, China*. CDM PPD. Qian'an City: UNFCCC Clean Development Mechanism.

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## Appendix B

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Process Gas Boilers Installation Data from the Clean Development Mechanism Project Design Documents													
Plant Name	Country	Year	Additional Information	Fuel and Heat Input	Pressure [kPa]	Temperature [C]	Production [t/hr]	Generation [GWh/Yr]	Installed Capacity [MW]	CO2 Reduction [T/Yr]	Capital Investment	Investment per MW	Reference
Rimbunian Sawait's Selangau Mill	Malaysia	2011	CFB boiler	Biomass & Methane	5,400.00	450.00	75.00	85.00	16.00	177,477.00			(UNFCCC, 2009)
Ledesma sugar mill	Argentina	2011	HP Boilers	Biomass & Natural Gas	4,500.00	425.00	698.00	141.71	76.40	60,305.00	140,766,834.04	1,842,497.83	(UNFCCC, 2010)
Ledesma sugar mill	Argentina	2011	LP Boilers	Biomass	1,700.00	320.00	180.00	16.36	10.80	60,305.00	38,910,460.00	3,602,820.37	(UNFCCC, 2010)
Joypurhat Bagasse	Bangladesh	2008	Two Boilers	Bagasse-fired	4,412.99	500.00	110.00		11.00		47,690,554.20	4,335,504.93	(UNFCCC, 2006)
Establecimiento Don Guillermo S.R.L	Argentina	2007	BGV-25000	Biomass	2,059.40	300.00	25.00		3.00		9,417,325.15	3,139,108.38	(UNFCCC, 2007)
NOBRECEL Biomass	Brazil	2002		Biomass	4,500.00	450.00	60.00		8.00		75,154,030.05	9,394,253.76	(UNFCCC, 2007)
Agro Industrial Paramonga	PERU	2006	Aqua tubular Boiler	Bagasse-fired	4,200.00	430.00	120.00				41,491,020.43		(UNFCCC, 2006)
Shaanxi Dongling Smelting	China	2012	Boiler Fire on Process Gas and Waste Heat	BFG, COG, BFG Surplus - 23,000 Nm3/h COG Surplus - 11,000 Nm3/h CLS & FFG Waste heat will feed boiler	5,300.00	450.00	90.00	135.00	20.00	112,910.00	207,621,996.08	10,381,099.80	(UNFCCC, 2011)
Jiangxi Pinggang Group	China	2009	Surplus Steam; 40 t/h Blast Furnace = 3 x 450 m3 Converter = 2 x 50 t	BFG Surplus: 76365 Nm3/h BOF Surplus: 6000 Nm3/h	3,820.00	450.00	150.00	108.00	20.00	103,368.00			(UNFCCC, 2009)
Chuanwei Group	China	2008	Process Gas Fired Boiler	11.95×108 m3 of blast furnace gas	3,820.00	450.00	150.00	190.00	24.00	183,021.00			(UNFCCC, 2008)

**Table B.2 - Process Gas Boilers Installation Data from the Clean Development Mechanism Project Design Documents**

UNFCCC, 2006. *Joypurhat Bagasse Cogeneration Project (JBCP)*. CDM PPD. Joypurhat: UNFCCC Clean Development Mechanism.

UNFCCC, 2006. *Paramonga CDM Bagasse Boiler Project*. CDM PPD. District of Paramonga: UNFCCC Clean Development Mechanism.

UNFCCC, 2007. *Don Guillermo Biomass Electricity Generation Project*. CDM PPD. Municipalidad de Santiago de Liniers, Dep. Eldorado.: UNFCCC Clean Development Mechanism.

UNFCCC, 2007. *NOBRECEL Biomass energy project*. CDM PPD. Pindamonhangaba city: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *Chuanwei Group 24 MW Waste Gas based Captive Power Plant*. CDM PPD. Lianjie Town, Weiyuan County, Neijiang City: UNFCCC Clean Development Mechanism.

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UNFCCC, 2009. *Jiangxi Pinggang Group 20MW Waste Gas and Surplus Steam based Captive Power Plant*. CDM PPD. Pingxiang City: UNFCCC Clean Development Mechanism.

UNFCCC, 2009. *Power generation with waste materials and recovered gas of palm oil mill in Selangau, Malaysia*. CDM PPD. Selangau town: UNFCCC Clean Development Mechanism.

UNFCCC, 2010. *Installation of a high-pressure/high-efficiency bagasse boiler to cogenerate heat and power*. CDM PPD. Libertador General San Martín - Ledesma Town: UNFCCC Clean Development Mechanism.

UNFCCC, 2011. *Shaanxi Dongling Smelting Waste Heat Recovery Project*. CDM PPD. Fengxiang County, Baoji City: UNFCCC Clean Development Mechanism.

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BOF Gas Recovery Systems Installation Data from the Clean Development Mechanism Project Design Documents													
Plant Name	Country	Year	Plant Description	Steam Production [t/h]	Steam Pressure [kPa]	Steam Temperature [C]	Generation [GWh/Yr]	Generation [MW]	Installed Capacity [MW]	CO2 Reduction [T/Yr]	Capital Investment	Investment per MW	Reference
TKCSA Siderúrgica do Atlântico	Brazil	2009	Gas recovery, gas combusted in gas turbine, sinter plant, blast furnace and steelworks. BOF Production: 5 Mil tons per annum						90.00	186,455.00	R 531,387,638.22	R 5,904,307.09	(UNFCCC, 2008)
Nanjing Iron and Steel Co., Ltd	China	2009	Gas recovery from two converters: 2 x 120t Process Gas will also be fired in boilers	440.00	9,800.00	540.00		20.4MW	100.00	105,681.00			(UNFCCC, 2009)
Anyang Iron and Steel Co., Ltd.	China	2008	Gas recovery from four converters: 1 x 100t 1 x 120t 2 x 150t Gas Available: 878 Mil Nm <sup>3</sup>	200.00	3,820.00	450.00	280.00		43.50	264,932.00	R 266,485,737.08	R 6,126,108.90	(UNFCCC, 2007)
Hangang Group HanBao Iron&Steel Co	China	2009	BFG and BOF Gas will be used in boiler BFG Surplus - 1,530,998,107 Nm <sup>3</sup> per year BOF Gas Surplus - 124,800,000 Nm <sup>3</sup> per year	780.00	9,800.00	540.00	617.76		180.00	977,684.00	R 967,977,725.85	R 5,377,654.03	(UNFCCC, 2008)

**Table B.3 - BOF Gas Recovery Systems Installation Data from the Clean Development Mechanism Project Design Documents**

UNFCCC, 2007. *Angang Waste Gas Recovery and Generation Project*. CDM PPD. Yindu District, Anyang City: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *Hangang Group HanBao Iron&Steel Co., Ltd. Waste Gas Cogeneration Project*. CDM PPD. Handan City: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *Recovery of Basic Oxygen Furnace gas (BOF gas) at TKCSA, in Rio de Janeiro, Brazil*. CDM PPD. Municipality of Rio de Janeiro: UNFCCC Clean Development Mechanism.

UNFCCC, 2009. *NISCO Converter Gas Recovery and Utilization for Power Generation Project*. CDM PPD. Nanjing City: UNFCCC Clean Development Mechanism.

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Waste Heat Recovery Systems Installation Data from the Clean Development Mechanism Project Design Documents												
Plant Name	Country	Year	Plant Information	Steam Pressure [kPa]	Steam Temperature [C]	Steam Production [t/hr]	Generated Power [MW]	CO2 Reduction [T/Yr]	Anual Generation [GWh]	Capital Investment	Investment per MW	Reference
Bhushan Power and Steel Limited	India	2008	Flue Gas per Kiln 120,000 Nm <sup>3</sup> /hr at 950 C Four Kilns	8,629.85	520.00	4 x 51	45.00		233.02	R 113,606,108.20	R 2,524,580.18	(UNFCCC, 2008)
Mono Steel India Ltd	India	2008	Flue Gas temperature 900 - 950 C	6,400.00	485.00	2 x 13	5.1 (6 MW installed)	409,130.00		R 43,910,833.41	R 7,318,472.24	(UNFCCC, 2007)
Electrotherm at Kutch	India	2008	Turbine already installed, this is only the inclusion of WHRB Flue Gas Flow Rate: 158400 Nm <sup>3</sup> /h	6,500.00	490.00	1 x 28.5 1 x 42	10.1 Assuming continuous operation and 90% availability	93,231.00	0.08			(UNFCCC, 2007)
Companhia Siderúrgica do Atlântico	Brazil	2009	Waste Heat Recovery From Non-Recovery Coke Ovens. Project Includes 12 Boilers	10,500.00	520.00	535.00	150.00	339,122.00	1,320.00	R 1,708,474,581.68	R 11,389,830.54	(UNFCCC, 2008)
Adhunik Metaliks Limited	India	2009	Flue Gas Flow Rate: 24000 Nm <sup>3</sup> /hr per Kiln Five Kilns Flue Gas temperature: 950 C	6,570.46	485.00	50.00	10.7 (17 MW installed)	80,065.00	69.49	R 71,221,128.48	R 4,189,478.15	(UNFCCC, 2009)
Sri Ramrupai Balaji Steel Limited	India	2006	Flue Gas Flow Rate: 24000 Nm <sup>3</sup> /hr Kiln Four Kilns Flue Gas temperature: 900 C	8,531.79	515.00	40.00	9.60	51,504.00	62.20			(UNFCCC, 2006)
Flat Steel Products Rolling Mill	NA	2009	Preheating oven exhaust gas - ORC Technology	NA	NA	NA	2.40	12,096.00	0.19	R 42,809,871.20	R 17,837,446.33	ORC (Vescovo, 2009)

**Table B.4 - Waste Heat Recovery Systems Installation Data from the Clean Development Mechanism Project Design Documents**

UNFCCC, 2006. SRBSL - *Waste Heat Recovery based Captive Power Generation*. CDM PPD. Banskopa Village: UNFCCC Clean Development Mechanism.

UNFCCC, 2007. *Electrotherm 30 MW combined waste heat recovery and coal based captive power plant at Kutch*. CDM PPD. Samikhiyali Village, Bhachau Taluk: UNFCCC Clean Development Mechanism.

UNFCCC, 2007. *Waste heat recovery and captive power generation at Mono Steel India Ltd, Gujarat, India*. CDM PPD. Gandhidham: UNFCCC Clean Development Mechanism.

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UNFCCC, 2008. *Bhushan Power and Steel Limited–Waste Heat Recovery based Captive Power Project*. CDM PPD. Thelkoloi Village, Post Lapanga, Rengali Tehsil, Sambalpur District, Orissa: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *Heat Recovery Coking Plant at TKCSA, in Rio de Janeiro, Brazil*. CDM PPD. Municipality of Rio de Janeiro: UNFCCC Clean Development Mechanism.

UNFCCC, 2009. *Waste Heat Recovery Based Captive Power Project of Adhunik Metaliks Limited*. CDM PPD. Kuarmunda: UNFCCC Clean Development Mechanism.

Vescovo, R., 2009. ORC Recovering Industrial Heat. Cogeneration and On-Site Power Production, March. p.54.

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Sinter Waste Heat Recovery Systems Installation Data from the Clean Development Mechanism Project Design Documents													
Plant Name	Country	Year	Plant Description	Steam Pressure [kPa]	Steam Temperature [C]	Steam Production [t/hr]	Generation [MW]	Installed Capacity [MW]	CO2 Reduction [t/Yr]	Annual Generation [GWh]	Capital Investment	Investment per MW	Reference
Shanxi Taigang Stainless Steel Co., Ltd	China	2009	Flue 425 & 65,000 Nm <sup>3</sup> /h per Boiler 2 Boilers and 1 Turbine	2,050.00	396.00	140.00	32.00		194,717.00	210.00	R 246,824,907.97	R 7,713,278.37	(UNFCCC, 2008)
Anyang Iron and Steel Co., Ltd	China	2008	Flue 375 , and the flow rate is 400,000 m <sup>3</sup> /h~500,000 m <sup>3</sup> /h	2,160.00	355.00	96.00	26.55		103,303.00	106.00	R 198,160,459.06	R 7,463,670.77	(UNFCCC, 2010)
Philippine Sinter Corporation	Philippines	2008	700,000Nm <sup>3</sup> /h 450°C	2,130.00	380.00		18.60		61,702.00	117.06			(UNFCCC, 2006)
Hunan VALIN Xiangtan Iron & Steel Co., Ltd	China	2011	about 25×104 Nm <sup>3</sup> /h (380 ) Exhaust gas from the boiler will be sent to sinter machine	1,800.00	330.00	22.00	4.39	4.50	116,295.00	29.50	R 198,389,120.00	R 8,097,515.10	(UNFCCC, 2010)
			650000 Nm <sup>3</sup> /h (420)	2,200.00	360.00	92.00	16.40	20.00		106.86			

**Table B.5 - Sinter Waste Heat Recovery Systems Installation Data from the Clean Development Mechanism Project Design Documents**

UNFCCC, 2006. *Philippine Sinter Corporation Sinter Cooler Waste Heat Recovery Power Generation Project*. CDM PPD. Phividec Industrial Estate, Villanueva: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *Shanxi Taigang Stainless Steel Co., Ltd. Sinter Machine Waste Heat Recovery and Generation Project*. CDM PPD. Taiyuan City: UNFCCC Clean Development Mechanism.

UNFCCC, 2010. *Angang Sinter Machine Waste Heat Recovery and Generation Project*. CDM PPD. Yindu District, Anyang City: UNFCCC Clean Development Mechanism.

UNFCCC, 2010. *Sinter Waste Heat Recovery for Power Generation in Hunan VALIN Xiangtan Iron & Steel Co., Ltd*. CDM PPD. Xiangtan city/ Yuetang Town: UNFCCC Clean Development Mechanism.

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CCGT Installation Data from the Clean Development Mechanism Project Design Documents										
Plant Name	Country	Year	Additional Information	Boilers				Gas Turbine Generator		
				Steam Pressure [kPa]	Steam Temperature [C]	Steam Production [t/hr]	Steam Generated Power [MW]	Exhaust Flow [t/h]	Exhaust Temp [C]	Turbine Generated Power [MW]
Schering-Plough Ltd	Singapore	2010	Waste Heat Recovered 494327 GJ/yr			24 t/h 8.5 t/h for heating and remainder for absorbtion chilling				
Beijing No.3 Thermal Power Plant	China	2007		HP - 10280 IP - 3420 LP - 441	HP - 538 IP - 566 LP - 249.7	HP - 287.4 IP - 313.8 LP - 53.2		2,409.10	587.00	
PT ASTA Keramasan Energi	Indonesia	2009					45.00		503.00	100.00
Termonorte CCGT Project	Brazil	2008	Convert from OCGT to CCGT				117.40			
Zhumadian Zhongyuan Power Plant	China	2009		HP - 12185 IP - 2903 LP - 0.33	HP - 564.4 IP - 549.4 LP - 237	HP - 260.104 IP - 308.19 LP - 43.132	133.80	2,396.50	586.50	243.40
Al-Samra Electric Power Generating Company	Jordan	2009					100.00			200.00
Gul Ahmed Combined Cycle Gas Turbine Project	Pakistan	2008		4,200.00			30.00	3.50		10.30
Power Plant in Liangang Group	China	2007	BFG fired 910.8 million Nm <sup>3</sup> per annum	6,100.00	485.00		76.00	22.00		28.50

**Table B.6 - CCGT Installation Data from the Clean Development Mechanism Project Design Documents**

Plant Name	Country	Year	Additional Information	Generation [MW]	Total Installed Capacity [MW]	CO2 Reduction [T/Yr]	Anual Generation [GW]	Capital Investment	Investment per MW	Reference
Schering-Plough Ltd	Singapore	2010	Waste Heat Recovered 494327 GJ/yr		9.78	23,123.00				(UNFCCC, 2009)
Beijing No.3 Thermal Power Plant	China	2007			406.83	633,341.00	1,400.00	R 1,761,312,550.54	R 4,329,357.60	(UNFCCC, 2007)
PT ASTA Keramasan Energi	Indonesia	2009			145.00	271,953.00	889.14			(UNFCCC, 2008)
Termonorte CCGT Project	Brazil	2008	Convert from OCGT to CCGT		117.40	304,085.00		R 90,941,747.53	R 774,631.58	(UNFCCC, 2007)
Zhumadian Zhongyuan Power Plant	China	2009		2 x 377.2	2 x 400	858,165.00	2,640.40			(UNFCCC, 2009)
Al-Samra Electric Power Generating Company	Jordan	2009			300.00	162,806.00		R 1,765,391,969.21	R 5,884,639.90	(UNFCCC, 2008)
Gul Ahmed Combined Cycle Gas Turbine Project	Pakistan	2008			13.80	35,089.00		R 60,423,333.21	R 4,378,502.41	(UNFCCC, 2007)
Power Plant in Liangang Group	China	2007	BFG fired 910.8 million Nm <sup>3</sup> per annum		50.00	331,675.00	351.50	R 492,054,432.59	R 9,841,088.65	(UNFCCC, 2007)

**Table B.7 - CCGT Installation Data from the Clean Development Mechanism Project Design Documents**

UNFCCC, 2007. *Beijing No.3 Thermal Power Plant Gas-Steam Combined Cycle Project using Natural Gas*. CDM PPD. Fengtai District: UNFCCC Clean Development Mechanism.

UNFCCC, 2007. *Gul Ahmed Combined Cycle Gas Turbine Project*. CDM PPD. Landhi Industrial Area – Karachi 75120: UNFCCC Clean Development Mechanism.

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UNFCCC, 2007. *Termonorte CCGT Project*. CDM PPD. Porto Velho Municipality: UNFCCC Clean Development Mechanism.

UNFCCC, 2007. *Waste Gas based Captive Power Plant in Liangang Group*. CDM PPD. Loudi City: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *PT ASTA Keramasan Energi - 145 MW new build CCGT*. CDM PPD. Keramasan, Palembang, South Sumatra: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *Samra 300 MW combined cycle project*. CDM PPD. Al-Hashimyah Town: UNFCCC Clean Development Mechanism.

UNFCCC, 2009. *Natural gas based captive thermal and power generation project at Singapore*. CDM PPD. UNFCCC.

UNFCCC, 2009. *Zhumadian Zhongyuan Gas-Steam Combined Cycle Power Project in Henan China*. CDM PPD. Zhumadian City: UNFCCC Clean Development Mechanism.

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CDQ Installation Data from the Clean Development Mechanism Project Design Documents															
Plant Name	Country	Year	Coke Oven Scale	Coke Oven Capacity	CDQ Capacity	Steam Pressure [kPa]	Steam Temperature [C]	Steam Production [t/hr]	Generation [GWh/Yr]	Generation [MW]	Installed Capacity [MW]	CO2 Reduction [T/Yr]	Capital Investment	Investment per MW	Reference
Laiwu Iron & Steel Group Corp	China	2008	No.1 - 2x55room Height 6m No.2 - 2x60room Height 6m No.3 - 2x60room Height 6m No.4 - 1x42 room Height 4.3m & 1x52room Height 4.3m	No.1 - 126 t/h No.2 - 137 t/h No.3 - 137 t/h No.4 - 70.78 t/h	No.1 - 140 t/h No.2 - 140 t/h No.3 - 140 t/h No.4 - 140 t/h	4,200.00	450.00		316.80	50.00	60.00	326,309.00	R 515,722,400.38	R 8,595,373.34 (UNFCCC, 2008)	
Jinan Iron and Steel Group Corporation	China	2008		150 t/h	9,800.00	450.00	79.00	176.78	21.35	25.00	167,055.00	R 194,398,280.57	R 7,775,931.22 (UNFCCC, 2008)		

**Table B.8 - CDQ Installation Data from the Clean Development Mechanism Project Design Documents**

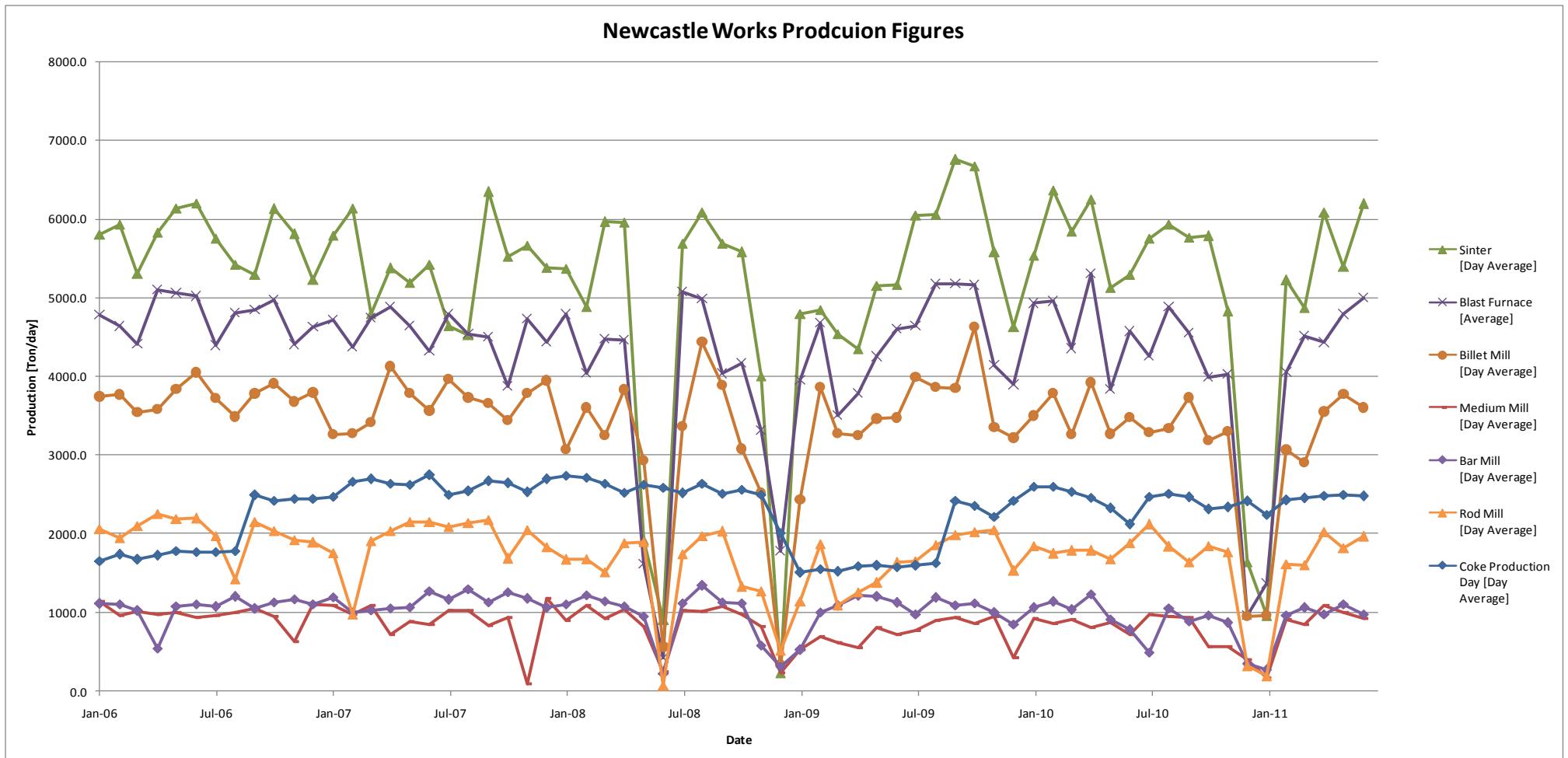
UNFCCC, 2008. *Captive power generation through waste heat recovery system in a steel plant in Jinan City, China.* CDM PPD. Jinan City: UNFCCC Clean Development Mechanism.

UNFCCC, 2008. *Coke Dry Quenching (CDQ) Waste Heat Recovery for Power Generation Project of Laiwu Iron & Steel Group Corp.* CDM PPD. Laiwu City: UNFCCC Clean Development Mechanism.

## **Appendix C**

### **The ArcelorMittal Newcastle Case**

### Appendix C.1 – Newcastle Works Production Figures



**Figure C. 1- ArcelorMittal Newcastle Works Daily Production Figures**

## Appendix C.2 – Varying Investment Cost Sensitivity Analysis

Coke Plant:

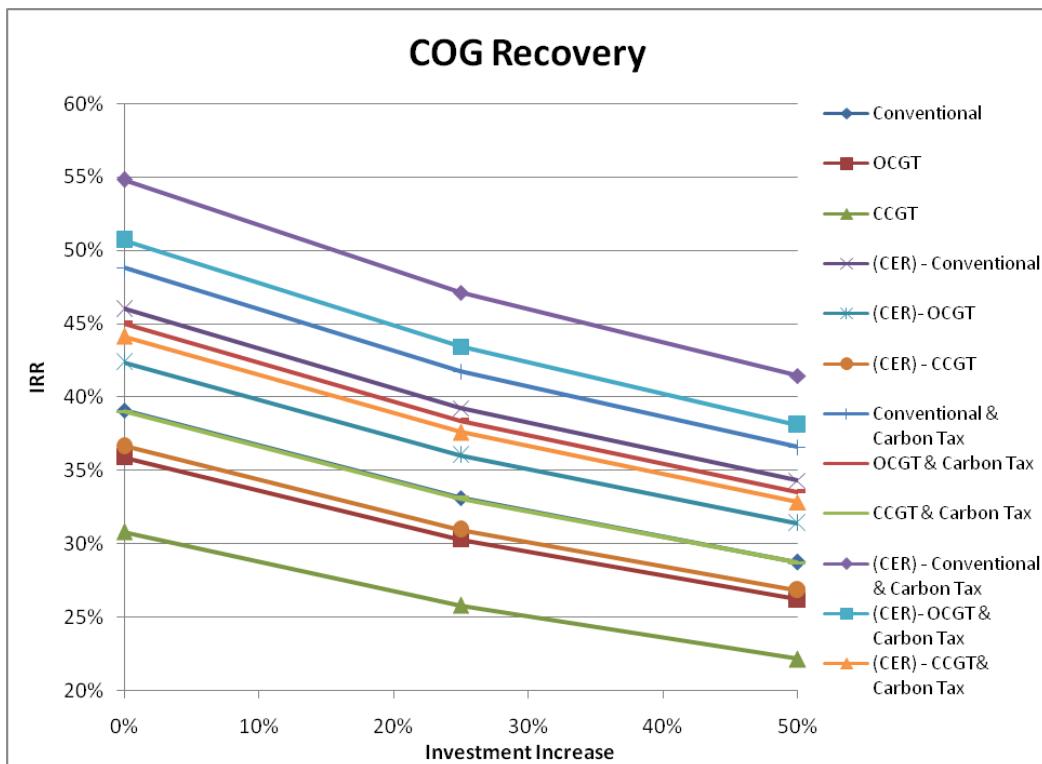


Figure C.2 - COG Recovery IRR vs Incremental Investment Increase

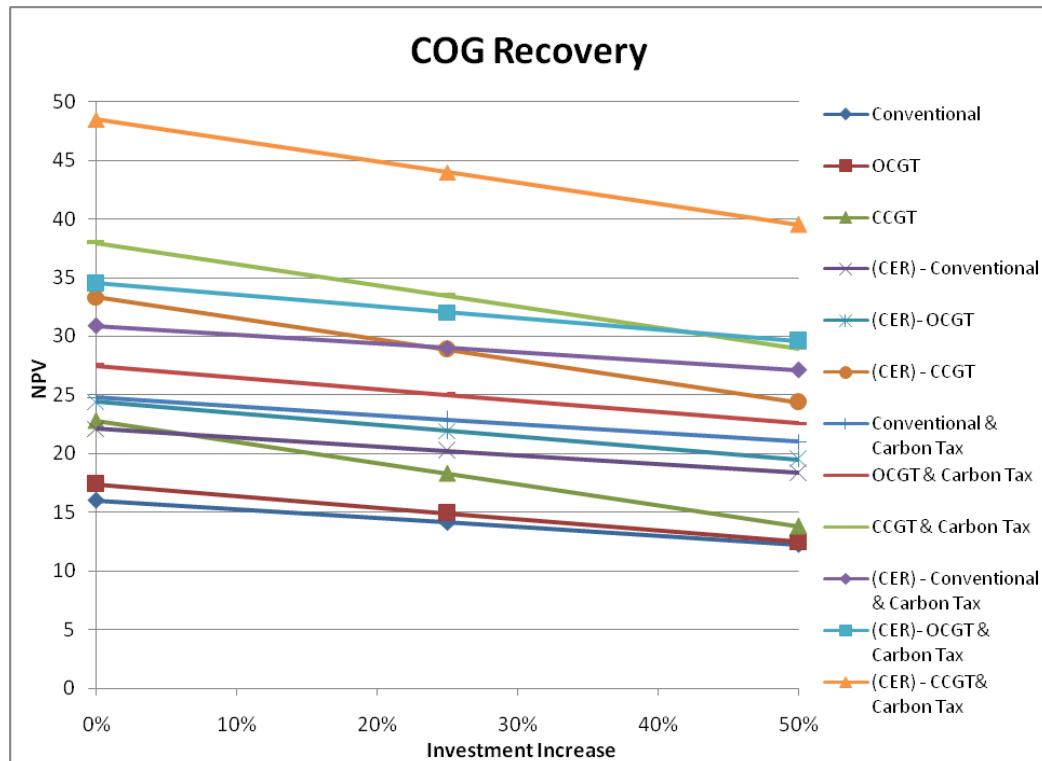


Figure C.3 - COG Recovery NPV vs Incremental Investment Increase

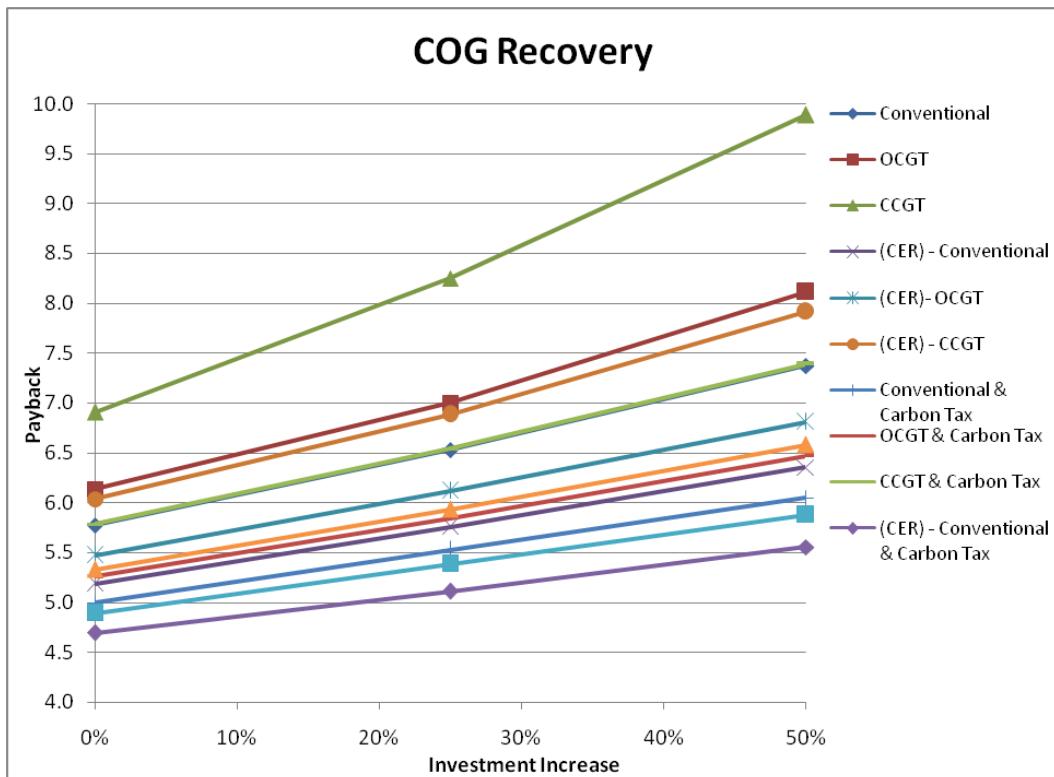


Figure C.4 - COG Recovery Payback vs Incremental Investment Increase

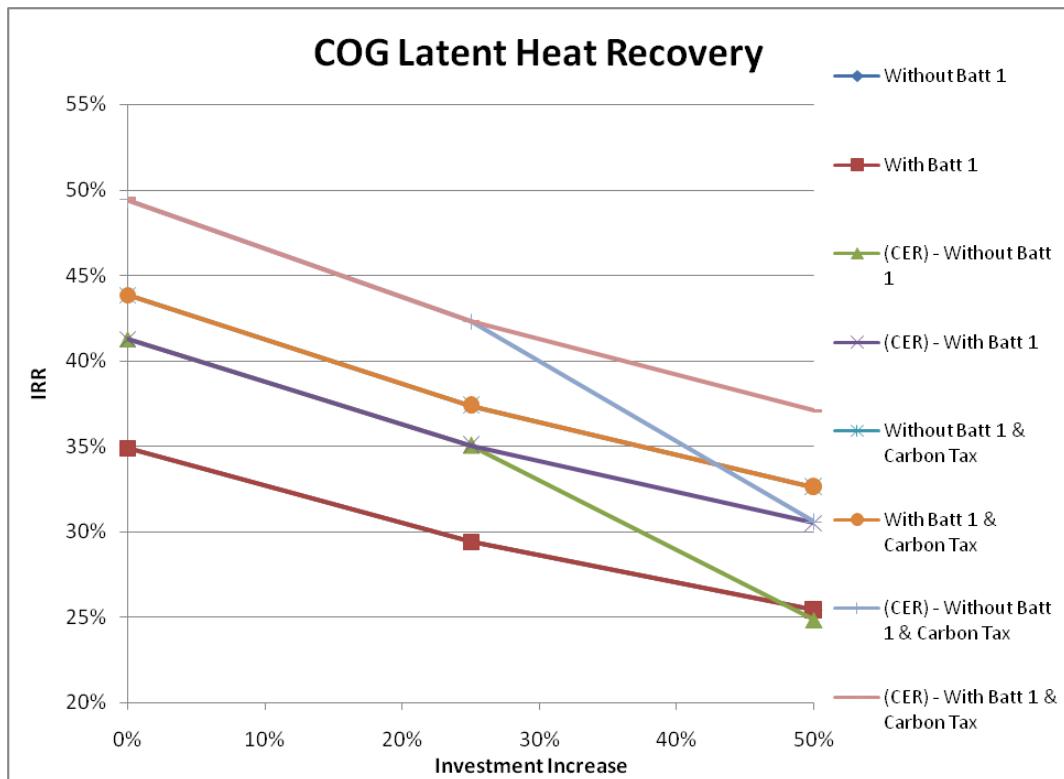


Figure C.5 - COG Latent Heat Recovery IRR vs Incremental Investment Increase

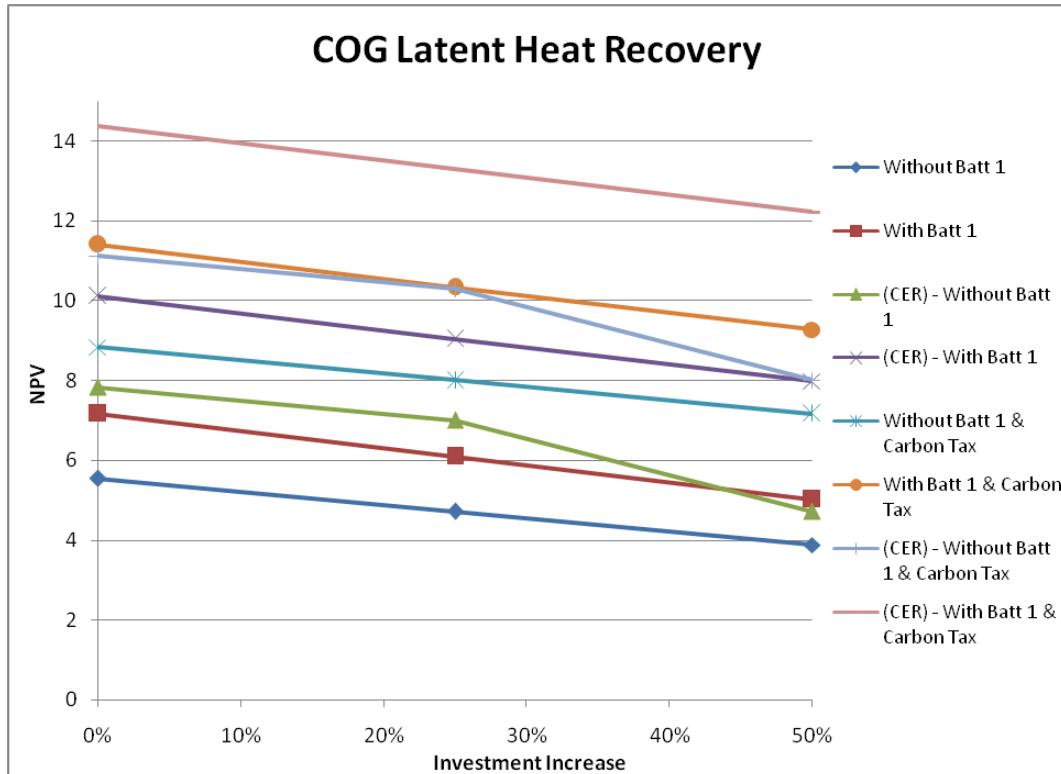


Figure C.6 - COG Latent Heat Recovery NPV vs Incremental Investment Increase

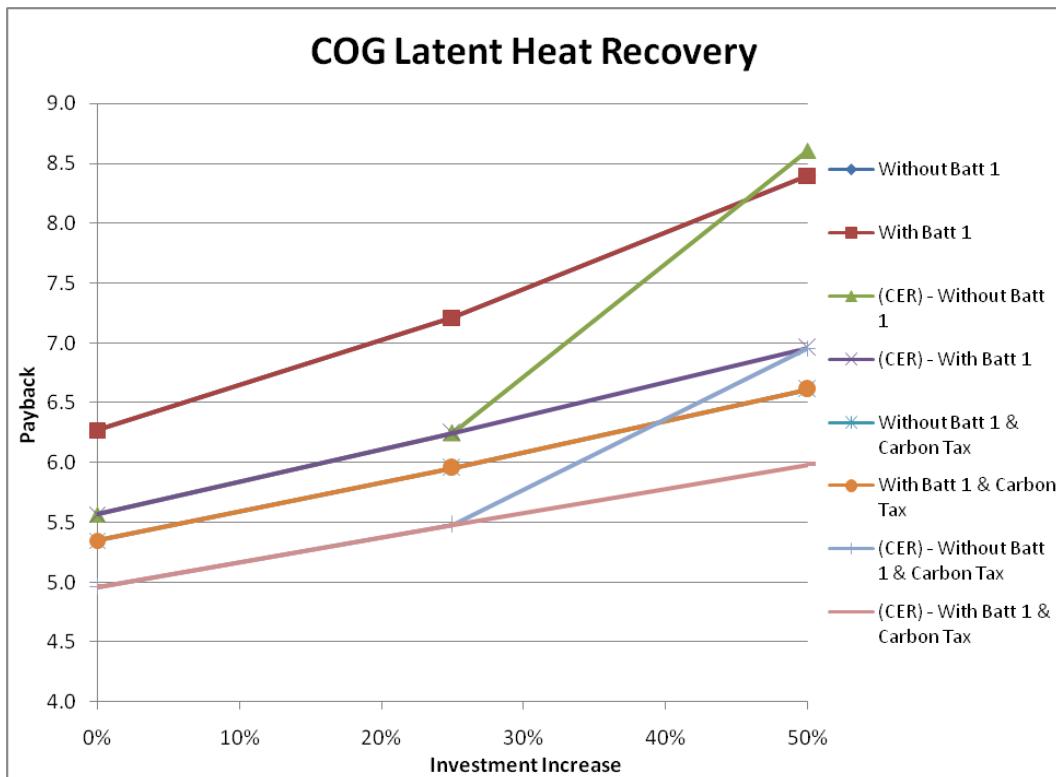
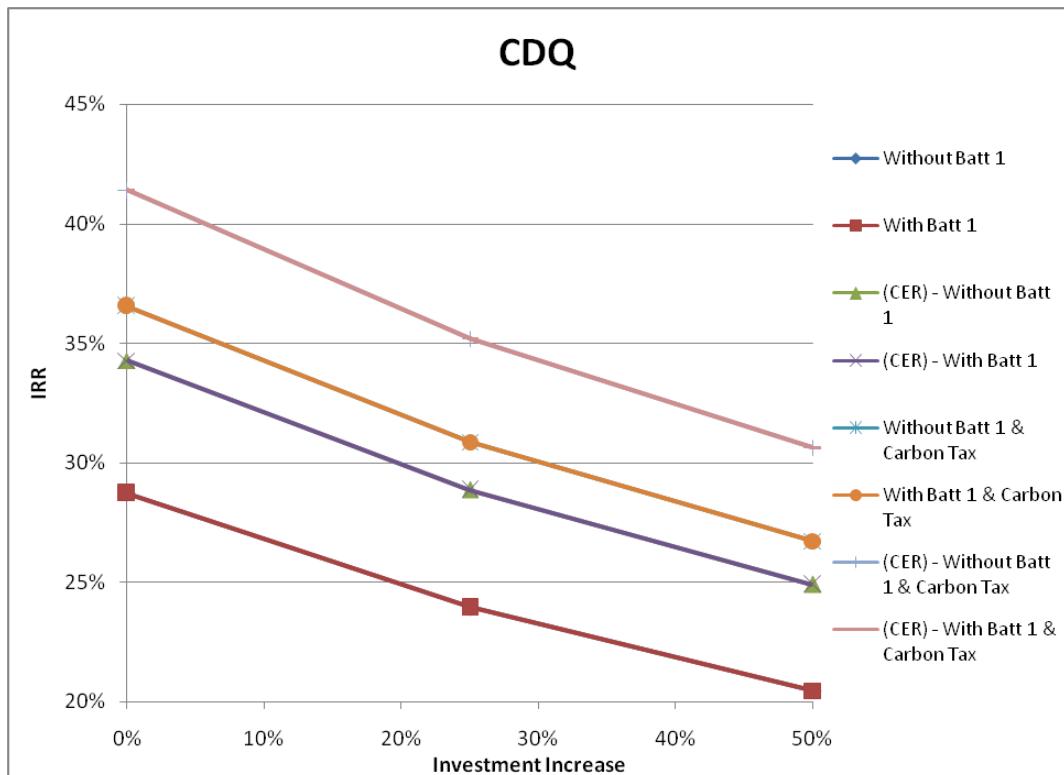
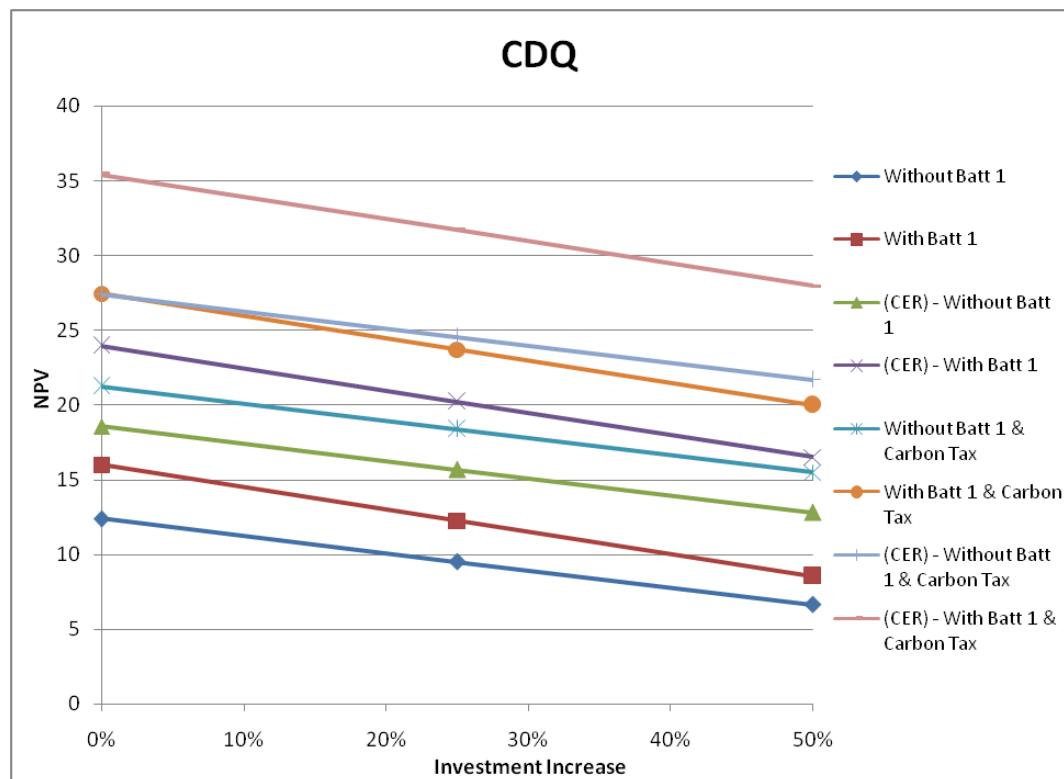


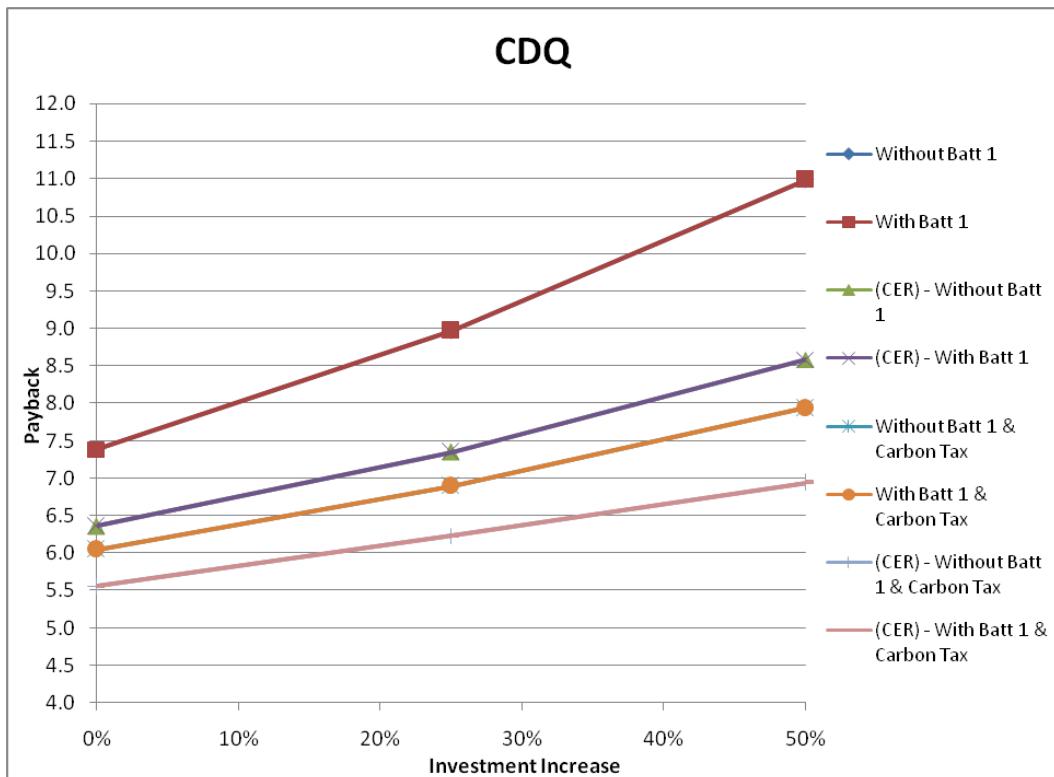
Figure C.7 - COG Latent Heat Recovery Payback vs Incremental Investment Increase



**Figure C.8 - CDQ IRR vs Incremental Investment Increase**

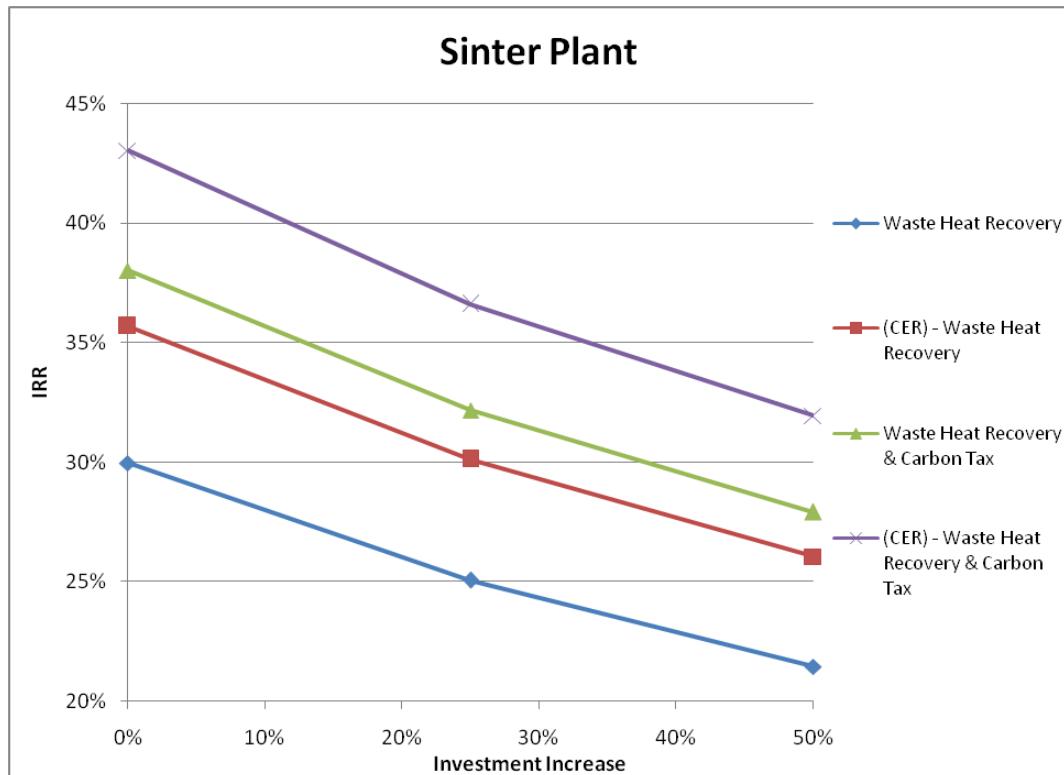


**Figure C.9 - CDQ NPV vs Incremental Investment Increase**

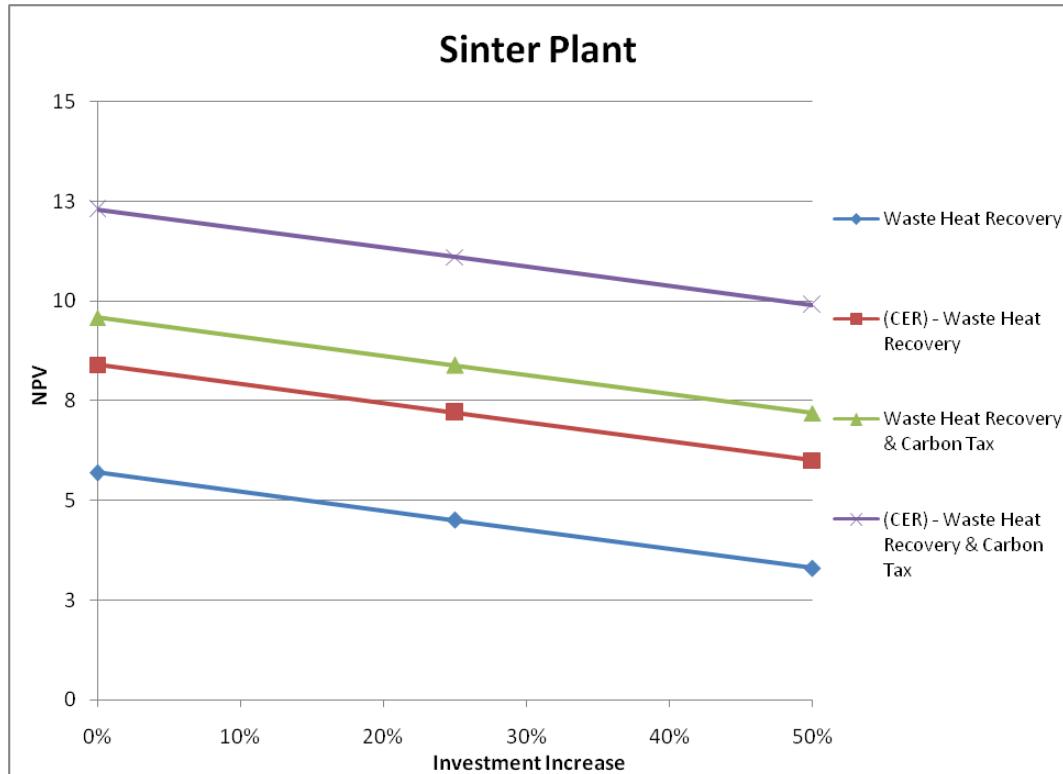


**Figure C.10 - CDQ Payback vs Incremental Investment Increase**

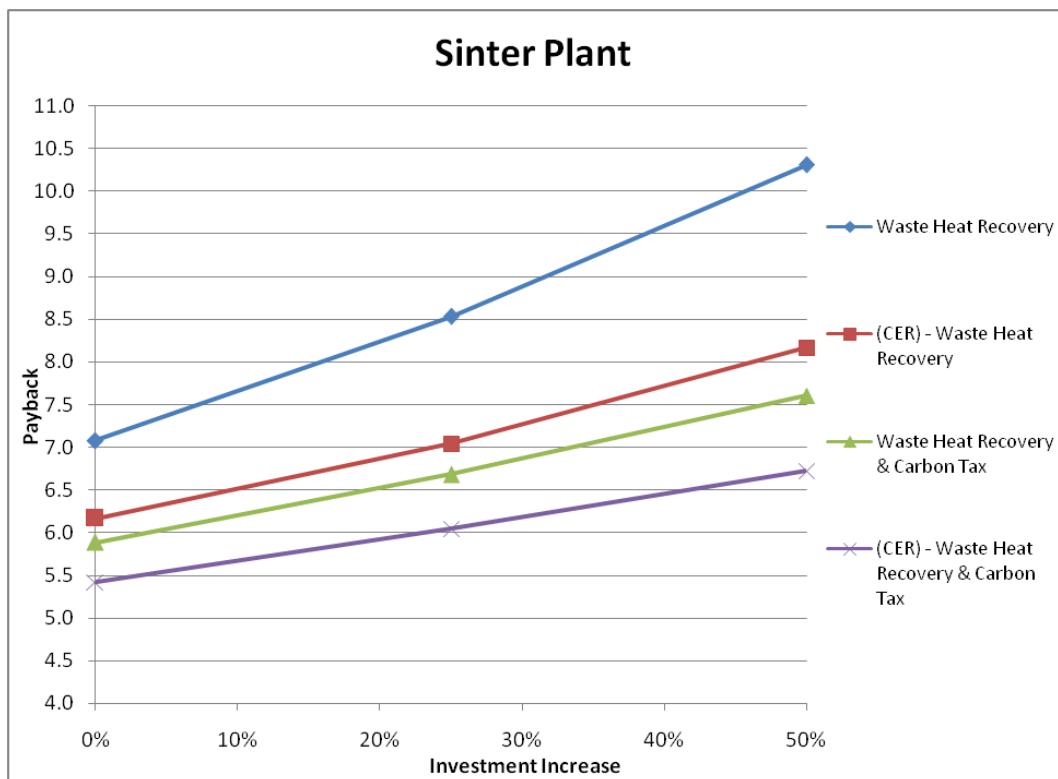
**Sinter Plant:**



**Figure C.11 - Sinter Plant IRR vs Incremental Investment Increase**



**Figure C.12 - Sinter Plant NPV vs Incremental Investment Increase**



**Figure C.13 - Sinter Plant Payback vs Incremental Investment Increase**

**Blast Furnace:**

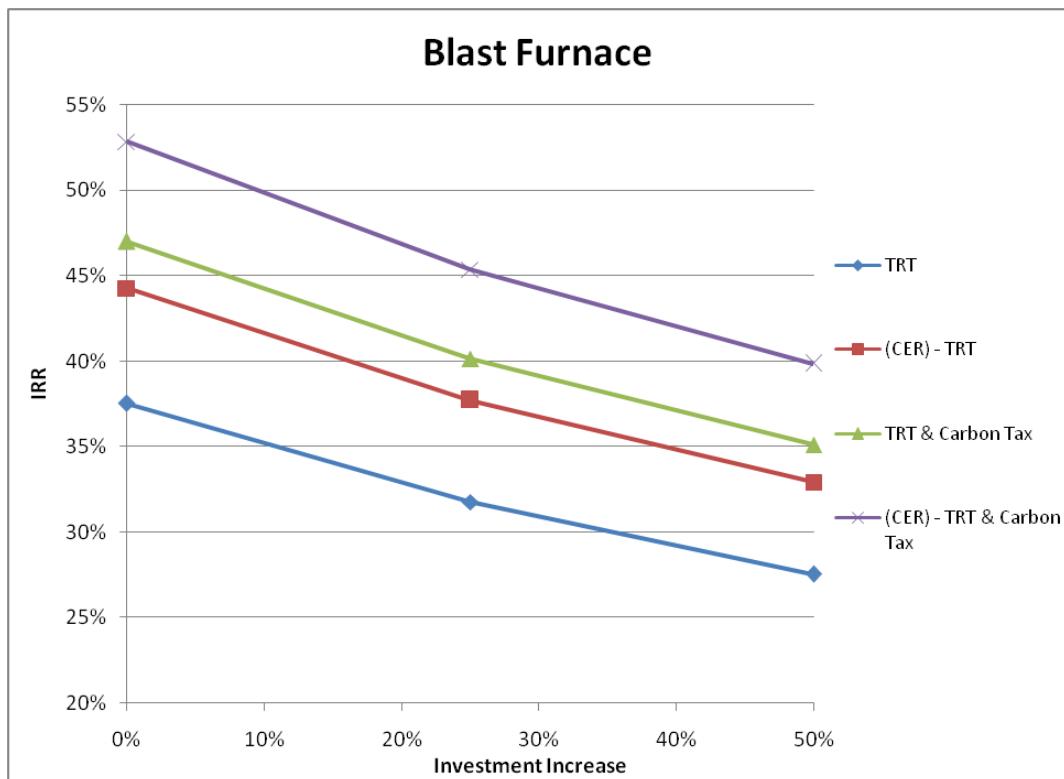


Figure C.14 - Blast Furnace IRR vs Incremental Investment Increase

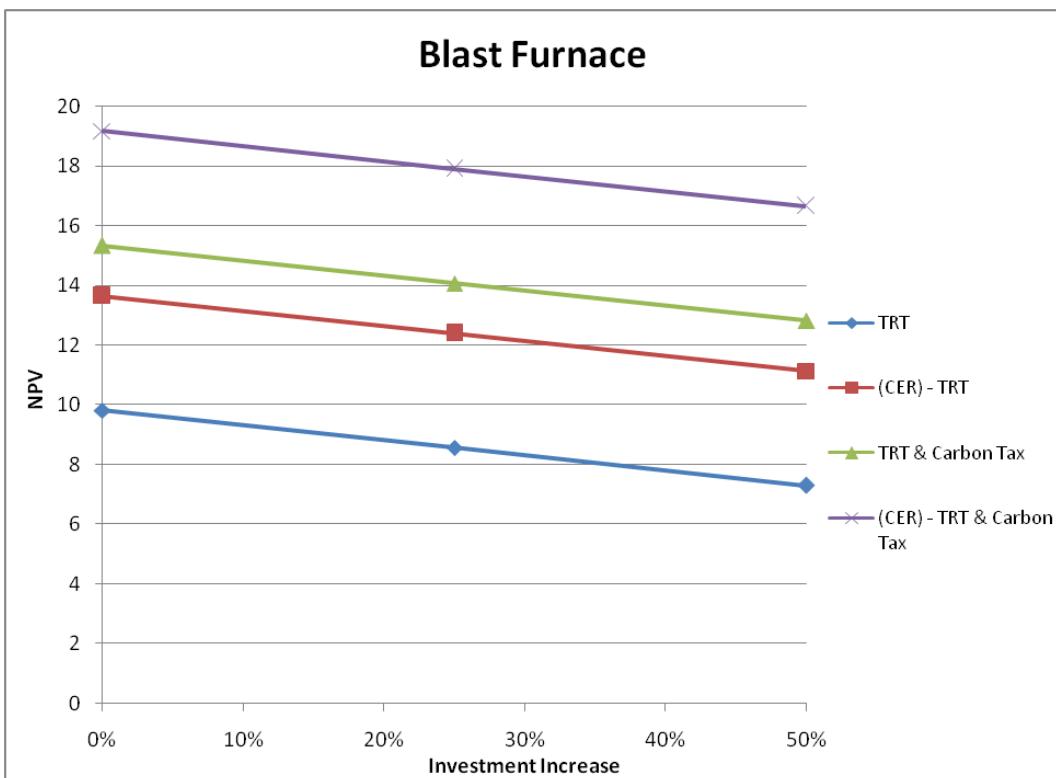


Figure C.15 - Blast Furnace NPV vs Incremental Investment Increase

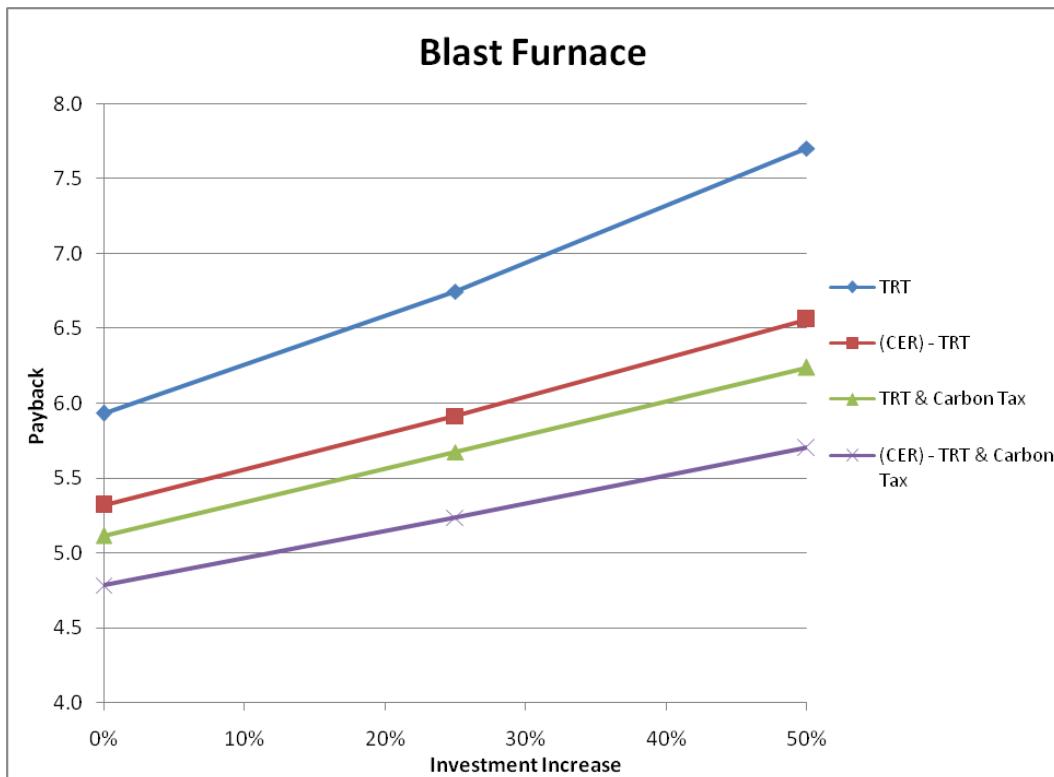


Figure C. 16 - Blast Furnace Payback vs Incremental Investment Increase

**Steel Plant:**

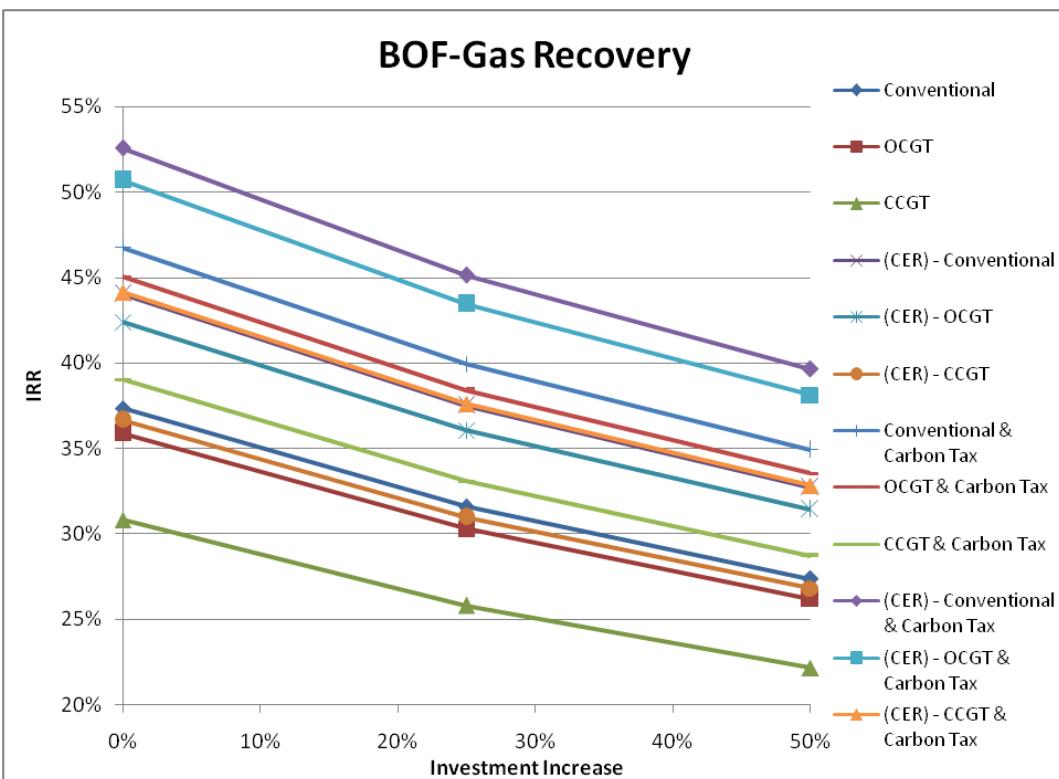
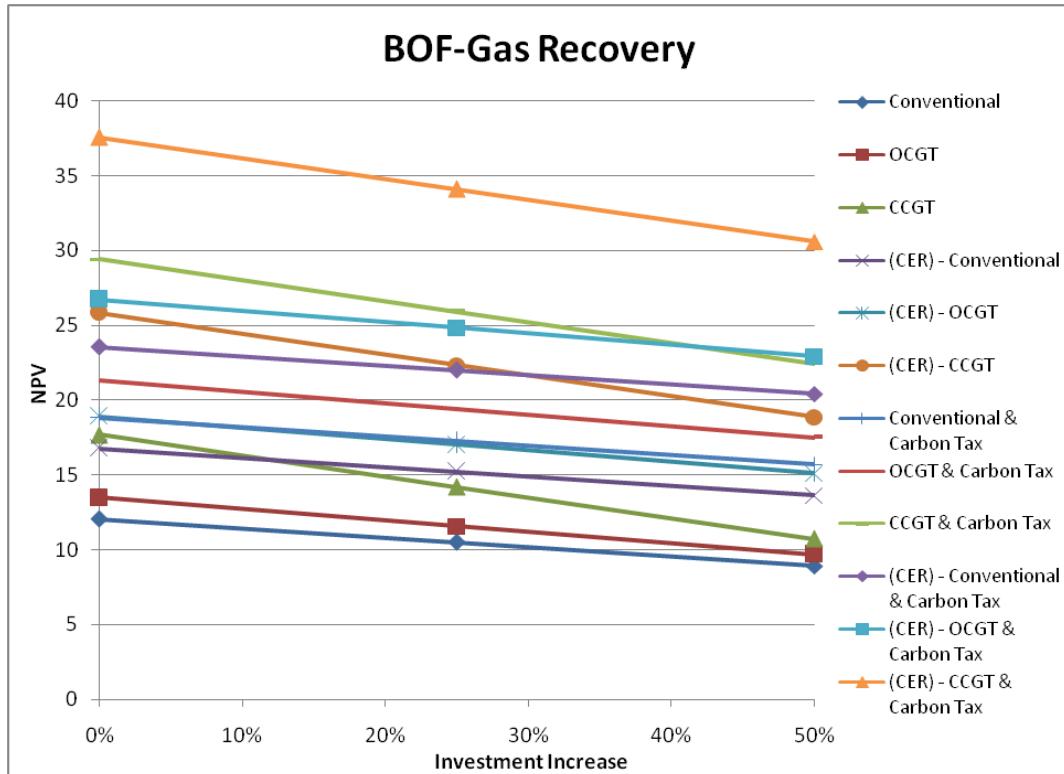
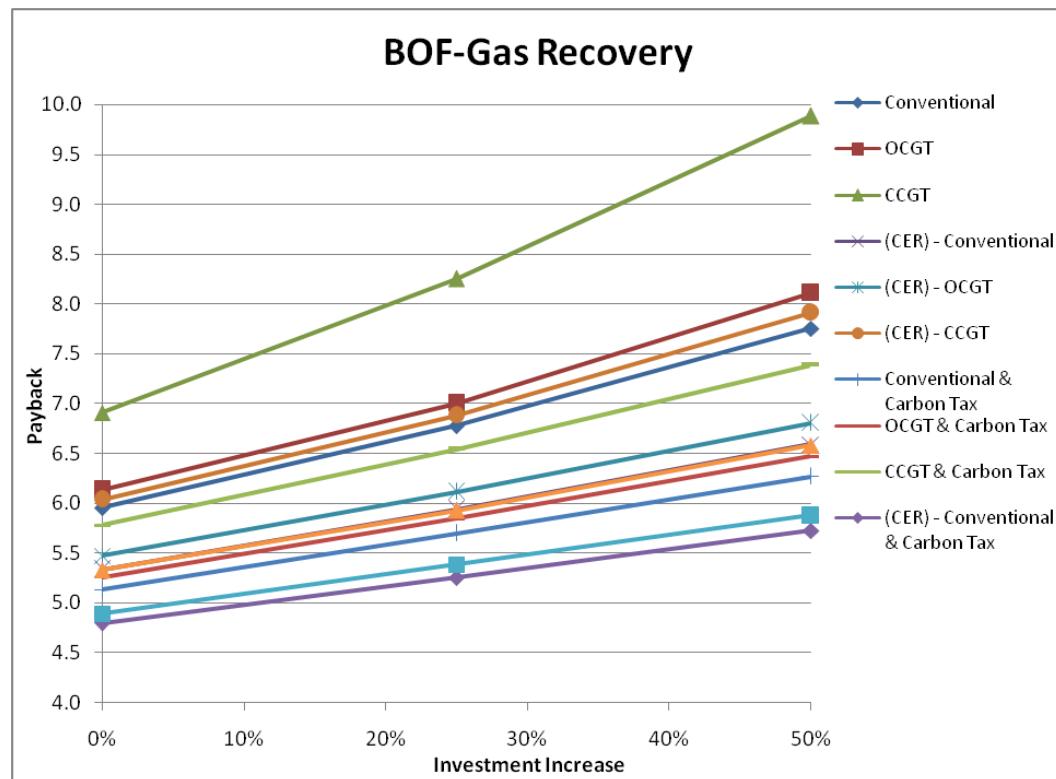


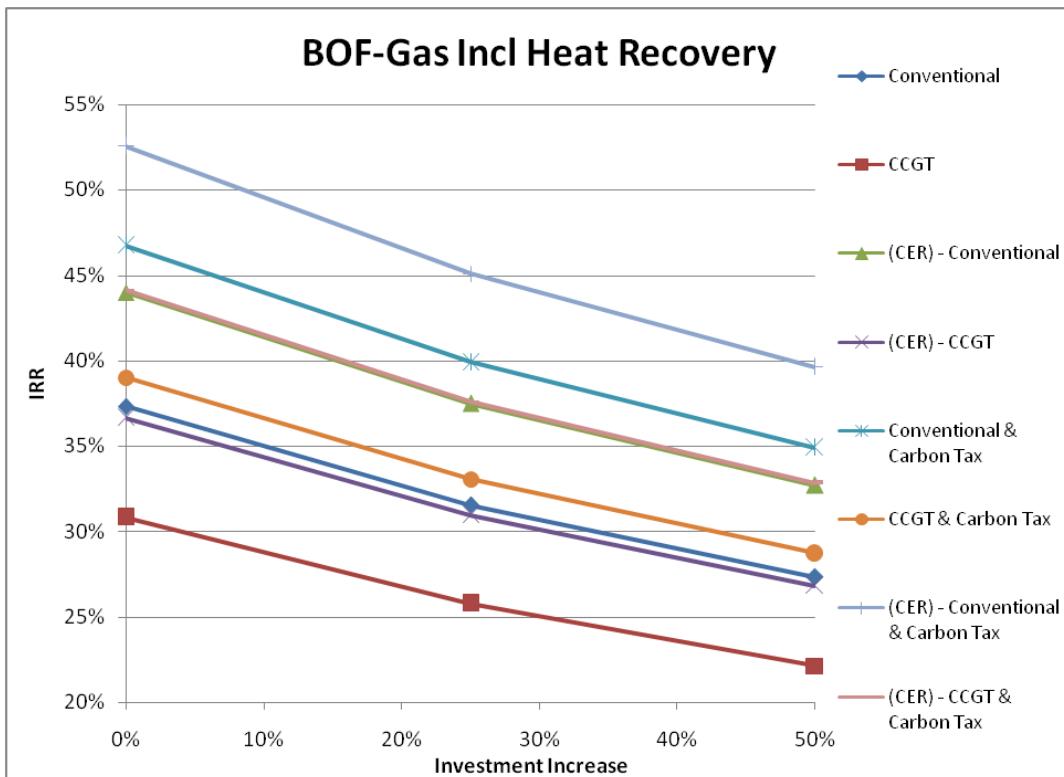
Figure C.17 - BOF Gas Recovery IRR vs Incremental Investment Increase



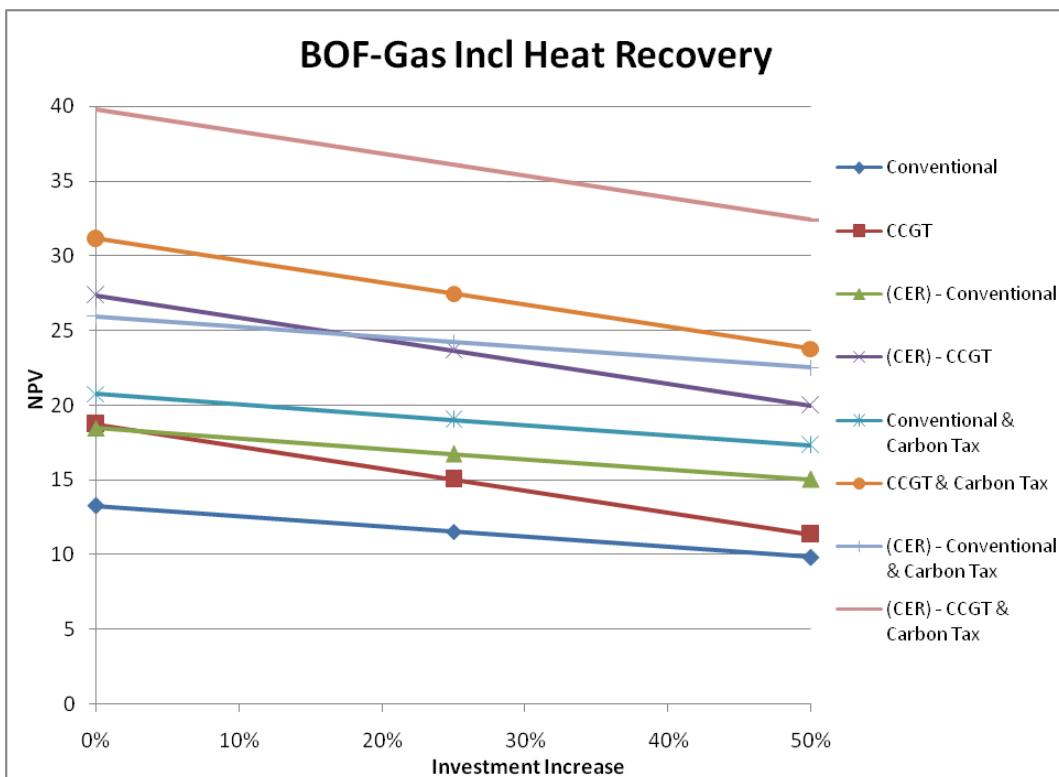
**Figure C.18 - BOF Gas Recovery NPV vs Incremental Investment Increase**



**Figure C.19 - BOF Gas Recovery Payback vs Incremental Investment Increase**

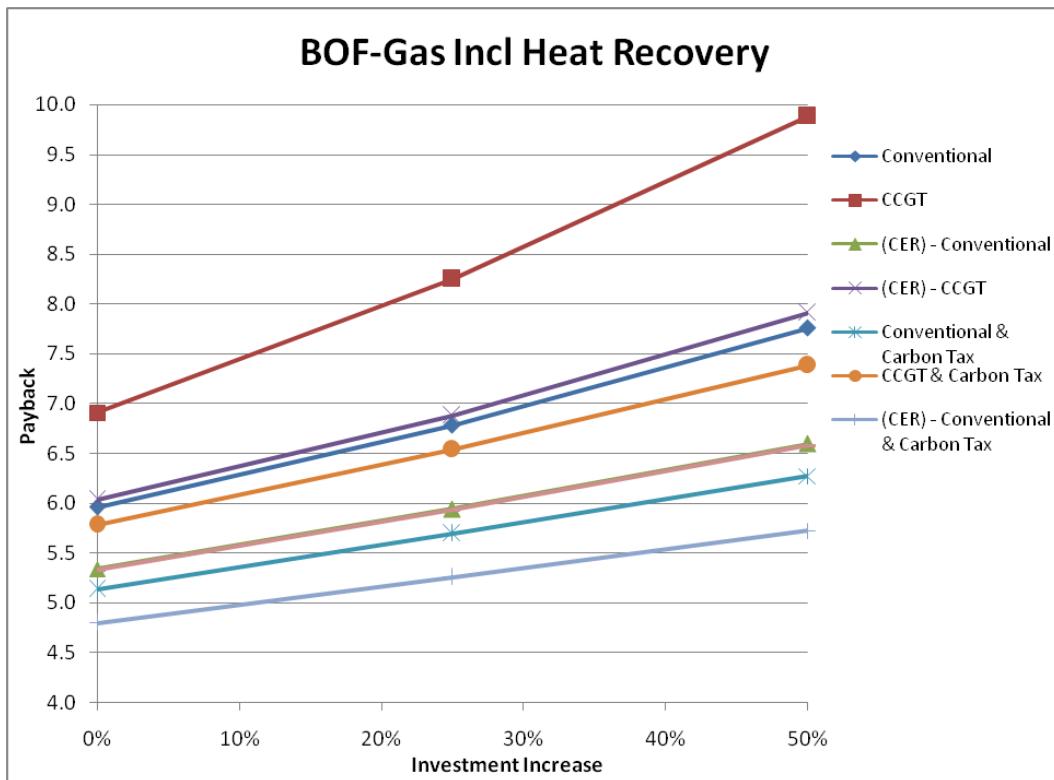


**Figure C.20 - BOF Gas Including Heat Recovery IRR vs Incremental Investment Increase**



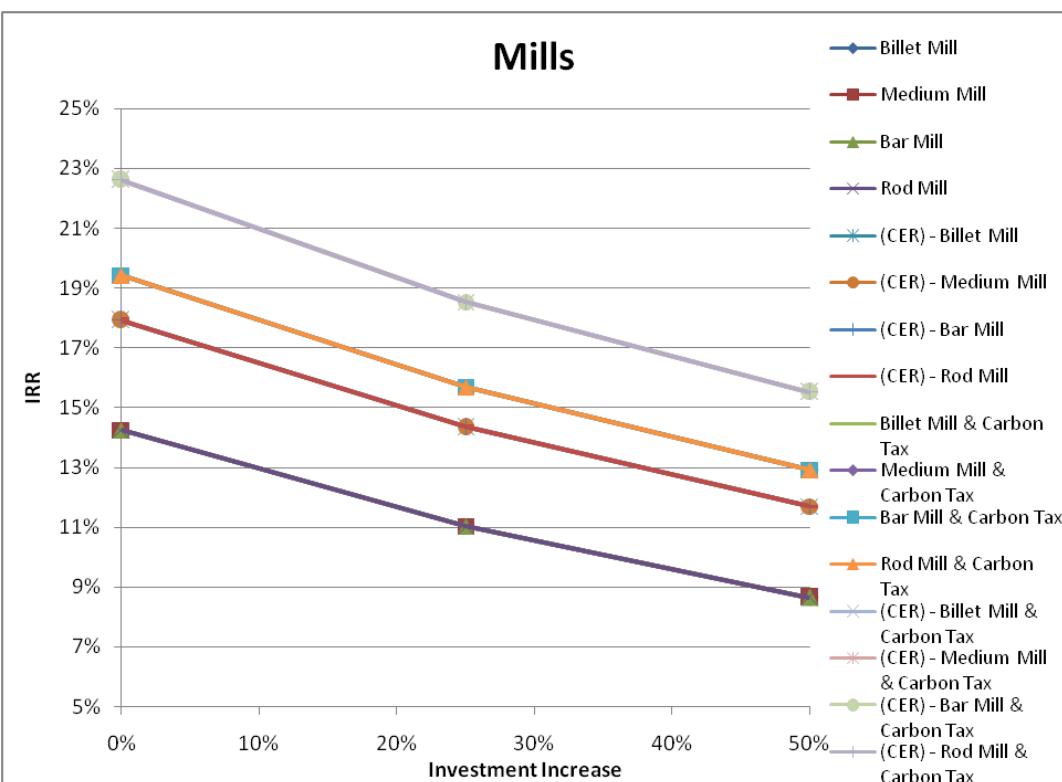
**Figure C.21 - BOF Gas Including Heat Recovery NPV vs Incremental Investment Increase**

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**Figure C.22 - BOF Gas Including Heat Recovery Payback vs Incremental Investment Increase**

**Mills:**



**Figure C.23 - Mills IRR vs Incremental Investment Increase**

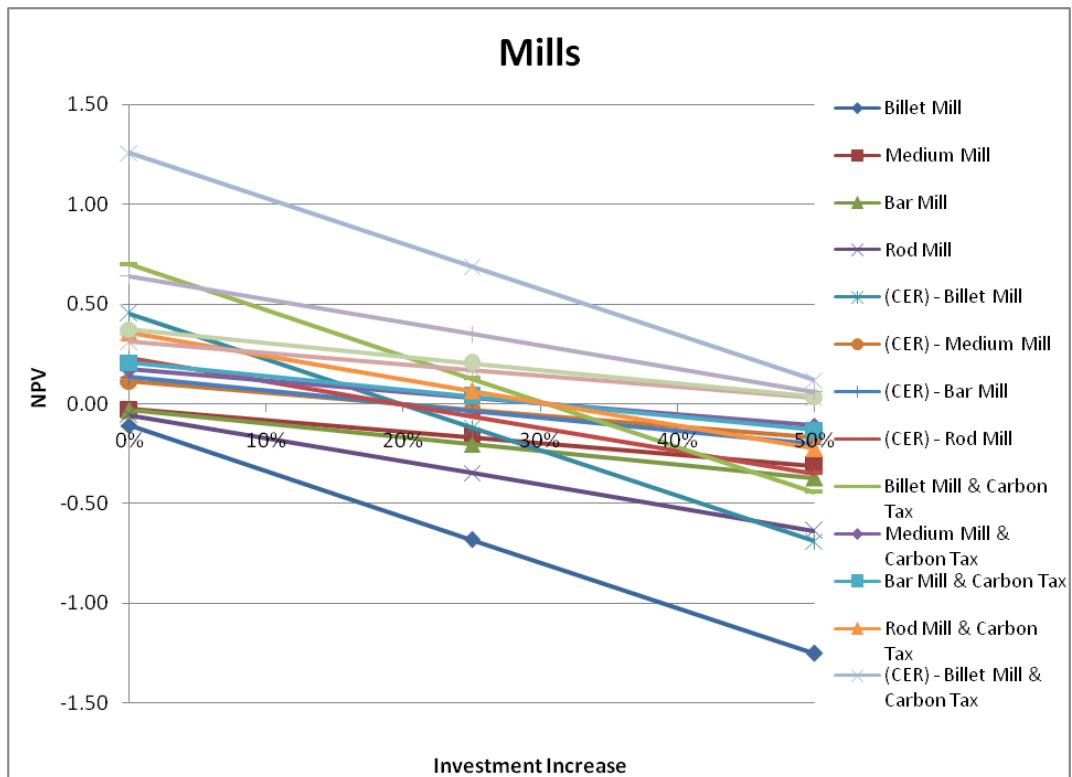


Figure C.24 - Mills NPV vs Incremental Investment Increase

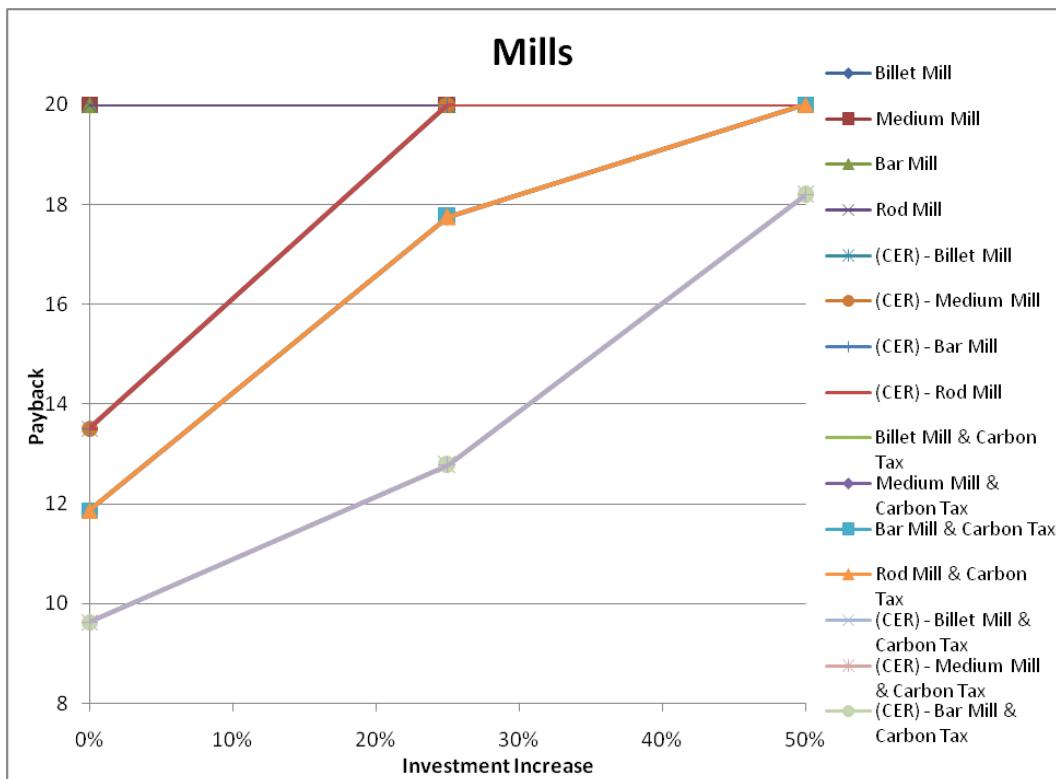
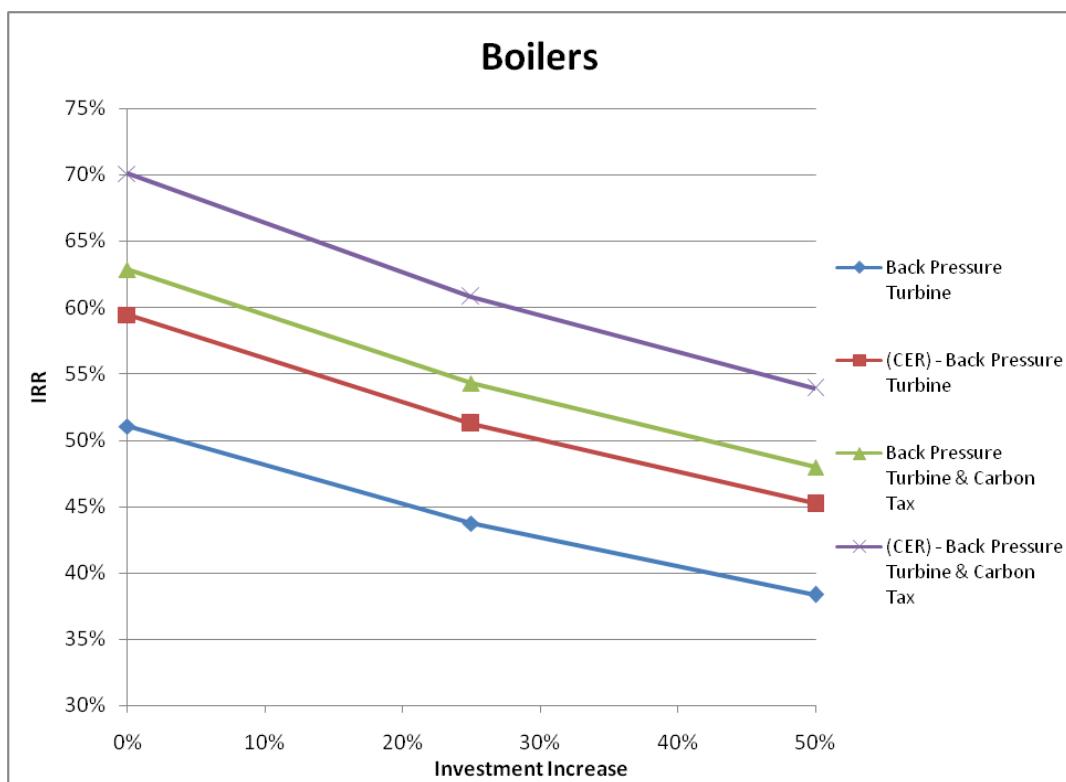
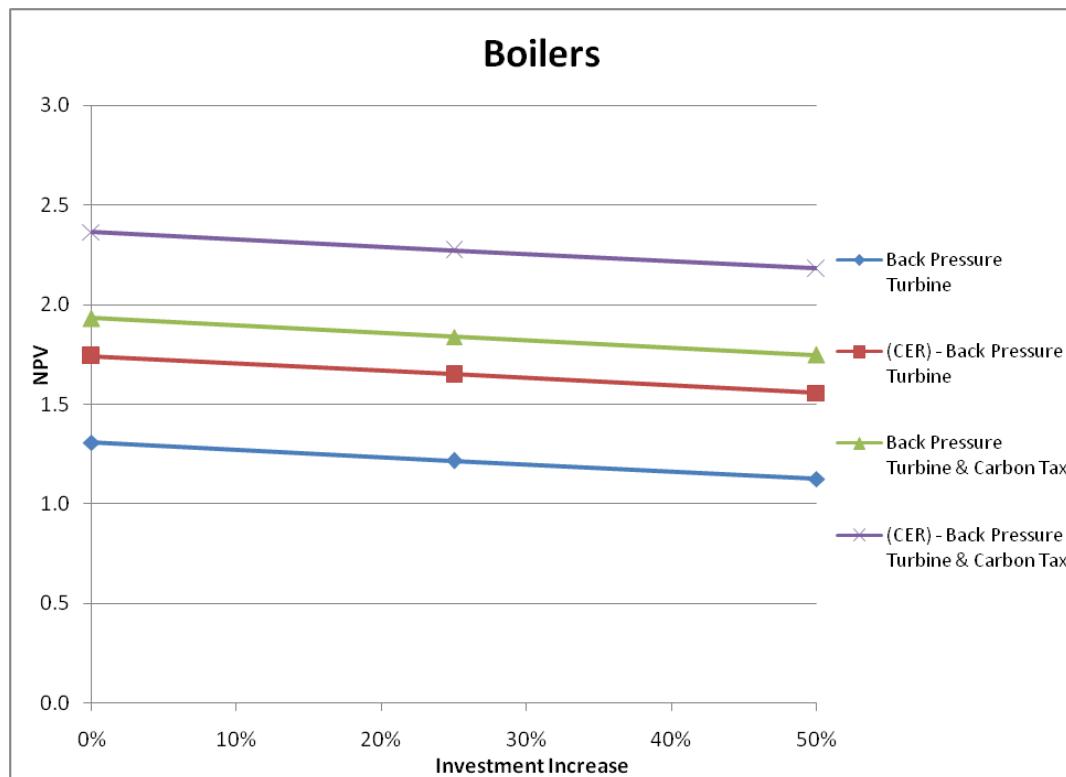


Figure C.25 - Mills Payback vs Incremental Investment Increase

**Boilers:**



**Figure C.26 - Boilers IRR vs Incremental Investment Increase**



**Figure C.27 - Boilers NPV vs Incremental Investment Increase**

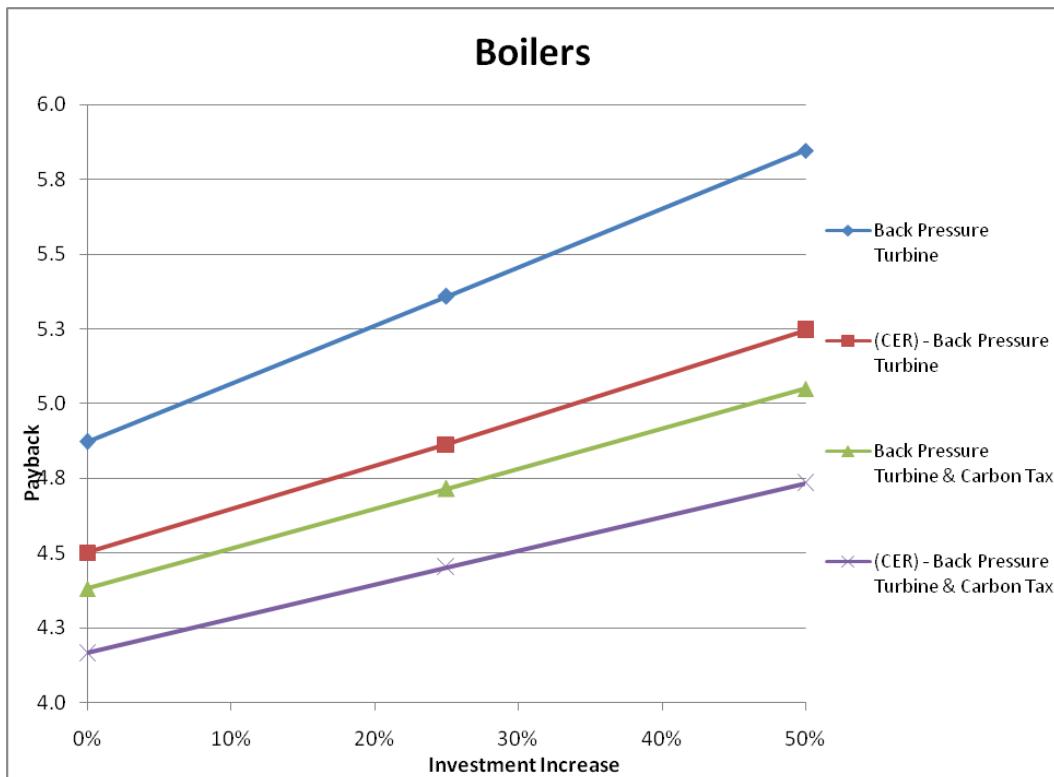


Figure C.28 - Boilers Payback vs Incremental Investment Increase

#### Combined Gas:

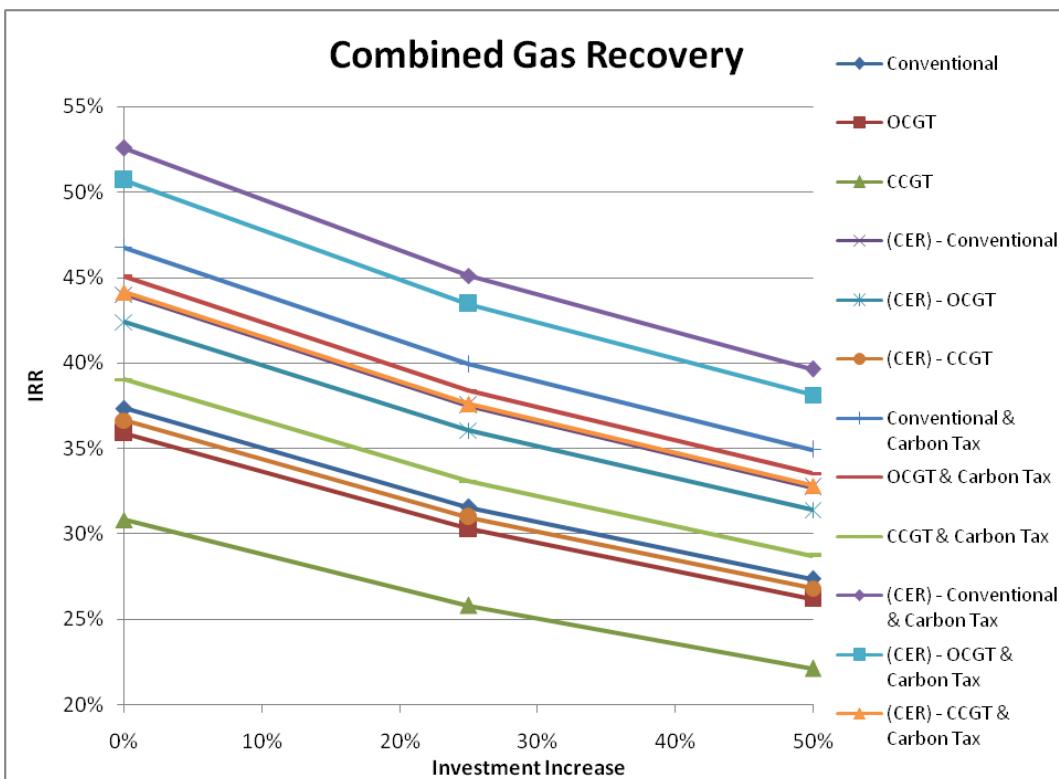


Figure C.29 - Combined Gas IRR vs Incremental Investment Increase

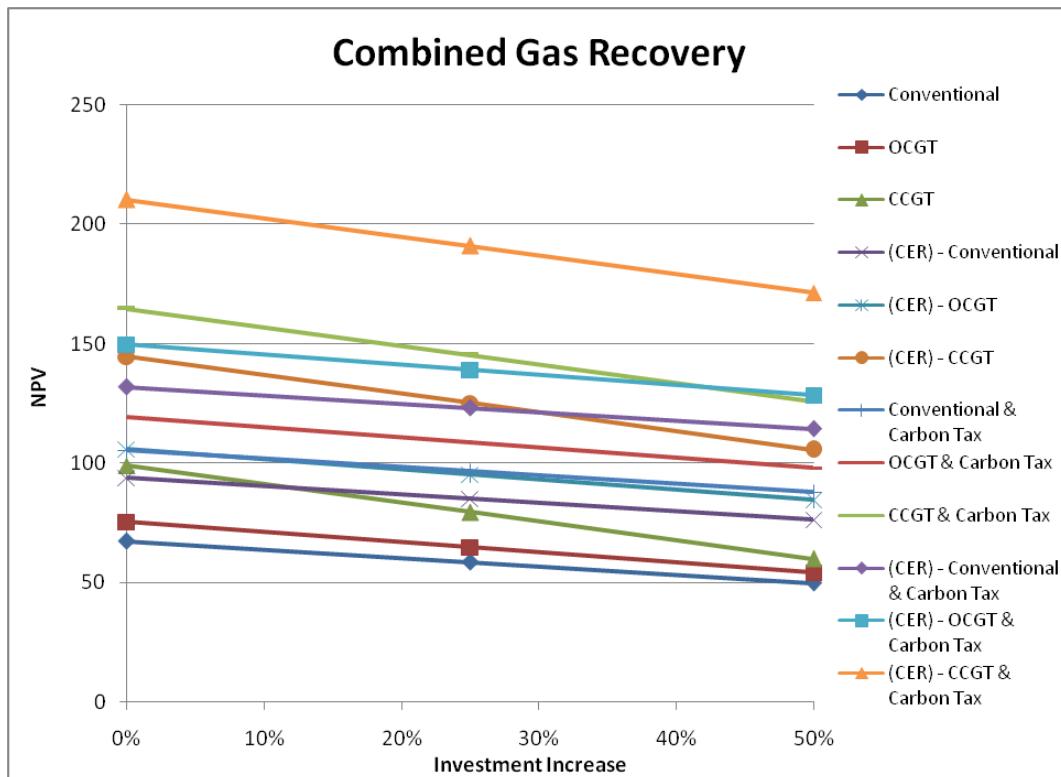


Figure C.30 - Combined Gas NPV vs Incremental Investment Increase

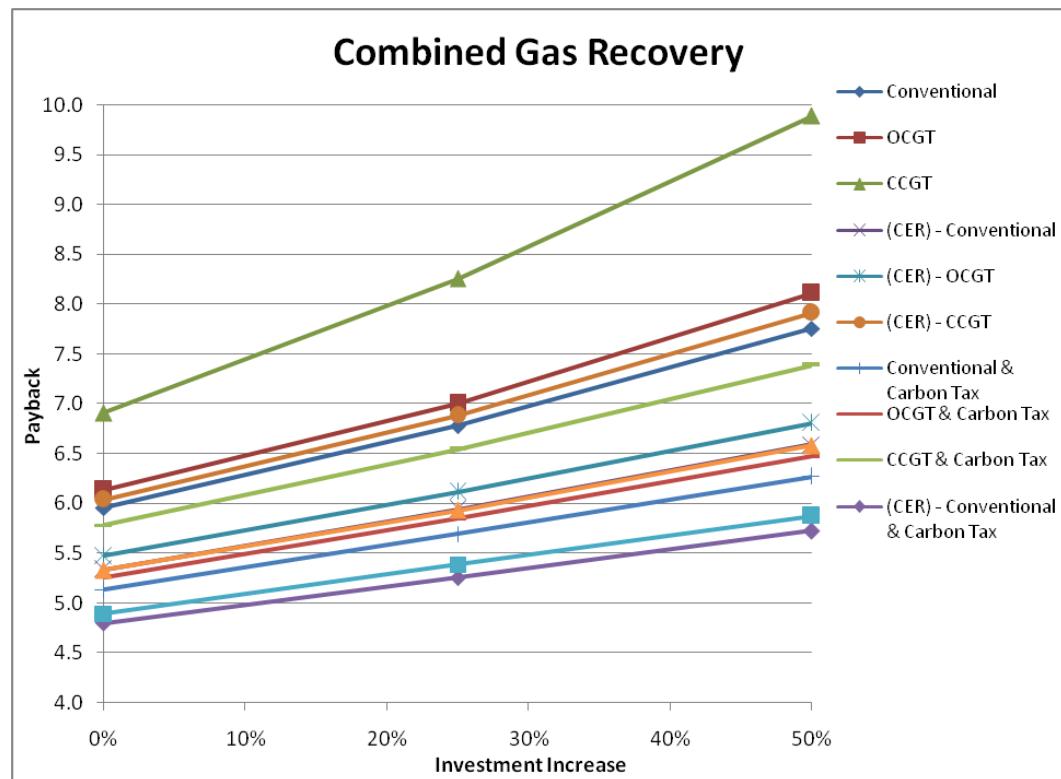


Figure C.31 - Combined Gas Payback vs Incremental Investment Increase

## Appendix C

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	Investment Increases								
	IRR			NPV			Payback		
	0%	25%	50%	0%	25%	50%	0%	25%	50%
<b>COG Recovery</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>
Conventional	39%	33%	29%	16.027	14.134	12.240	5.775	6.531	7.375
OCGT	36%	30%	26%	17.378	14.928	12.479	6.137	7.001	8.112
CCGT	31%	26%	22%	22.801	18.309	13.818	6.907	8.251	9.886
(CER) - Conventional	46%	39%	34%	22.123	20.230	18.336	5.187	5.759	6.354
(CER)- OCGT	42%	36%	31%	24.397	21.948	19.498	5.472	6.116	6.807
(CER) - CCGT	37%	31%	27%	33.331	28.840	24.348	6.038	6.882	7.912
Conventional & Carbon Tax	49%	42%	37%	24.791	22.897	21.004	4.995	5.527	6.046
OCGT & Carbon Tax	45%	38%	34%	27.469	25.019	22.570	5.260	5.846	6.470
CCGT & Carbon Tax	39%	33%	29%	37.939	33.447	28.955	5.782	6.540	7.387
(CER) - Conventional & Carbon Tax	55%	47%	41%	30.887	28.993	27.100	4.692	5.108	5.554
(CER)- OCGT & Carbon Tax	51%	43%	38%	34.488	32.039	29.589	4.893	5.385	5.876
(CER) - CCGT& Carbon Tax	44%	38%	33%	48.469	43.977	39.486	5.329	5.929	6.579
<b>COG Latent Heat Recovery</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>
Without Batt 1	35%	29%	25%	5.542	4.713	3.884	6.271	7.210	8.397
With Batt 1	35%	29%	25%	7.162	6.091	5.020	6.271	7.210	8.397
(CER) - Without Batt 1	41%	35%	25%	7.830	7.001	4.718	5.570	6.250	8.610
(CER) - With Batt 1	41%	35%	31%	10.119	9.048	7.977	5.570	6.250	6.961
Without Batt 1 & Carbon Tax	44%	37%	33%	8.831	8.002	7.173	5.350	5.955	6.614
With Batt 1 & Carbon Tax	44%	37%	33%	11.413	10.342	9.271	5.350	5.955	6.614
(CER) - Without Batt 1 & Carbon Tax	49%	42%	31%	11.118	10.290	8.007	4.961	5.479	6.954
(CER) - With Batt 1 & Carbon Tax	49%	42%	37%	14.369	13.298	12.227	4.961	5.479	5.985
<b>CDQ</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>
Without Batt 1	29%	24%	20%	12.382	9.501	6.620	7.383	8.967	10.985
With Batt 1	29%	24%	20%	15.984	12.265	8.546	7.383	8.967	10.985
(CER) - Without Batt 1	34%	29%	25%	18.556	15.675	12.794	6.360	7.347	8.583
(CER) - With Batt 1	34%	29%	25%	23.955	20.236	16.517	6.360	7.347	8.583
Without Batt 1 & Carbon Tax	37%	31%	27%	21.258	18.377	15.496	6.051	6.898	7.937
With Batt 1 & Carbon Tax	37%	31%	27%	27.442	23.723	20.004	6.051	6.898	7.937
(CER) - Without Batt 1 & Carbon Tax	41%	35%	31%	27.432	24.552	21.671	5.557	6.232	6.940
(CER) - With Batt 1 & Carbon Tax	41%	35%	31%	35.413	31.694	27.975	5.557	6.232	6.940
<b>Sinter Plant</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>
Waste Heat Recovery	30%	25%	21%	5.696	4.498	3.300	7.077	8.531	10.307
(CER) - Waste Heat Recovery	36%	30%	26%	8.405	7.207	6.009	6.164	7.043	8.168
Waste Heat Recovery & Carbon Tax	38%	32%	28%	9.590	8.392	7.194	5.886	6.681	7.602
(CER) - Waste Heat Recovery & Carbon Tax	43%	37%	32%	12.299	11.101	9.903	5.419	6.042	6.722
<b>Blast Furnace</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>
TRT	38%	32%	28%	9.821	8.561	7.302	5.933	6.748	7.706
(CER) - TRT	44%	38%	33%	13.659	12.399	11.140	5.318	5.917	6.563
TRT & Carbon Tax	47%	40%	35%	15.338	14.079	12.819	5.116	5.674	6.241
(CER) - TRT & Carbon Tax	53%	45%	40%	19.176	17.916	16.657	4.784	5.235	5.702
<b>BOF Gas Recovery</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>	<b>0%</b>	<b>25%</b>	<b>50%</b>
Conventional	37%	32%	27%	12.039	10.477	8.915	5.957	6.779	7.754
OCGT	36%	30%	26%	13.467	11.568	9.670	6.137	7.001	8.112
CCGT	31%	26%	22%	17.668	14.187	10.707	6.907	8.251	9.886
(CER) - Conventional	44%	38%	33%	16.763	15.201	13.638	5.337	5.939	6.593
(CER) - OCGT	42%	36%	31%	18.906	17.008	15.110	5.472	6.116	6.807
(CER) - CCGT	37%	31%	27%	25.827	22.347	18.866	6.038	6.882	7.912
Conventional & Carbon Tax	47%	40%	35%	18.830	17.268	15.705	5.134	5.695	6.270
OCGT & Carbon Tax	45%	38%	34%	21.286	19.388	17.490	5.260	5.846	6.470
CCGT & Carbon Tax	39%	33%	29%	29.397	25.917	22.437	5.782	6.540	7.387
(CER) - Conventional & Carbon Tax	53%	45%	40%	23.554	21.992	20.429	4.798	5.254	5.723
(CER) - OCGT & Carbon Tax	51%	43%	38%	26.726	24.828	22.929	4.893	5.385	5.876
(CER) - CCGT & Carbon Tax	44%	38%	33%	37.557	34.076	30.596	5.329	5.929	6.579

**Table C.1 - Investment Increase Sensitivity Analyses Data**

## Appendix C

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	Investment Increases								
	IRR			NPV			Payback		
	0%	25%	50%	0%	25%	50%	0%	25%	50%
<b>BOF Gas Incl Heat Recovery</b>									
Conventional	37%	32%	27%	13.263	11.540	9.818	5.958	6.781	7.757
CCGT	31%	26%	22%	18.710	15.024	11.339	6.907	8.251	9.886
(CER) - Conventional	44%	37%	33%	18.468	16.746	15.023	5.338	5.941	6.595
(CER) - CCGT	37%	31%	27%	27.351	23.665	19.980	6.038	6.882	7.912
Conventional & Carbon Tax	47%	40%	35%	20.746	19.023	17.301	5.135	5.696	6.272
CCGT & Carbon Tax	39%	33%	29%	31.132	27.446	23.760	5.782	6.540	7.387
(CER) - Conventional & Carbon Tax	53%	45%	40%	25.951	24.229	22.506	4.799	5.255	5.725
(CER) - CCGT & Carbon Tax	44%	38%	33%	39.773	36.087	32.401	5.329	5.929	6.579
<b>Mills (ORC)</b>									
Billet Mill	14%	11%	9%	-0.110	-0.681	-1.251	20.000	20.000	20.000
Medium Mill	14%	11%	9%	-0.027	-0.168	-0.310	20.000	20.000	20.000
Bar Mill	14%	11%	9%	-0.033	-0.202	-0.371	20.000	20.000	20.000
Rod Mill	14%	11%	9%	-0.056	-0.347	-0.637	20.000	20.000	20.000
(CER) - Billet Mill	18%	14%	12%	0.452	-0.119	-0.690	13.514	20.000	20.000
(CER) - Medium Mill	18%	14%	12%	0.112	-0.030	-0.171	13.514	20.000	20.000
(CER) - Bar Mill	18%	14%	12%	0.134	-0.035	-0.204	13.514	20.000	20.000
(CER) - Rod Mill	18%	14%	12%	0.230	-0.061	-0.351	13.514	20.000	20.000
Billet Mill & Carbon Tax	19%	16%	13%	0.697	0.126	-0.444	11.866	17.753	20.000
Medium Mill & Carbon Tax	19%	16%	13%	0.173	0.031	-0.110	11.866	17.753	20.000
Bar Mill & Carbon Tax	19%	16%	13%	0.207	0.037	-0.132	11.866	17.753	20.000
Rod Mill & Carbon Tax	19%	16%	13%	0.355	0.064	-0.226	11.866	17.753	20.000
(CER) - Billet Mill & Carbon Tax	23%	19%	16%	1.258	0.688	0.117	9.632	12.775	18.197
(CER) - Medium Mill & Carbon Tax	23%	19%	16%	0.312	0.170	0.029	9.632	12.775	18.197
(CER) - Bar Mill & Carbon Tax	23%	19%	16%	0.373	0.204	0.035	9.632	12.775	18.197
(CER) - Rod Mill & Carbon Tax	23%	19%	16%	0.641	0.350	0.060	9.632	12.775	18.197
<b>Boilers</b>									
Back Pressure Turbine	51%	44%	38%	1.308	1.216	1.125	4.872	5.358	5.846
(CER) - Back Pressure Turbine	59%	51%	45%	1.741	1.649	1.557	4.501	4.863	5.246
Back Pressure Turbine & Carbon Tax	63%	54%	48%	1.931	1.839	1.747	4.380	4.716	5.049
(CER) - Back Pressure Turbine & Carbon Tax	70%	61%	54%	2.364	2.272	2.180	4.165	4.452	4.734
<b>Combined Gas Recovery</b>									
Conventional	0%	25%	50%	0%	25%	50%	0%	25%	50%
OCGT	37%	32%	27%	67.409	58.661	49.914	5.957	6.779	7.754
CCGT	36%	30%	26%	75.400	64.771	54.143	6.137	7.001	8.112
(CER) - Conventional	31%	26%	22%	98.923	79.436	59.948	6.907	8.251	9.886
(CER) - OCGT	44%	38%	33%	93.858	85.110	76.363	5.337	5.939	6.593
(CER) - CCGT	42%	36%	31%	105.857	95.228	84.600	5.472	6.116	6.807
Conventional & Carbon Tax	37%	31%	27%	144.608	125.121	105.633	6.038	6.882	7.912
OCGT & Carbon Tax	45%	38%	34%	119.183	108.555	97.926	5.260	5.846	6.470
CCGT & Carbon Tax	39%	33%	29%	164.598	145.111	125.623	5.782	6.540	7.387
(CER) - Conventional & Carbon Tax	53%	45%	40%	131.880	123.133	114.385	4.798	5.254	5.723
(CER) - OCGT & Carbon Tax	51%	43%	38%	149.640	139.012	128.383	4.893	5.385	5.876
(CER) - CCGT & Carbon Tax	44%	38%	33%	210.283	190.796	171.309	5.329	5.929	6.579

**Table C.2 - Investment Increase Sensitivity Analyses Data**