UNIVERSITY OF CAPE TOWN

Energy Efficiency in the South African Crude Oil Refining Industry: Drivers, Barriers and Opportunities

MSc Sustainable Energy Engineering

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Plagiarism Declaration

"I know the meaning of plagiarism and declare that all of the work in the dissertation, save for that which is properly acknowledged, is my own."

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‘The decisions we make today, individually and collectively, will determine whether the planet goes to hell or goes to Heaven. One thing, however, is sure: we are the transitional generation. The critical choices lie in our hands. Future generations will know who we were. They will think of us often. They will curse us, or they will bless us.’ Marianne Williamson

Acknowledgements

To my father, mother and brother, foremost thanks are to you for your unconditional support and love on this journey, and always. To my best supervisor, Brett, thank you for your all-enduring patience, wisdom and kindness over the past 2 years. Thank you to Nicholas for supporting me with the basics of truth and steadfast advice when it was needed. Also a big thank you to all the people at the Energy Research Centre who helped make this journey of postgraduate life- fun, interesting and thought-provoking. I have so much respect for the community that you are for your abundant enthusiasm and efforts in making South Africa a ‘greener’ and better place.

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Executive Summary

This study has explored a range of barriers, drivers and opportunities to improving energy performance in the South African crude oil refining industry, thus providing information to further support energy efficiency improvement efforts. Energy efficiency is a cost effective means of reducing greenhouse gas emissions and energy costs, bringing additional quality and production benefits.

South Africa is chiefly dependent on fossil fuels for its energy supply and in 2009 was ranked as the 13th highest carbon emitting country in the world. What is more, industry is the largest contributor to final energy consumption, at 32.2% (in 2006) and to national greenhouse gas emissions, a trend which has been projected to continue to 2030.

In December 2009, the President announced that South Africa will implement mitigation actions that will collectively result in a 34% and a 42% deviation below its ‘Business As Usual’ emissions growth trajectory by 2020 and 2025 respectively. This commitment has been restated, with more detail on the target level on emissions reductions, within the National Climate Change White Paper. In addition, the Energy Efficiency Strategy sets a national final energy demand reduction target of 12% by 2015. The sectoral target for Industry and Mining has been set at 15% by 2015 based on a ‘business as usual’ baseline scenario, where South African Petroleum Industry Association (SAPIA) members have entered into this voluntary agreement with the government which acknowledges the final national target.

Refiners worldwide are faced with many challenges which include rising energy costs, increasing refinery energy intensity and increasing fuel quality specifications. These are in addition to the concerns of increasing greenhouse gas emissions and the associated costs and regulatory requirements. Within industry worldwide, energy efficient technologies and best practices are already contributing to reducing energy demand and greenhouse gas emissions. However, literature cites the existence of an ‘energy efficiency gap’, which is said to stem from numerous barriers which remain to impede the uptake of energy best practices and investment in energy efficient technologies. This thesis has provided a sector specific study of the interconnected dynamics which promote and inhibit improvements in energy efficiency. Few such studies currently exist and this thesis adds to current literature in the field of ‘barriers and drivers’ for energy efficiency.

Refinery energy costs are significant, typically 40-50% of operating costs. Therefore energy costs are a major driver for energy efficiency improvement, however South African crude oil refiners are in the last 25% (fourth quartile) in terms of energy efficiency performance (EII ranking) when compared to the refining industry worldwide. Worldwide, the potential for energy improvements in petroleum refineries has been cited to be between 10-25% for industrialised countries and 40-45% for developing countries in 2007. The average improvement potential for different energy efficiency measures were found to range between 41 and 47% in this thesis, however these had large standard error values of between 12 and 14% and this survey was indicative only, as this range could not be extrapolated to the same improvement in overall energy performance. The values have been used as a guideline of the most prominent improvement measures and the large improvement which could be made.

Refineries are differentiated from most other energy intensive industries by the fact that thermal energy requirements constitute a large proportion of these energy costs, with electricity accounting only to the order of 5 to 10% of total energy demand. Opportunities for reducing energy consumption generally arise in areas of utilities (30%), fired heaters (20%), heat exchangers (15%), process optimisation (15%), motor and motor applications (10%), and other areas (10%). Target areas for energy efficiency improvements typically include steam and power systems, and process units such as the crude distillation or FCC units.

It was found that in general, improvements can be made in energy management through behaviour change, improved maintenance (steam traps, insulation etc.) and process control, but significant changes in energy efficiency improvement need capital expenditure. However, most notably, organisational culture change and individual behaviour change for operational excellence were found to be key steps to realising these opportunities.

The most significant barriers impeding the uptake of energy efficient technologies were firstly financial, economic and market barriers. These were most notably: competition for available capital, the slow rate of return of energy efficiency investments compared to other investments and high specific installation costs. Secondly, uncertainty barriers were inhibiting the uptake of energy efficiency technologies quite significantly. These barriers comprised of changing energy prices and the uncertainty in the future of the refineries. Other important barriers included technologies fitting into existing processes and configurations, and the availability of skilled personnel is reduced due to a focus on daily production problems which leaves less time for non-urgent items.

From the findings of this research, the overall recommendations for industry and government include actions of implementing: i) long term government financial incentives ii) information initiatives such as energy audits and training /information transfer, iii) increasing corporate support for organisational energy objectives and iv) organisational culture and individual behaviour change. These recommendations were substantiated from the research findings of the most significant drivers and energy efficiency measures with the greatest improvement potential.

Further recommendations were made to perform sector specific case studies in other energy intensive industries, in efforts to meet national energy and greenhouse gas targets.

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List of Abbreviations

ASD	Adjustable Speed Drive
bbl	Barrel of Crude Oil
CAPEX	Capital Expenditure
CD	Catalytic Distillation
CDU	Crude Distillation Unit
CHP	Combined Heat and Power
CTL	Coal to Liquid
DoE	Department of Energy
DME	Department of Minerals and Energy (now two separate departments – Department of Energy and Department of Mineral Resources)
DTI	Department of Trade and Industry
ESCO	Energy Service Company
FCC	Fluid Catalytic Cracker
GHG	Greenhouse Gas
GTL	Gas to Liquid
HEM	High Efficiency Motor
HRSG	Heat Recovery Steam Generator
HP	High Pressure
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IMO	International Maritime Organisation
KPI	Key Performance Indicator
LP	Low Pressure
MCFC	Molten Carbonate Fuel Cell
MP	Medium Pressure
NERSA	National Energy Regulator of South Africa
NG	Natural Gas
OATS	Olefin Alkylation of Thiphenic Sulphur
ODP	Oxidative desulphurisation process
OECD	Organisation for Economic Co-operation and Development
PAFC	Phosphoric Acid Fuel Cell

PEM	Polymer Electrolyte Membrane
PSA	Pressure Swing Absorption
SAPIA	South Africa Petroleum Industry Association
SDB	Social Desirability Bias
SMEs	Small and Medium Sized Entities
SMR	Steam Methane Reformer
SOFC	Solid Oxide Fuel Cell
ULSD	Ultra Low Sulphur Diesel
US	United States
VDU	Vacuum Distillation Unit
VFD	Variable Frequency Drive
VOC	Volatile Organic Carbon
VSD	Variable Speed Drive

1 INTRODUCTION

Growing concern around climate change, increasing energy prices and concern for energy security are important issues in today's society. Energy efficiency is being seen as the quickest way to reduce greenhouse gas emissions, thereby contributing to climate change mitigation. It is also seen as a way to meet growing energy demands and as a means to protect economies from sharp energy price increases, shortages and disruptions (World Economic Forum, 2010). Utilising energy more efficiently has inherent financial benefits, and there are well- documented cost-effective opportunities for energy reduction. Furthermore, the negotiation of future action on greenhouse gas mitigation requires that countries evaluate the potential for emission reductions in their portfolio of emitting activities, and the cost to make these reductions happen (Baron and others, 2007).

The industrial sector is a large contributor to total country energy consumption and hence greenhouse gas emissions. There is a debate over the existence of an 'energy efficiency gap' within industry worldwide as many economically profitable energy efficiency opportunities exist which are not always realised. The energy efficiency gap suggests that opportunities such as such as technologies, methods, or processes that may reduce energy use in an industry, are somewhat neglected. In the theory of economic rationality, actors would systematically try to minimise their cost for energy services and spontaneously take profitable economic measures. In reality however, the fact that this is only partially true shows the existence of impediments to energy conservation measures. These barriers obstruct the exhaustive exploitation of the savings potential (Weber, 1997).

This study aims to provide a greater insight into industrial energy efficiency potential in the South African crude oil refining industry. This is done through trying to understand what drives energy efficiency and to recognise barriers which challenge improvement. In addition, opportunities to improve the status quo of refinery energy consumption are explored.

The results of this study add to literature in the field of barriers and drivers for energy efficiency in energy intensive industries. Presently, there seems to be a shortage of sector specific studies in this field, therefore this thesis aims to further the understanding of the crude oil refining industry in this context.

1.1 Scope & Research Limitations

The focus of this research is limited to the 4 crude oil refineries in South Africa, namely, Sapref, Enref, Calref and Natref. The study has not included the GTL and CTL plants (PetroSA and Secunda refineries), as they have substantially different process requirements, although they are part of the refining industry. The scope of the study is therefore focused on crude oil refineries to give a similar basis of process and energy requirements when discussing opportunities, drivers and barriers to energy efficiency improvement.

1.2 Research Objectives and Key Questions

The objectives of this thesis are twofold: Firstly, to explore opportunities to improve energy efficiency in a refinery, and secondly, to get a better understanding of the uptake of energy efficiency opportunities in South African crude oil refineries. In clarifying the second objective, this study aims to recognise what influences promote or inhibit the implementation of energy efficiency opportunities in the refining industry. In other words, the drivers and barriers of energy efficiency improvement within the refinery environment will be investigated.

To meet these objectives, this thesis answers the following research questions:

1) What is the status quo of energy efficiency in South African crude oil refineries?

The following sub questions need to be answered in order to answer the above.

a. Where is energy used in a typical refinery?
b. What are the technical and practical opportunities for energy savings in refineries and where do they lie?
c. What is the potential for energy efficiency improvement in South African refineries and where do South African refiners stand in comparison to refineries worldwide?

2) What are the major influences on the uptake of energy efficiency projects in the South African refining industry?

The following sub questions are posed to answer this question:

a. What are the barriers to energy efficiency improvement?
b. What are the drivers to energy efficiency improvement?

This study utilises a methodological approach which includes both qualitative and quantitative aspects. Data for the study was collected via semi-structured interviews. Respondents were also required to complete a quantitative questionnaire. This approach was chosen so as to attain a holistic view of the complex and interrelated set of factors which affect energy efficiency improvement.

Chapter 2 gives more detail of the methodology used in this research.

1.3 Thesis Structure

The remainder of this thesis is structured as follows:

Chapter 2 discusses the **Methodology** used in this research.

Chapter 3 introduces **Energy Efficiency in South African Industry**. The intention of this chapter is to give an overview of industrial energy consumption in the country and motivations for energy efficiency improvement. A background to South African energy policies is discussed in closing.

Chapter 4, **Petroleum Refining Process and Energy Characteristics**, aims to give a general understanding of the refining process. This serves as a backdrop to understanding how energy is used in a refinery.

In **Chapter 5**, a **Background to the Oil Industry in South Africa** discusses the refineries involved in the study and the relative sizes of the plants.

A **Review of Opportunities for Energy Efficiency in Refineries** is provided in **Chapter 6**. This aims to give an overview of both the technical and 'soft skills' opportunities required to improve a refinery's energy performance. Citing literature in this field, the beginning of the chapter initially discusses the extent to which refineries worldwide can improve on their current situation, by implementing energy efficiency measures. This serves to give a basis of comparison when discussing the status quo and improvement potential of South African refining industry in the results section of Chapter 8. In addition, examples of opportunities are presented with typical savings achieved in refineries.

To understand the contributing factors to energy improvement an initial literature **Review of the Drivers and Barriers to Energy Efficiency Improvement** is given in **Chapter 7**.

Following this, **Chapter 8**, the **Results and Discussion** of this research are presented and discussed.

To bring the thesis to a close, the **Conclusions and Recommendations** are presented in **Chapter 9**.

2 METHODOLOGY

Figure 1 illustrates the research methodology used in this thesis. Initially a literature review was carried out in the field of barriers and drivers to energy efficiency, and opportunities for energy efficiency improvement. This then led to the development of a set of broad research questions. To explore these research questions, an initial questionnaire and preliminary set of interview questions were then tested for relevance through a series of preliminary pilot interviews. Links between industry practice and literature were identified from the observations and interpretation of the initial findings from these pilot interviews. These initial findings helped to build a foundational basis to update and focus the overall research questions. The questionnaire and interview questions were then refined and finalised.

Eleven face-to-face and one telephonic semi-structured *interviews* were carried out with representatives in the crude oil refining industry in South Africa. Respondents were made up of engineers and managers in the four crude refineries, Calref, Enref, Natref, and Sapref. At the same time as conducting the interviews, a *questionnaire* was completed by the respondents.

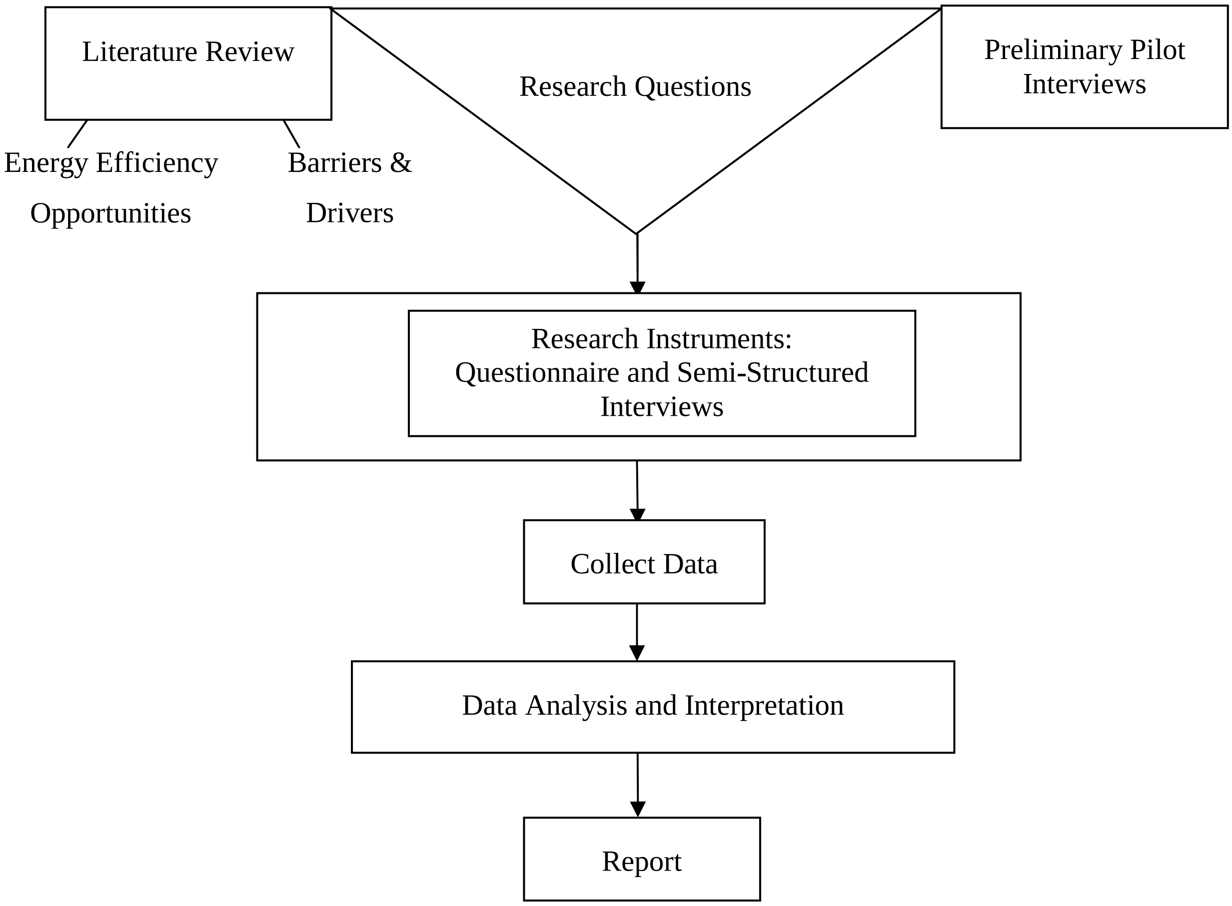

Figure 1 Research Methodology Flow Scheme

Note: Adapted from Cooper & Schlinder (2003)

The *interviews* extracted information to provide an understanding of the factors involved in the successful adoption of energy efficiency measures. The term ‘measures’ in this research is taken to include capital, maintenance and optimisation for energy efficiency improvement. The main focus of the interview questions was on the factors which influence the uptake of *capital* projects. However consideration was also given to the low/no cost interventions of maintenance and optimisation, often referred to as ‘low hanging fruit’.

The *questionnaire* was made up of rating questions to attempt to provide a quantitative evaluation of the factors addressed in the interviews. Consideration here was given to:

- The improvement potential of energy efficiency measures,
- The significance of influences involved in driving a project forward,
- The policy and institutional drivers to the uptake of energy efficient technologies,
- The significance of barriers to the adoption of energy efficient technologies.

The study by de Groot, Verhoef & Nijkamp (2001) was used as a basis for formulation the questions relating to the rating of barriers and drivers. The scores range from 1 (completely insignificant) to 5 (very significant). The individual factors used in the rating questions arose from the literature review, and the policy and institutional drivers to the uptake of energy efficient technologies was slightly modified from Curras (2010).

2.1 Research Limitations

In interpreting the results of this study, certain limitations need to be taken into account. Firstly, at present there is hypersensitivity on sharing or giving out information by petroleum industry players mainly due to restrictions imposed by the Competition Tribunal. The scope of this research has therefore not included detailed energy data such as energy consumption, but has rather focused on trends of energy usage in the industry. Within this thesis measures such as indexing and aggregating data have been employed.

According to Brace (2004), Social Desirability Bias (SDB) is a challenge when conducting research involving people and social interactions. SDB can stem from the fact respondents may wish to appear different to what they are. Another bias is the respondent may try to maintain their own esteem, convincing themselves that they think and behave in socially responsible ways. In addition, instrumentation bias can occur, meaning the respondent gives answers designed to bring about a socially desirable outcome, for example a wish for a new energy policy to be put in action. Brace (2004) states the SDB could be lowered by guaranteeing the respondent confidentiality. In order to limit the SDB, therefore, within this thesis respondents were given full anonymity.

All the information was aggregated so as not to be able to isolate individual companies, in line with the requirements of confidentiality agreements. The data thus serves to understand the industry in totality with regards to energy efficiency improvement.

3 ENERGY EFFICIENCY IN SOUTH AFRICAN INDUSTRY

When considering industry, the manufacturing sector worldwide contributes nearly one third of the global energy demand and CO_2 emissions. This is especially in industries such as chemicals and petrochemicals, iron and steel, cement, paper and aluminium. In addition, understanding how energy is used in the manufacturing sector, the national and international trends and the potential for efficiency gains, is crucial (IEA, 2007).

South Africa is a fast growing developing country and energy efficiency, to generate more economic output with less energy input, is essential for reasons such as security of energy supply, economic competitiveness, global warming and environmental sustainability (Taylor and others, 2008). There is a major opportunity to abate energy demand growth in a cost-effective way that offers investors attractive returns. Of the opportunities available in industrial sectors worldwide, developing countries are suggested to represent 80% of the total savings opportunity (Farrell and others, 2008).

This section discusses i) Industrial Contribution to Final Energy Demand in South Africa, ii) Motivation for an Increased Focus on Energy Efficiency in South Africa, and iii) Energy Efficiency and South African Energy Policy.

3.1 Industrial Contribution to Final Energy Demand in South Africa

Industry is the largest contributor to final energy consumption in South Africa, representing a 32.2% share in 2006. Figure 2 below illustrates the components of national energy use.

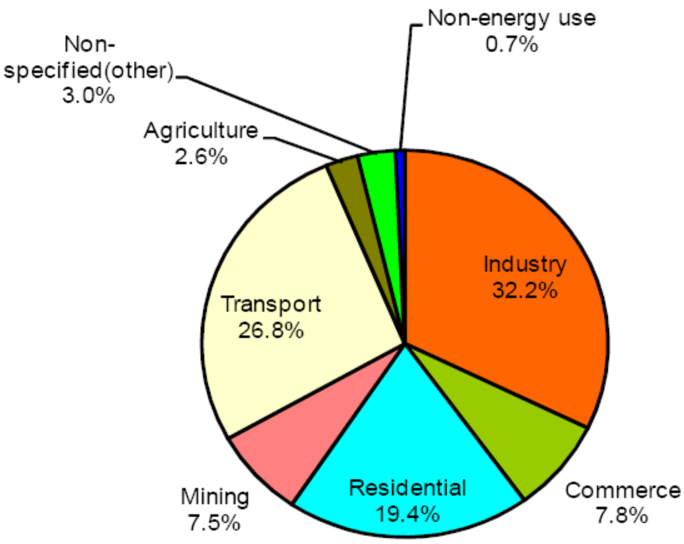

Figure 2 Sectoral Consumption of Energy in South Africa, 2006

Source: (Subramoney and others, 2009)

The sub-sectoral contribution of industrial energy consumption is illustrated in Figure 3. Energy intensive users in the industrial sector include iron and steel, chemical and mining industries. The chemical sector makes up a large contribution of industrial energy consumption at 22%, with oil refineries sitting in this sector.

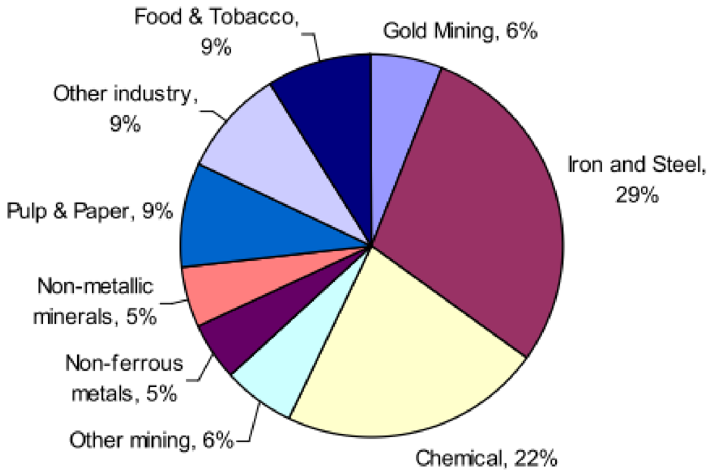

Figure 3 Final Industrial Energy Consumption by Sub-Sector, 2001

Source: Winkler et al (2006) from (Haw & Hughes, 2007)

3.2 Motivation for an Increased Focus on Energy Efficiency in South Africa

Energy efficiency has become recognised as one of the most cost effective ways of meeting the demands for sustainable development. It reduces greenhouse gas emissions and plant operating costs, in addition to extending supply and affordability of conventional energy sources (Sebitosi, 2008). The IEA estimates that two thirds of the desired carbon dioxide emissions reductions worldwide must come from improved energy efficiency, and the balance from changes in the mix of energy supply technologies[1] (Taylor, la Grange & Gous, 2000; Taylor and others, 2008).
The South African National Energy Association estimates that a savings of between 10 and 20% of current consumption could be achieved by greater energy efficiency, which in turn could lead to an estimated increase in GDP of between 1.5 and 3% (Nkomo (2006) from Govender (2008)).

Energy efficiency is defined in the context of this thesis as a reduction in the energy input required by a process which provides the same level of activity (World Energy Council, 2010).

The following sections discuss the motivations for energy efficiency improvement in industry in greater detail.

3.2.1 *Greenhouse Gas Emissions Reductions*

South Africa is a significant contributor to greenhouse gas emissions and was listed in 2009 as the 13th highest emitter of carbon dioxide in the world by the International Energy Agency. It is one of the largest developing country emitters (DEA- RSA, 2010). This is largely because of the economy's dependence on fossil fuels. In 2000, the national energy intensity of South Africa stood about 3.3

[1] This is in an Alternative Policy Scenario by the IEA developed to investigate how a more sustainable global energy supply could be developed by 2030.

times the average in OECD countries, despite having half the energy consumption per capita as OECD countries (Praetorius and Bleyl (2006) from Sebitosi (2008)).
Figure 4, shows the increasing trend in carbon dioxide emissions of South Africa from 1960 to 2006.

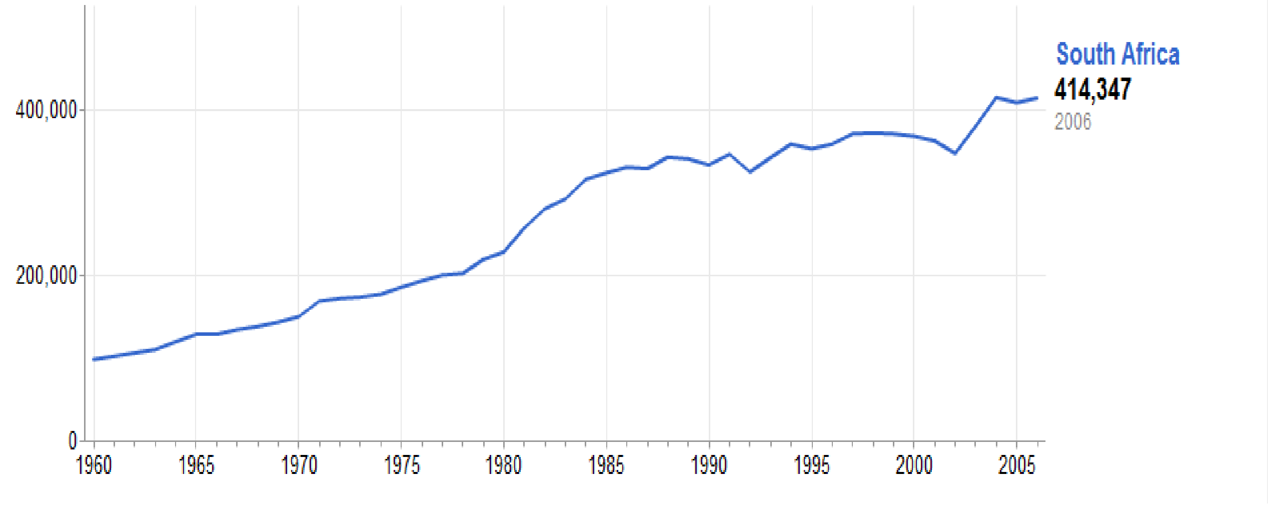

Figure 4 South African CO_2 Emissions (Kilotons) Per Year

Source: (World Bank)

Within the energy sector, industry was the major producer of GHG emissions in 2007, a trend that is projected to continue to 2030. This is shown in Figure 5 below.

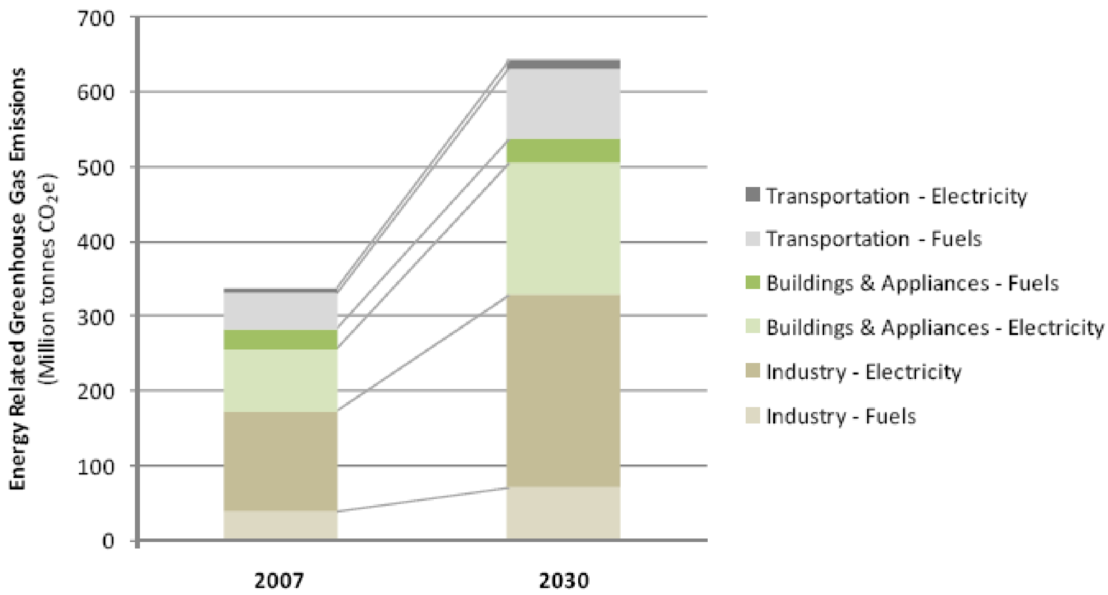

Figure 5 Projected Baseline Energy-sector Greenhouse Gas Emissions in South Africa in 2030

Source: (Erickson, Heaps & Lazarus, 2009)

The dependency of South African energy supply on hydrocarbons, as traditional and affordable supply options, has serious consequences in terms of climate change. The role played by CO_2 in global warming is becoming a major concern for energy intensive industries, particularly due to factors that could impact upon business models such as the introduction of a proposed carbon tax and other regulatory mechanisms which could be introduced in an attempt to reduce emissions.

From a manufacturing company's point of view, new environmental regulations with associated costs for CO_2 emissions are an important driver for energy efficiency. Companies that improve their energy efficiency and consequently their carbon footprint can improve their position to face challenges and costs resulting from CO_2 regulations (Bunse and others, 2011).

3.2.1.1 *South Africa's Commitment to Reducing Greenhouse Gas Emissions*

Historically, commitments to greenhouse gas emissions reductions in South Africa have been voluntary. South Africa joined the Kyoto Protocol in March 2002 although it is a Non-Annex 1 (developing) country, implying that it does not have to reduce its greenhouse gas emissions in the first commitment period of 2008 to 2012, although this agreement is coming up for review.

At the Copenhagen summit, in 2009, South Africa committed to reduce its greenhouse gas emissions by 34% by 2020 and 42% by 2025 below its business as usual emissions growth trajectory, contingent on technical support and funding from developed countries (DEA- RSA, 2010). This has been restated according to the National Climate Change Response White Paper, and a National GHG Emissions Trajectory Range, projected to 2050, will be used as the benchmark against which to measure the effectiveness of mitigation action.

In summary, South Africa's GHG emissions will:

- peak in the period 2020 to 2025 in a range with a lower limit of 398 Megatonnes (Mt) CO_2-eq and upper limits of 583 Mt CO_2-eq and 614 Mt CO_2-eq for 2020 and 2025 respectively.
- plateau for up to ten years after the peak within the range with a lower limit of 398 Mt CO_2-eq and upper limit of 614 Mt CO_2-eq.
- decline From 2036 onwards in absolute terms to a range with lower limit of 212 Mt CO_2-eq and upper limit of 428 Mt CO_2-eq by 2050.

The White Paper states further that "as part of the Energy Efficiency and Energy Demand Management Flagship Programme, the DoE will continue to develop and facilitate an aggressive energy efficiency programme in industry, building on the experience of Eskom's Demand Side Management programme and the DTI's National Cleaner Production Centre, and covering non-electricity energy efficiency as well. A structured programme will be established with appropriate initiatives, incentives and regulation, and a well-resourced information collection and dissemination process" (South African Government, 2011).

3.2.2 *Contribution to Energy Security*

South Africa has experienced blackouts (2008) and fuel shortages in the past (2005), and this has highlighted the vulnerability of the economy to energy shortages. The electricity power crisis of 2008 saw a country capacity shortfall of over 10% (5000MW), leading to load shedding by Eskom, the national power utility, to stabilise the national power grid (Sebitosi, 2008). As one of the measures in a strategy for meeting the consumer electricity demand and counteracting the shortfall in 2008, Eskom responded with introducing demand side management (DSM) initiatives.

At present, South Africa is developing new, and upgrading older power plants. However, before new supply capacity is brought online (2012-2015), Eskom has forewarned that peak demand for electricity will outstrip supply, therefore giving rise to load shedding such as those experienced in 2008[2]. With these energy security concerns, industrial demand side management has clear importance for mitigating short-term supply shortages. Long-term energy supply requirements and dependence on fossil fuel can also be reduced through improved energy efficiency.

The Energy Master Plan of Liquid Fuels recommends that as part of the energy security strategy, energy efficiency be strongly promoted in all energy-consuming sectors of the economy. A major part of energy security is managing the energy demanded by all sectors in the economy (DME- RSA, 2007).

3.2.3 *Reducing Operating Costs*

"Energy prices are linked to efficiency and industrial structure" (US OTA, 1993).

Historically South Africa's low electricity price and labour cost has contributed towards a competitive industrial economy. South Africa's electricity price has been amongst the cheapest in the world, this is partially as a result of its abundant coal reserves and over-investment in generating capacity in the 1980's. This price is less than half that in the UK (Haw & Hughes, 2007). Low energy prices increase energy intensity by attracting energy-intensive industries. Low energy prices also act as a disincentive to save (US OTA, 1993). Like most traditional utilities, the primary objective of the power utility (Eskom) has been to maximise sales (Sebitosi, 2008).

The price of electricity is set to increase in large increments in the next few years. This is to cover the new generating capacity required to meet on-going increases in demand as shown in Figure 4. The National Energy Regulator of South Africa (NERSA) approved a tariff increase of 24.8% for the year starting 1 April 2010, and subsequent increases of 25.8% and 25.9% in 2011 and 2012 respectively. This results in an average standard price of 41.5 c/kWh, 52.30 c/kWh and 65.85 c/kWh for 2010/11, 2011/12 and 2012/13 financial years respectively (NERSA, 2010).

In addition to electricity price increases, electricity usage has been increasing which is largely driven by the increasing demand in the industrial sector. Figure 6 shows the projected increasing South African sectoral energy demand from 2001 to 2030, where industry is a key consumer (Haw & Hughes, 2007b).

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[2] Reasons for the discrepancy between energy demand and supply include poor planning, as older power plants are shut down periodically for maintenance and new power plants progressively come online after construction.

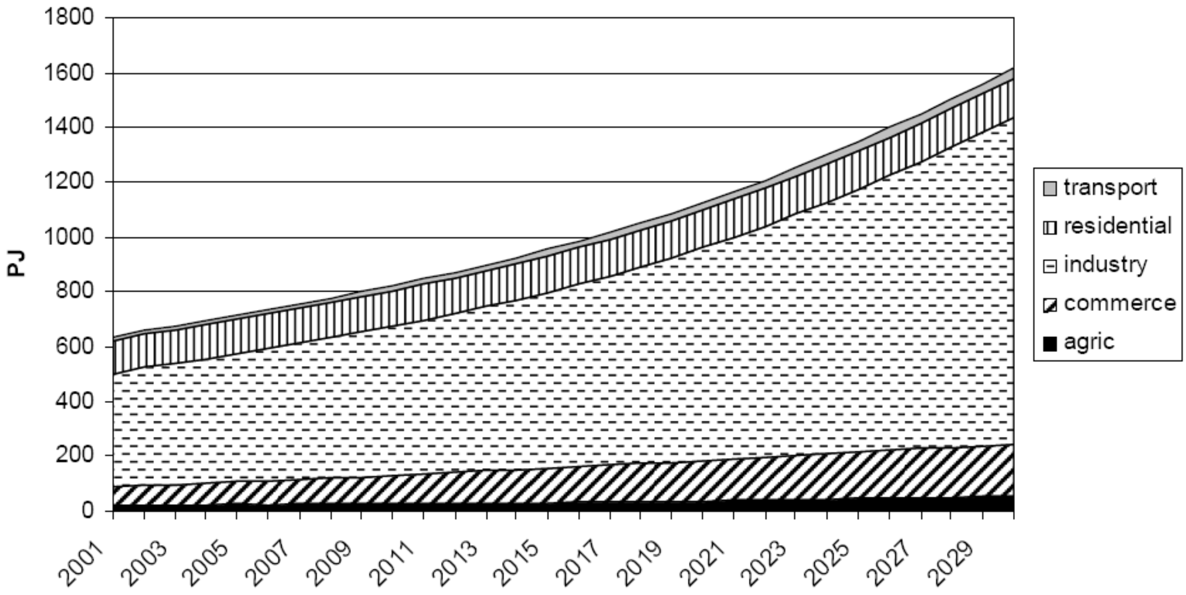

Figure 6 Projected Electricity Demand by Sector

Source: (Haw & Hughes, 2007b)

Energy represents a strong factor for competitiveness in energy-intensive manufacturing industries. In downstream refining, energy costs are a significant portion of operating costs, where the cost of crude oil is a major contributor. The crude oil price has an increasing trend in the long term as shown in Figure 7.

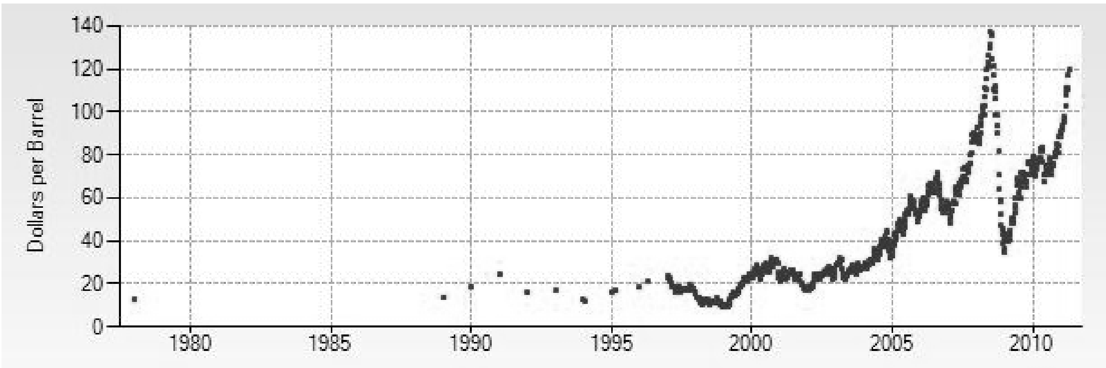

Figure 7 Weekly All Countries Spot Price FOB Weighted by Estimated Export Volume

Source: (US EIA, 2011)

Furthermore, fuel consumption in industry is increasing as is shown in the historical and projected demand from 2001 to 2030 (Figure 8).

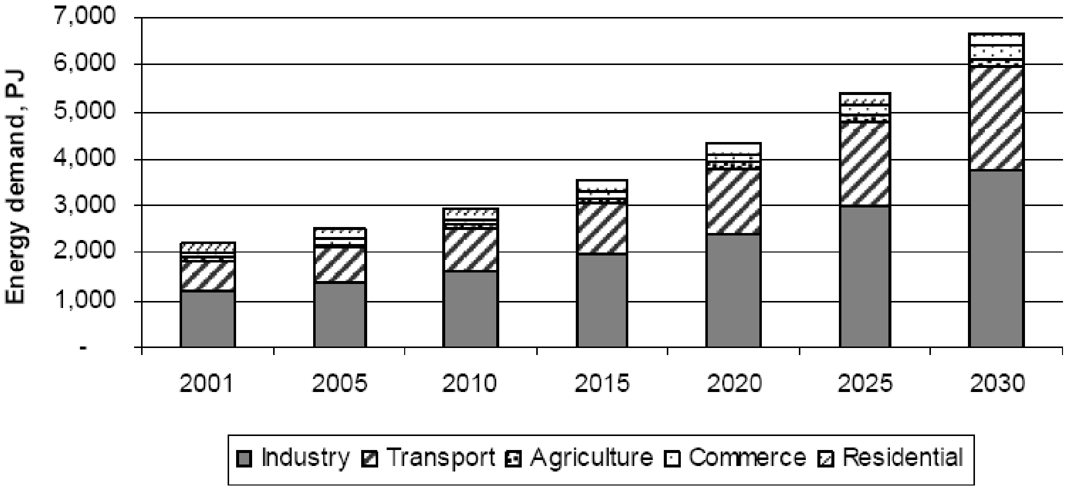

Figure 8 Fuel Consumption by Major Energy Demand Sector

Source: (Haw & Hughes, 2007b)

3.2.4 *Improving Environmental Image*

Energy efficiency in manufacturing can be a contributor to reducing the total environmental impact of a product. Consumers' purchasing behaviour is changing in regards to 'green' and efficient products and services, and more and more consumers would like to purchase 'green products' (BCG 2009 from Bunse and others (2011)).

Industrial energy efficiency can enhance environmental performance by reducing CO_2 and other emissions. In addition, energy efficiency can give manufacturing companies a competitive advantage by mitigating energy price volatility. Thus energy efficiency can enhance company reputation.

The following section aims to give an overview of South African energy policy, and energy efficiency objectives for the country.

3.3 Energy Efficiency and South African Energy Policy

The White Paper on Energy Policy (1998) and the Energy Act (2008) at present constitutes the national energy policy. In support of some of the objectives spelt out in the 1998 White Paper on Energy Policy, the South African Department of Minerals and Energy (DME) published the National Energy Efficiency Strategy of South Africa (2005). The Strategy acknowledges that there exists, "*Significant potential for energy efficiency across all sectors of our national economy*."

The Energy Efficiency Strategy has set a national final energy demand reduction target of 12% by 2015. The sectoral target for Industry and Mining has been set at 15% by 2015 based on a 'business as usual' baseline scenario[3].

Within the petroleum refining industry, the topic of this thesis, South African Petroleum Industry Association (SAPIA) members have entered into a voluntary Energy Efficiency Accord with the government which acknowledges this target of a national final energy demand reduction of 12% by

[3] Starting with a baseline year of 2000.

2015. This Energy Efficiency Strategy also sets out a target improvement in energy intensity of 1% per annum for chemical and petrochemical industries until 2015.
According to the Department of Minerals and Energy[4] (DME), the assumptions made in arriving at sectoral targets are considered conservative as these are based solely on technical interventions. Over and above these savings there exist non-technical opportunities for energy savings in the building, industry and mining sectors. These are classified broadly as ‘Energy Management Best Practice’ and revolve around behavioural change from increased awareness, training, accountability and information systems (DME - RSA, 2008).

[4] This department no longer exists but has split to form the Department of Energy and the Department of Mineral Resources.

4 PETROLEUM REFINING PROCESS AND ENERGY CHARACTERISTICS

Chapter 3 provided a context of energy efficiency in South African industry. In this chapter a broad overview of the crude refining process and its energy usage is presented.

4.1 Introduction to the Petroleum Refining Process

The process of refining crude oil to refined product can be achieved via a diverse range of refinery configurations. These configurations can be generalised into four types: simple, compound, complex and petrochemical. The simplest type consists of crude distillation, catalytic reforming and refining processes. The compound type includes the simple refinery units and units for vacuum distillation and catalytic cracking. The complex refineries have a complete slate of products including the production of lube oils. Lastly, the petrochemical type includes petrochemical plants and those which produce aromatic hydrocarbons.
Refineries can also be categorised according to the type of units it has within its operation. These can be seen in Table 1 below (Ocic, 2005).

Table 1 Type of Refinery and Typical Units

Refinery types	Units
Hydroskimming	Crude unit, pretreatment, gas concentration by amine, catalytic reforming and hydrodesulphurisation.
Catalytic cracking	In addition to hydroskimming units include vacuum distillation, vacuum residue visbreaking and catalytic cracking usually with alkylation.
Deep conversion refineries: – Hydrocracking- catalytic cracking – Hydrocracking- coking	In addition to hydroskimming units, deep conversion refineries include hydrogen generation by steam reforming, vacuum distillation, hydrocracking, vacuum-residue deasphaltation by solvent, hydrodesulfurization of deasphalted oil and catalytic cracking with alkylation.

Source: (Ocic, 2005)

The process flow diagram and products produced from a typical complex refinery are shown in Figure 9.
Although a large product slate is produced, the high-volume profitable products produced within a refinery are: gasoline, diesel, jet fuel and the light heating oils, No.1 and No. 2 (Gary & Handwerk, 1994).

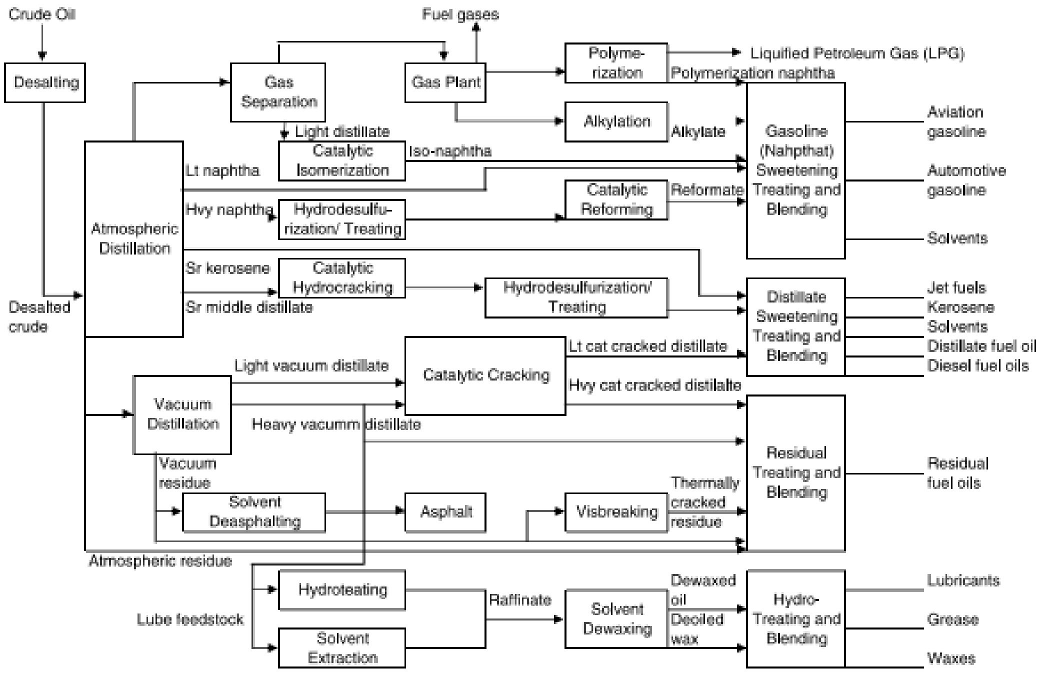

Figure 9 Typical Petroleum Refining Process

Source: (Al-Muslim & Dincer, 2005)

During the process the crude oil feedstock is distilled into a number of different fractions. The lighter fractions are the refinery gas liquids: naphtha, kerosene, and light gas oil cuts (diesel), respectively. These fractions only require slight to moderate upgrading or processing to be used as fuels (LPG, gasoline, jet fuel, diesel). The remaining fractions are heavier than premium refined products, and are a significant part of the crude barrel. These heavier fractions are transformed via cracking processes to maximise the production of transportation fuels, which are premium products.

To process crude into products, most petroleum refineries use between ten and twenty different processes. Refineries are set apart from other energy related industries by a number of factors, in addition to plant complexity. These factors are relevant in understanding how energy is used in refining, and how this is fundamentally different to other industries. Marano (2007) cites Gary, Handwerk & Kaiser (2007) with the following summary of differences (Table 2):

Table 2 Characteristics which set Petroleum Refining apart from other Industries

1. Every individual refinery is unique, and no two crude oils are the same. – Refineries vary in complexity and size due to the types of crudes they process and products they produce. Often these differences become obvious on a regional or geographic scale. – Crude gravity is decreasing and sulphur content of crude is increasing. – The processing configuration of a refinery evolves over time.
2. Refineries are capital intensive, highly specific and long-lived assets.
3. Refineries are energy intensive and operations and products impact the environment.
4. Refiners are price takers. – Refinery products are commodities which are sold in segmented markets. – Prices of refined products are volatile and correlate to crude oil prices
5. Optimisation of a refinery involves multiple trade-offs.

Source: (Marano, 2007)

The next section aims to discuss the energy requirements and CO_2 emissions of a refinery.

4.2 Refinery Energy Requirements and CO_2 Emissions

4.2.1 *Refinery Energy Sources*

Energy feedstock for a refinery can be classified into thermal and electrical energy. The thermal energy requirement in a refinery far outweighs electricity consumption. Refineries are distinctive within industry in that they produce most of their own fuel and only use purchased fuel as supplement (Hochhalter, 2008). The required power can also be generated on site or purchased from a utility.

The fuel required for steam and electricity generation is derived mainly from process wastes which include: refinery gas, residual fuel oils (fuel oil, vacuum wastes and asphalt wastes) and FCC coke. These vary widely in composition and quality and are the outcome of a fine balance between energy required by processes, type of crude processed and constraints on emissions and economic analyses (Szklo & Schaeffer, 2007).

The electricity requirements (to drive pumps, compressors, motors, fans, cooling systems, lighting, etc) for the average refinery approaches up to 8% of the total energy demand, whereas the steam requirement is approximately 30%. The thermal requirements (heat consumption rate) for an average refinery are between 0.348-0.580 GJ/bbl (Hydrocarbon Publishing Company, 2011). Together, the cost of energy for heat and power in a typical refinery is significant, and accounts for approximately 40% of operating costs (US DOE- OIT, 1998).

Figure 10 below shows the various energy feed stocks used in US refineries. It can be seen that refinery fuel gas is the largest feedstock of energy (46%). This is then followed by natural gas (25%). Electricity use within US refineries is approximately 5% of the energy requirement.

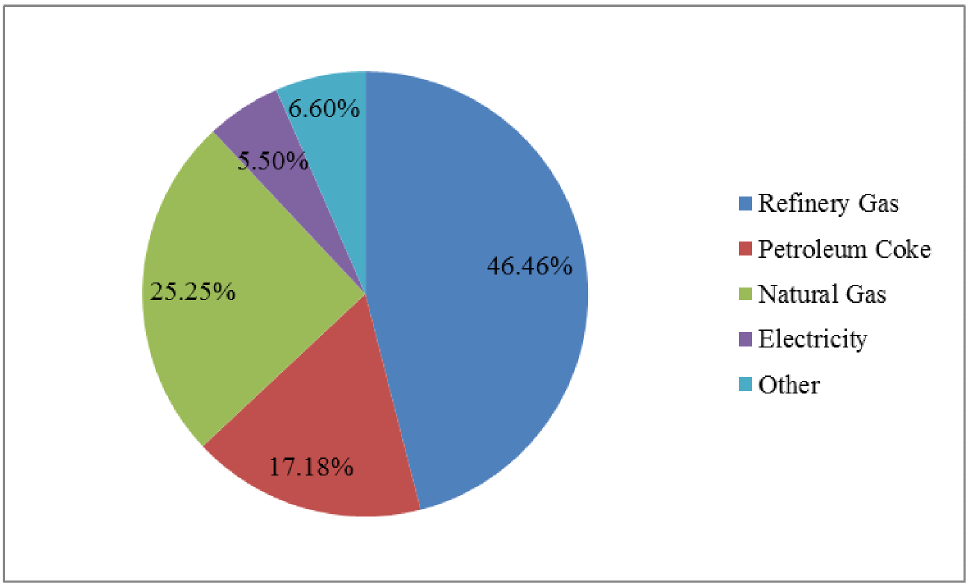

Figure 10 Energy Feedstock in U.S. Refineries

Source: (US DOE, 2000)

4.2.2 *Energy Consumption in Refineries*

Energy consumption within the refining process is typically greater in units which have a large throughput, as opposed to units which are energy intensive per barrel processed. The atmospheric and vacuum distillation units have a high throughput on number of barrels processed and account for 35-40% of energy use in a refinery, however they are not the most energy intensive per barrel processed. Referring to Table 3, the most energy intensive process is the manufacture of lube oils (1589 MJ/bbl) although it only accounts for about 5% of the total refinery energy consumption as there is only a small throughput. In advanced refining industries, where there is a focus on fuels with low contaminant content levels and considerable conversion capacity, hydrotreating units are large energy consumers. Hydrotreating, which removes sulphur, nitrogen and metal contaminants, accounts for about 19% of energy consumption. This is followed by reforming at approximately 15%. These values are representative of the average energy use at US refineries, and the top four highest energy consuming units (atmospheric and vacuum distillation, hydrotreating and reforming) have been highlighted in the table below (US DOE- OIT, 1998).

Table 3 Energy Use by Refinery Process in US Refineries (1998)

Process	**Specific Energy Use** (MJ/bbl)	**Average Use** (MJ/bbl)	**Annual Energy Use** (%)
Atmospheric Distillation	87-196	120.1	**25.79**
Vacuum Distillation	54-119	96.5	**9.60**
Visbreaking -*Coil*	143	143.5	0.04
-*Soaker*	26-100	66.5	0.04
Delayed Coking	120-243	175.1	4.61
Fluid Coking	272	272.2	0.29
Flexi Coking	176	176	0.27
Fluid Catalytic Cracking	53-172	105.5	7.66
Catalytic Hydrocracking	168-339	253.2	4.41
Catalytic Hydrotreating	64-173	126.6	**18.83**
Catalytic Reforming	225-361	299.6	**15.13**
Alkylation -*Sulfuric acid*	348-359	353.4	2.14
-*Hydrofluoric Acid*	423	423	3.84
Ethers Production	311-595	425.2	1.34
Isomerization -*Isobutane*	379	379	0.52
-*Isopentane/Isohexane*	108-249	184.6	1.09
Isobutylene	502	502	n/a
Lube Oil Manufacture	1589	1589	4.40

Source: (US DOE- OIT, 1998)

The actual energy consumed within a refinery will vary with configuration, feedstock and refinery operation. In addition, higher fuel constraints will increase energy use in hydrotreatment, as this unit is used to achieve quality specifications for oil products.

4.2.3 *CO_2 Emissions from Refinery Energy Use*

Depending on factors which affect energy use (as discussed in 4.2.4), CO_2 emissions from refinery process units can vary. Figure 11 below shows the percentage distribution of CO_2 emissions from a 207 000 bbl/day refinery based on thermal energy usage. The figure indicates the best units to target for an emissions reduction program are the FCC, reformer and crude unit, which account for 75% of CO_2 emissions produced in this case.

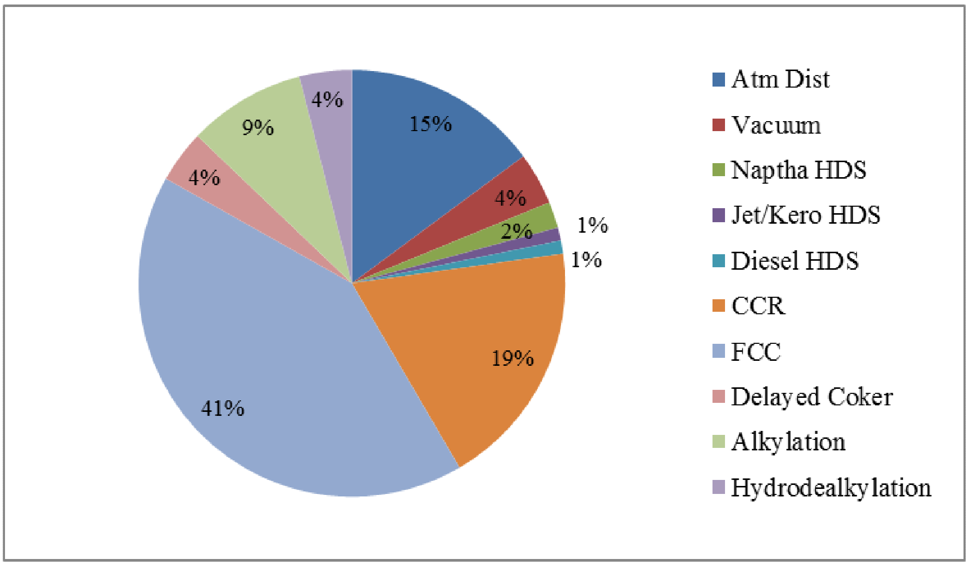

Figure 11 Breakdown of CO_2 Emissions by Refinery Process (Based on Thermal Energy Usage for a 207 000 bbl/day Refinery)

Source: (Habibullah, Rameshni & Passmore, 2009)

CO_2 emissions arising from thermal and electricity use, in a typical 100 000 bbl/day refinery, are generally between 1.2 and 1.5 million tons/yr. Approximately 50% of the CO_2 emissions would arise from process heaters, 35% from FCC and hydrogen plants, and the remainder (15%) from steam and power systems (Sheehan & Zhu, 2009).

4.2.4 *Factors Affecting Energy Use in Refining*

Within the crude oil refining process, the total crude oil input includes a contribution that is used for energy generation in the form of refinery fuel gas. The amount of crude used for energy generation is dependent on the complexity of the oil refinery, and this can range between 7 and 15% of crude oil feedstock used by the refining process (Szklo & Schaeffer, 2007). As the complexity of the plant is increased, the energy requirements increase to accommodate the range of products produced and the increased number of secondary units. Refineries with the same level of complexity can have vastly different levels of energy efficiency. Energy inefficient oil refineries can decrease their internal energy consumption by 20-30% by including more efficient organisational, energy and technological solutions; this is a substantial opportunity for reducing operating costs, as a refinery whose crude oil energy consumption is 5%, must operate 16 days a year just to meet its energy requirement (Ocic, 2005).

According to Petrick & Pellegrino (1999), a petroleum refinery's energy use, energy efficiency and the type of fuels consumed are dictated by the following:

- The cost and availability of fuels and energy,
- Quality of the crude feedstock processed,
- Product slate produced,
- The refinery configuration i.e. complexity and size,
- Capital availability, and
- Environmental regulations (specifications of products).

The quality of crude oils processed is expected to deteriorate slowly in the future as sulphur contents and densities increase (Gary & Handwerk, 1994). Together with this shift toward cheaper sourer crudes, increased regulation on more stringent fuel specifications (cleaner fuels) has had an increased impact on energy consumption within refineries. The production of 'cleaner' diesel and petrol, in terms of sulphur content, results in higher energy use and carbon dioxide emissions as more advanced processing capability is required as refining complexity is increased. On average, US refineries have increased consumption of crude oil by 5% merely to comply with stricter fuel specifications (Petrick & Pellegrino, 1999; Szklo & Schaeffer, 2007).

5 BACKGROUND TO THE OIL INDUSTRY IN SOUTH AFRICA

South Africa depends heavily on crude oil imports which are then refined locally- crude oil is South Africa's single largest import (Vanderschuren, Jobanputra & Lane, 2008). The South African Petroleum Industry Association (SAPIA) represents South Africa's seven oil companies, namely BP, Chevron, Engen, PetroSA, Sasol Oil, Shell and Total. The members operate all South Africa's six refineries- four crude refineries, one coal-to-liquid (CTL) refinery and one gas-to-liquid (GTL) refinery. Table 4 below shows the capacity and location of refineries in South Africa.

Table 4 SAPIA Members and Refining Capacity

Refinery	Type	Owners	Location	Capacity (bbl/day)
Sapref	Crude	BP & Shell	Durban	180 000
Enref	Crude	Engen	Durban	125 000
Calref	Crude	Caltex	Cape Town	100 000
Natref	Crude	Sasol &Total	Sasolburg	92 000
Sasol	CTL	Sasol	Secunda	*150 000
PetroSA	GTL	State- owned	Mossel Bay	*45 000
TOTAL				**692 000**

Source:(SAPIA, 2010)

Note: *Crude Oil Equivalent

These refineries make up the second largest oil refinery system in Africa at 692 000 bbl/day and this is only surpassed by Egypt at 726 250 bbl/day. They contribute approximately 2% of South Africa's Gross Domestic Product and supply approximately 18% of South Africa's primary energy. The petroleum industry is also an important source of revenue for the government, collecting over R35-billion in fuel taxes on petrol, diesel and paraffin. It also supports employment for over 100 000 people directly or indirectly. Energy is a key strategic sector for South Africa because it underpins the growth and developmental objectives set out by government (SAPIA, 2010).

South Africa's current refining capability is stretched to capacity with the country unable to meet current demand without product imports. In addition, most of the refinery assets were built more than 40 years ago. A new 400,000 bbl/d refinery in Coega, in the Eastern Cape is under consideration to meet rapidly growing product demand and energy security concerns. The final investment decision, on what would be Africa's largest proposed refinery, has been deferred to 2012 (PricewaterhouseCoopers, 2010).

5.1 General Challenges for the Refining Industry

The refining industry worldwide faces challenges which affect industry decision making. In the US, key challenges facing the refining industry have been cited as:

- Environmental regulations
- Increasing cleanliness standards for fuels

- Globalisation
- The requirement for increasing yields from crudes of decreasing quality
- Uncertainty about future consumer fuels of choice
- Pressure to reduce emissions of CO_2
- Attaining adequate profit margins
- Proactively dealing with public scrutiny on environmental, global warming and other issues (US DOE, 2000).

Although these influences have been attributed to affect the US refining industry, they are also relevant to the refining industry worldwide. Particular regulatory and demand influences which will impact energy intensity in South African refineries moving into the future are discussed in the following section.

5.1.1 *Energy Challenges for South African Refineries*

'An important parallel issue, and a major potential barrier to making improvements/modifications to improve energy utilisation, is the fact that refiners are also being forced to modify refinery processes/configurations to be able to refine crudes of lower quality and to comply with environmental dictates. Such changes can readily have undesirable impacts on energy usage and/or emissions' (Petrick & Pellegrino, 1999).

5.1.1.1 ***Clean Fuels Regulations***

The South African refining industry faces influences from regulation in terms of cleaner fuels. The current format of refineries operates at Euro 2 standards, with regulatory authorities requiring refinery upgrades to Euro 5; and the investment costs of upgrading from Euro 2 to Euro 5 are significant, even without a significant increase in refining capacity (PricewaterhouseCoopers, 2010). The specifications for Clean Fuels are illustrated in the appendix.

Strict regulatory requirements towards cleaner fuels will have a significant effect on energy intensity of oil refineries and consequently will increase refinery CO_2 emissions. This trade-off, between sulphur and energy use, has objective implications for countries in view of current discussions surrounding greenhouse gas reduction targets (Szklo & Schaeffer, 2007). To illustrate this, the Clean Fuels 1 requirements imposed in the USA at the start of the 1990s required an estimated 5% increase, on average, of the total amount of crude oil processed by US refineries. This was merely to comply with stricter specifications for diesel and gasoline (500 ppm sulphur) (Petrick & Pellegrino, 1999). Furthermore, Valero Benicia California refinery releases an additional 16 000 metric tons of CO_2 because of the extra energy needed to operate the Ultra-Low Sulphur Diesel (ULSD) unit each year (from 500 ppm to 15 ppm diesel) (Malik, 2011).

5.1.1.2 ***Marine Fuel Regulations (IMO)***

The International Maritime Organisation (IMO) regulates the sulphur content of marine fuels on a worldwide basis. The IMO's Global standards for allowable levels of sulphur in fuels are set to be reduced substantially in the future, moving from 4.5% to 0.5% sulphur (by weight) by 2020 or 2025 at the latest (subject to review in 2018). A proposal was adopted to decrease global marine fuels sulphur cap to 3.5% by 2010 and down to 0.5% by 2020 or 2025 at the latest. The IMO cap reduction proposal leaves open the possibility of using seawater scrubbers as opposed to fuel desulphurisation at refineries. The proposal does not directly mandate the indicated fuel sulphur content but rather emissions consistent with these sulphur contents (Dastillung and others, 2008). The option for fuel desulphurisation would have a notable increase on refinery energy intensity, as there will be increased bottom of the barrel processing.

5.1.1.3 ***Demand for Light Products***

With increasing sulphur regulations there are trends towards decreased demand for heavy fuels. There is an expected development of increased demand for light products, and within the light products a shift toward 'middle distillates', particularly automotive diesel and jet fuel with erosion in petrol demand (Dastillung and others, 2008). This is primarily from expected increases in demand for transportation fuel driven by economic growth (freight use). Figure 12 shows the increasing trend in the diesel/petrol consumption ratio for South Africa.

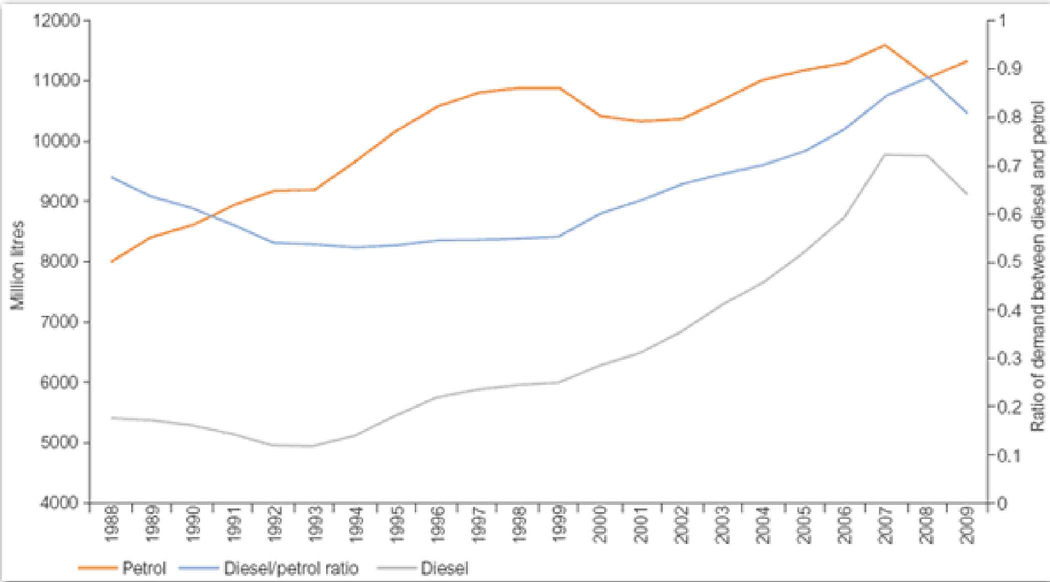

Figure 12 Diesel/Petrol Consumption Ratio

Source: (SAPIA, 2010b)

These demand shifts will affect refinery product slate in future years, and according to Dastillung and others (2008) this will also increase refinery energy intensity. Refinery CO_2 emissions will thus increase due to an increase in diesel demand. This is illustrated in Figure 13 below, which shows Europe's increasing diesel demand and the effect on refinery CO_2 emissions.

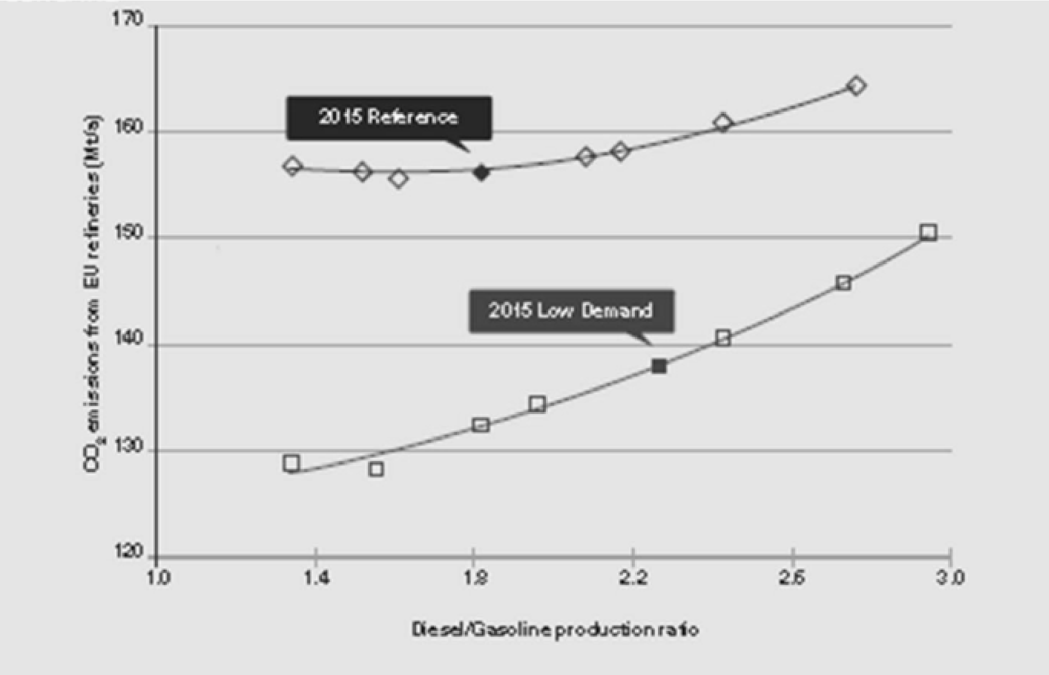

Figure 13 Europe's Increasing Demand for Diesel Contributes to Increased Refining Industrial CO_2 Emissions.

Source: (Dastillung and others, 2008)

5.1.1.4 *Effect of Heavier Crude*

In the long term, the quality of the world's oil reserves will inevitably trend towards heavier, more sulphurous crudes due to greater worldwide competition for premium crudes as existing reserves of oil are depleted. This will also have an effect of increasing energy intensity in refineries, as these crudes require more energy-intensive processing, to obtain the same level of output light 'premium' products (Dastillung and others, 2008; US EPA, 2007).

With these future challenges, opportunities for refineries to become more energy efficient will become increasingly more important. The following chapter aims to explore opportunities to improve refinery energy efficiency.

6 REVIEW OF REFINERY ENERGY EFFICIENCY OPPORTUNITIES

This chapter initially gives a background to understanding energy efficiency improvement in refineries. Subsequently, section 6.2 explores various energy efficiency opportunities that are currently available for refiners, as a means to reduce carbon emissions and reduce operating expenses in the face of high energy costs. Section 6.3 introduces long term opportunities for energy efficiency improvement which require further research and development.

There is a large body of literature which discusses opportunities for energy efficiency improvement in industry, and these give a more comprehensive view of opportunities. This chapter does not intend to give a comprehensive view but rather focus on the main elements.

6.1 Background to Refinery Energy Efficiency Improvement

Energy is a significant cost factor in downstream business; typically, refineries spend 50% of cash operating costs on energy. Energy use is also a major source of emissions in the petrochemical industry; it is the refineries' high energy consumption due to the combustion of fossil fuels that contributes significantly to the GHG emissions[5]. As a result, energy efficiency is an attractive opportunity for cost and GHG[6] emissions reductions (Worrell & Galitsky, 2005). A major incentive for refineries is thus to fully implement energy efficiency opportunities to access the likely financial benefit that will accrue to the business.

A large variety of opportunities exist to lower energy consumption. In addition to the cost saving, some projects may offer strategic advantages, whereas others may offer quantifiable yield and capacity benefits while maintaining product quality. Furthermore, with marginal fuel cost increases and environmental constraints, some previously rejected energy projects may become economically viable. However, the feasibility of selected opportunities and the applicability of these opportunities would have to be individually assessed for a selected refinery, as each refinery is unique in its configuration and the most favourable energy efficiency opportunities will be refinery specific.

The following table from Worrell & Galitsky (2005) gives a brief summary of energy efficiency opportunities and where they can be applied generally within the refining process.

[5] Although process emissions such as methane and other GHGs also contribute to a refinery's GHG emissions.

[6] Greenhouse gas emissions in this context will be taken to include CO_2 emissions from the combustion of fossil fuels and not process emissions of methane and other GHGs.

Table 5 Matrix of Energy Efficiency Opportunities in Petroleum Refineries.

Process	Energy Management	Flare Gas Recovery	Power Recovery	Boilers	Steam Distribution	Heat Exchanger	Process Integration	Process Heaters	Distillation	Hydrogen Management	Motors	Pumps	Compressed Air	Fans	Lighting	Cogeneration	Power Generation	Other Opportunities
Desalting	x											x						
CDU	x	x			x	x	x	x	x		x	x		x				
VDU	x				x	x	x	x	x					x				
Hydrotreater	x				x	x	x	x	x	x				x				
Cat. Reformer	x	x			x	x	x	x	x	x				x				
FCC	x	x	x		x	x	x	x	x					x				
Hydrocracker	x	x	x		x	x	x	x	x	x				x				
Coker	x	x			x	x	x	x	x					x				
Visbreaker	x	x			x	x	x	x	x					x				
Alkylation	x				x	x	x	x	x					x				
Light End	x				x	x	x		x									
Aromatics	x				x	x	x	x	x									
Hydrogen	x				x	x	x	x		x								
Utilities	x	x	x	x	x	x	x			x			x		x	x	x	x

Source: (Worrell & Galitsky, 2005)

* ‘x’ denotes areas where opportunities can be implemented

To provide a perspective on South African refinery energy efficiency improvement, the next two sections (6.1.1 and 6.1.2) look at the potential for improving refinery energy efficiency and where these opportunities are generally found, and secondly, reasons for inefficiencies in existing refineries.

6.1.1 *The Potential for Improving Refinery Energy Efficiency*

“Refiners must deal with the expansion of in-house CO_2 emissions and energy use, as the first is an increasing issue for industrial activities, and the latter represent an important share of refiners’ operational costs.” (Szklo & Schaeffer, 2007)

The average potential for refinery energy efficiency improvements, globally, has been found to be about 30% (based on European refineries). Of the 30% energy cost saving potential, it is estimated that 17% is attributable to cogeneration and the remaining 13% to refinery fuel savings. Therefore on average, refineries worldwide should be able to economically justify projects that could save 13% of their fuel usage. Regardless of environmental or other issues, these savings are justifiable from a purely energy cost reduction point of view (Milosevic & Cowart, 2002). According to a report by UNIDO (2010), petroleum refineries located in developing countries had an energy improvement potential of 40-45% whereas industrialised countries had a potential of 10-25% (in 2007).

Similarly, according to a report by McKinsey and Company, the US refining industry could reduce its energy use by 13 % in 2020 by utilising and investing in commercially available technologies. These are investments that provide an estimated internal rate of return of at least 10% (Mckinsey & Company, 2009).

6.1.1.1 *Target Areas for Refinery Energy Efficiency Improvement*

Energy efficiency opportunities can be categorised in various ways, including investment cost, expected time to achieve identified savings, process unit, or crosscutting areas within the plant. This section aims to highlight some of these crosscutting areas which are integrated in refinery processes. (Worrell & Galitsky, 2005) emphasises the major areas for efficiency improvement (and the percentage of total energy saving opportunities) to include:

- Utilities (30%),
- Fired heaters (20%),
- Heat exchangers (15%),
- Process optimisation (15%),
- Motor and motor applications (10%), and
- Other areas (10%).

Of these, the lowest investment opportunities for improving energy efficiency are often found in areas of utilities[7], heat exchangers and fired heaters (Worrell & Galitsky, 2005). Furthermore, of refineries worldwide, approximately 90% of the 'performance gap'[8] can be directly related to inefficiencies in these areas:

1. Steam and power systems (in utilities). The largest gap in efficiency is typically found in the efficiency of the steam and power systems, with more than 50% of potential benefits in European refineries arising from improvements in steam and power systems. This high contribution of savings is related to benefits of cogeneration, and those benefits may be smaller if a refinery already has a cogeneration system installed (KBC Process Technology Limited, 2008).
2. Process configuration (fired heaters/furnaces and heat integration). Retrofitting process units within European refineries can achieve roughly 25% of process improvements. These projects include process modifications, furnace improvements (eg. addition of air pre-heater), and improved heat integration (eg. revamping and adding heat exchangers to feed preheat train in crude distillation units).
3. Residual areas of improvement. These areas make up roughly 20% of benefits and include projects such as the optimisation of fuel system and flare systems, LPG recovery and reduction of losses (eg improved insulation) (KBC Process Technology Limited, 2008).

[7] Utilities include steam generation and distribution, power generation, compressors and various smaller applications.

[8] This can mean the difference between desired and actual performance.

This distribution of potential benefits is typically as illustrated in

Figure 14 below; this is concluded by KBC from over 200 energy studies at European refineries.

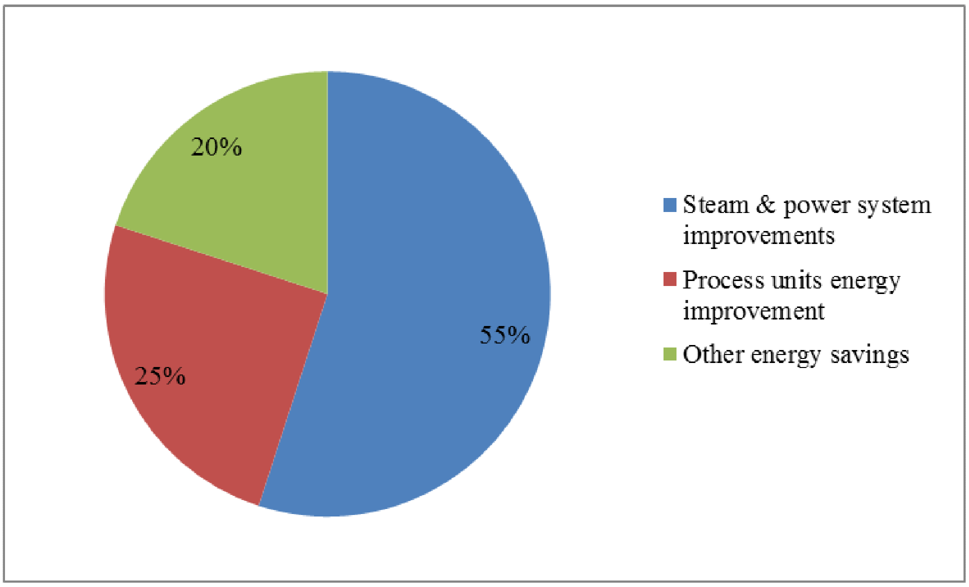

Figure 14 The Distribution of Benefits from Energy Efficiency Improvements in Three Main Areas

Source: (KBC Process Technology Limited, 2008)

Certain areas have been highlighted above, where the major energy savings can be achieved. The methods to achieve energy savings are varied and include:

- Behavioural change,
- Housekeeping and maintenance,
- Operational improvements for optimisation,
- Recovering more heat by heat integration of processes, and
- Investments in new process technology that fundamentally improves the efficiency of the operation.

The last three of these methods have been emphasised as key to achieving the most improvement in efficiency (Sheehan & Zhu, 2009). Although the most substantial efficiency increases come from investment in plants and equipment, greater attention to housekeeping and maintenance can still improve energy efficiency. Smaller efficiency gains can be obtained by retrofitting and optimising existing facilities (US OTA, 1993).

6.1.1.2 *Refinery Energy Efficiency Opportunities for GHG Abatement*

Energy efficiency measures contribute to cost effective GHG mitigation in refineries. This is shown in Figure 15 by (Mckinsey & Company, 2009). The figure gives an overall indication of the global GHG abatement potential for measures within upstream, midstream and downstream operations for Petroleum and Gas sectors. However, more specifically, the downstream GHG mitigation measures which refineries can utilise include:

· Energy efficiency from behavioural changes
· Energy efficiency from improved maintenance and process control
· Energy efficiency requiring CAPEX at process unit level
· Energy efficiency requiring CAPEX at process until level on retrofits
· Cogeneration
· Carbon capture and storage

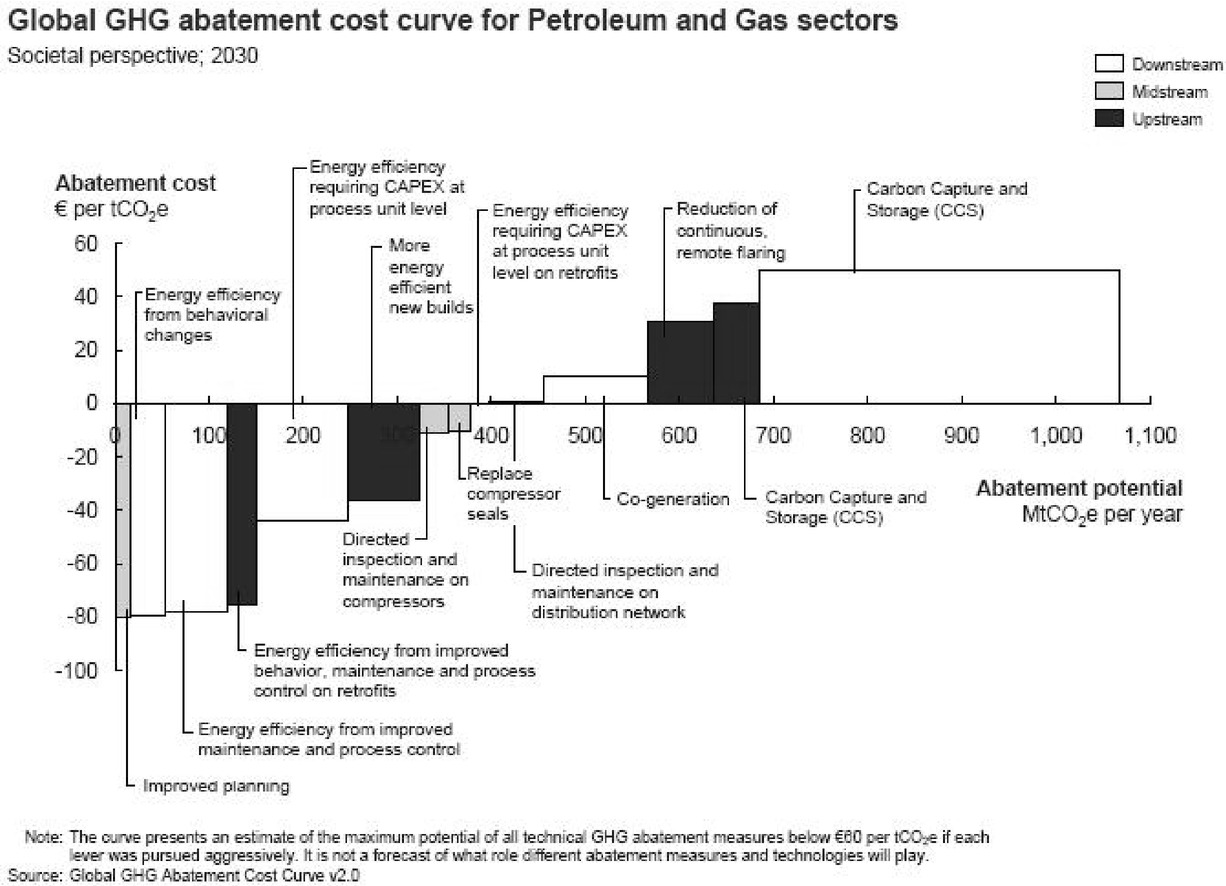

Figure 15 Global GHG Abatement Curve for Petroleum and Gas Sectors

Source: (Mckinsey & Company, 2009)

In Figure 15, the opportunities below the zero line can be achieved using existing technologies at a marginal cost of less than zero (which can also be shown as a cost saving). This figure shows that within the downstream segment (refining), energy efficiency opportunities have a negative abatement cost for GHG mitigation. These opportunities are:

- Energy efficiency from *behavioural changes*
- Energy efficiency from *improved maintenance* and *process control*
- Energy efficiency requiring *capital expenditure* at process unit level (Mckinsey & Company, 2009).

Although energy efficiency opportunities exist which are cost effective, there are a number of reasons for inefficiencies in existing refineries. These are discussed in the following section.

6.1.2 *Reasons for Inefficiencies in Existing Refineries*

While optimal energy performance can be achieved in grass-roots designs, it is very difficult to bring an existing refinery to the same efficiency (KBC Process Technology Limited, 2008). Even a refinery in the top 25% of energy efficient refineries worldwide (a first quartile pace-setter), consumes 50% more energy than an optimised refinery designed and built today (Milosevic & Cowart, 2002). Therefore it is very important to get things right in the design phase (KBC Process Technology Limited, 2008).

Reasons for inefficiency within the refining industry are generally cited as:

- Units were designed when the cost of energy was low.
- Phased expansion- new units were built stand-alone and not heat –integrated with older units.
- Utility systems were seldom optimised when onsite expansions were made.
- Capital savings- units were designed for minimum investment cost.
- Refineries rely on power import and have low in-house power generation efficiency (Milosevic & Cowart, 2002).

From the operational side, a number of well-known target interventions for energy efficiency include effectively managing initiatives such as:

1. Steam traps and steam leaks
2. Furnace flue gas excess oxygen levels
3. Burner maintenance
4. Steam header control

According to Shell Global Solutions, many refiners have not been able to fully sustain the focus and commitment for campaigns in these areas in the past due to various reasons. Frequently however, deteriorating performance with time arises particularly from competitive pressures on budgets and staff responsibilities. This can go somewhat unnoticed when plant performance management systems do not include sufficient detail on relevant energy data and management attention is occupied elsewhere (Heyman & Accattatis).

Understanding the causes of inefficiencies in refineries is central to improving energy efficiency, in addition to identifying the best areas to target improvements and ways to perform improvements.

The way in which the following sections (6.2 and 6.3) are structured has been derived from (Petrick & Pellegrino, 1999). They are structured into short- medium term and long term opportunities for energy efficiency improvements for existing refineries. Short- medium[9] term opportunities are considered

[9] The medium term is typically associated with the modification, retrofitting, replacement of near end of useful life and periodical major revamp of equipment to meet market or environmental dictates. The short term improvements are generally relatively straight forward equipment, maintenance and operational changes. Short

those that can be implemented with commercially available technologies, and long term opportunities, although having significant potential, are still in the research and development stages.

The information outlined in the following section (6.2) highlights energy efficiency opportunities together with examples of improvements and savings from existing refineries.

6.2 Short- Medium Term Opportunities for Energy Efficiency Improvement in Refineries

This section reviews opportunities for energy efficiency improvement. Consideration is given to both behaviour and best practices (housekeeping and maintenance) and capital expenditure projects; however the focus has been on the latter.

Capital projects can be differentiated into two categories, ‘standard’ projects and ‘restructuring renovation’ projects. ‘Standard’ energy efficiency projects may be defined to include renovation projects whose main objective is to improve energy efficiency and thereby reduce energy costs. These projects tend to focus on renovation of energy- intensive processes, specific equipment and energy service systems (Taylor, la Grange & Gous, 2000). Within European refineries, roughly 25% of process improvements can be achieved by a range of retrofits of process units. These include process modifications, furnace improvement (eg addition of air pre-heater), and improved heat integration (eg revamping and adding heat exchangers to feed preheat train in crude distillation units) (KBC Process Technology Limited, 2008) .

Substantial energy efficiency gains may also be achieved through ‘restructuring renovation projects’ of existing processes. These ‘restructuring renovation projects’ often have broader goals fundamental to the company’s core business. They may include expansions to incorporate greater economies of scale, major transformations in production processes and/or major changes in product quality or type. The benefits of these projects may include greater flexibility, reduction in input costs and higher quality products (Taylor and others, 2008).

Often, efficiency improvements can be incorporated during an expansion project. This allows a portion of the energy penalty of the older asset to be recuperated (Davis & Patel, 2004). In addition, executing a project in conjunction with an expansion project will lower the incremental cost of expansion of affected units. Simultaneous execution also provides some engineering and construction economies and makes an improvement on the overall return on investment (Marano, 2007). However, in this case, energy efficiency gains are often seen as co- benefits to broader improvements in the firm’s financial performance, which are the focus of a project’s appraisal (Taylor and others, 2008).

6.2.1 *Energy Management*

Performance management processes, such as the careful monitoring of key performance indicators (KPI’s), the application of energy management systems, and good housekeeping practices, are no to low cost opportunities for improvement in refineries. Other energy management solutions can consist

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term improvements typically have longer payback periods than industry standards, but could produce substantial savings with appropriate investment incentives (Petrick & Pellegrino, 1999).

of operational changes such as process optimisation, steam system optimisation, fuel system optimisation, reflux rate reduction and furnace excess air control. On average, the benefits from non/minor investments, such as energy management solutions, may amount to about 25% of the total benefits achievable, and these are typically considered short term interventions (KBC Process Technology Limited, 2008).

Training programs, energy awareness programs and accountability are additional methods of increasing energy efficiency with no to low investment in human capital through behavioural change. Low risk, low- tech solutions such as training for proper maintenance and operation is especially effective in reducing energy waste and increasing plant profitability. Training is often seen as a cost and not an investment, although significant savings can arise. Training has a high return, a quick payback time and additional benefits such as increased productivity, lower maintenance costs, improved reliability and most importantly, plant safety (Madan, 2002).

Behavioural changes however are always gradual and, for large companies, building increased awareness of the importance of energy conservation and CO_2 emissions reductions will take time and continued reinforcement. High level management attention will be required for this focus to remain effective (Mckinsey & Company, 2009). Leadership support for energy efficiency can promote implementation of projects, thereby integrating energy efficiency into business operations. Furthermore, training must be treated as a fundamental requirement of comprehensive energy management. Without the support of management to provide an environment to support implementation, including understanding the focus and purpose of training, expected results are greatly reduced. Management must be committed, proactive, and supportive, both attitudinally and financially, to implement a successful training program (Madan, 2002).

6.2.1.1 *House-keeping, Maintenance and Operational Best Practices*

Surprisingly large amounts of energy can often be saved through housekeeping, particularly so in older plants (US OTA, 1993). Housekeeping, maintenance and operational best practices are often regarded as ‘low hanging fruit’. These non/minor investment measures can lead to substantial accumulated savings. These measures include:

- Carrying out inspections to encourage conservation;
- Instituting training programs on operating energy-intensive equipment;
- Installing and using energy monitoring equipment;
- Wrapping tanks and pipes with insulation; and
- Repairing leaks.

(US OTA, 1993)

Handbooks and manuals for maintenance best practices are numerous. These span topics such as motor and motor applications, fans, compressed air systems, steam systems etc and give a thorough account of opportunities for energy savings through maintaining plant equipment.

Other short term opportunities for energy best performance or ‘operations excellence’ of plant equipment consist of operational best practices, which can reduce energy consumption. These include maintaining optimum reflux ratios, low pressure operation, wherever possible and optimising pump arounds (Kumar, 2008). An example of an operational excellence type improvement is in the area of fractionation. This is one of the areas where opportunities are frequently found, from stripping steam optimisation to adjusted fractionation settings on main columns in both primary distillation and major conversion units (Heyman & Accattatis).

Due to the comprehensive information found in manuals and handbooks, only some of the foremost maintenance and operational opportunities for energy savings will be highlighted and acknowledged here, and they can be carried out in the short term and on-going.

6.2.1.2 *Monitoring Overall Performance*

Improving energy use measurement and enhancing the understanding of a refinery's energy use, as a whole, is fundamentally important to initiate reductions in energy consumption. By promoting energy efficiency stewardship in the form of energy management programs, estimates of savings that can be realised range from 1- 4%.

Metering and monitoring equipment, process and overall refinery energy performance would effectively estimate and evaluate net savings and benefits from identified opportunities. Energy usage for key equipment and systems must be measured and compared to efficient, established performance criteria. This approach identifies opportunities by revealing energy use that is not required, regardless of the processes or technologies involved, and can initiate corrective action. Furthermore, it also provides useful data for quality and productivity improvement (Australian Government, 2010; Petrick & Pellegrino, 1999).

Energy management systems are already widely used in various industrial sectors although the performance can be improved to reduce costs and increase savings. Optimising process performance can be very low cost, for example, reduction of standby equipment, turning off redundant equipment, better start-up and shut-down procedures, and re-diverting activity but this requires good data and communication with operational managers to manage perceived risk (Australian Government, 2010). The specific savings for implementation of an energy monitoring system will vary greatly for different plants (Hydrocarbon Processing, 2001). The following table gives an example of typical achievable cost savings for a refinery energy optimisation and management system.

Table 6 Example of Identified Energy Efficiency Opportunity in Monitoring Overall Performance

Refinery and Location	Description of Opportunity	Savings
Valero Houston refinery[10]	During a plant-wide energy assessment, a refinery Energy Optimisation and Management System (OEMS) by Aspen Technology Inc. was developed. The OEMS is based on AspenTech's Aspen Utilities™ software and will be used in assessing, implementing, and tracking results of identified opportunities using real-time data to reflect current performance.	Typical cost savings are between 2-8% of energy expenditures.

Source: (Valero Energy Corporation, 2003)

6.2.2 *Utility System Improvements*

Utility generation accounts for around 40% of a refinery's total operating costs and is one of the largest consumers of energy in the plant. Utility management techniques can be applied in a refinery with varying benefits and investment requirements (Hydrocarbon Publishing Company, 2011). The principle utility systems consisting of steam, fuel-gas, power, and cooling systems, generally speaking, do not receive the same level of attention as critical refining process sub-systems as they support these systems. By improving their function and operation these supporting utility systems can have a significant impact on refinery energy savings and CO_2 emission reductions (Petrick & Pellegrino, 1999).

As one example, a potential energy improvement of 2- 3% from the use of Honeywell utilities optimisation solutions would save between $1.5 - 2.5 million per year. The table below gives an example of savings achieved in a refinery utilising a utility model and optimisation system.

Table 7 Example of Implemented Energy Efficiency Opportunity in Utility System

Refinery and Location	Description of Opportunity	Savings
Sunoco Philadelphia refinery	A computer-based utility model and optimisation program, known as Visual MESA, was implemented.	In the last six months of 2005 nearly $200,000 worth of energy was conserved.

Source: (Sunoco, 2011)

6.2.2.1 *Fuel-gas Systems*

Typically a refinery's fuel- gas system supplies approximately half to two-thirds of the energy utilised in the refining process (Petrick & Pellegrino, 1999). Refinery fuel gas is generally referred to as any gas that is generated by a petroleum refinery process unit, and also includes any gaseous mixture of natural gas and fuel gas (Zanganeh, Shafeen & Thambimuthu).

[10] The refinery is mid-sized with a throughput capacity of approximately 136 000 bbl/day.

Under certain conditions, the refinery can have excess energy -this occurs when the heat content of the fuel gases' combustion products exceed the energy requirement of the refinery. In the past, inefficient combustion has been tolerated and the excess fuel- gas has traditionally been flared and used for generating excess steam. Moreover, in the summer months, this excess gas problem is worsened, giving additional losses, as the light- ends separation systems are overtaxed (Petrick & Pellegrino, 1999). This valuable flammable gas may be recycled back for its material value or into the process for fuel (depending on the recovered gas composition). The specific savings for recovering fuel gas will vary from refinery to refinery.

Hydrocarbon loss in refinery flare is a direct energy loss; therefore the recovery of flare gas is a direct fuel recovery. Typically the vent gas is recovered by using a flare/vent gas recovery system, and reclaiming gases from vent header systems have increased due to economic and environmental considerations. By improving flare-gas recovery systems, flaring can be reduced. Furthermore the additional fuel gas which is then recovered can be utilised in other refinery processes such as process furnaces, gas turbines, HRSGs (Heat Recovery Steam Generators) and auxiliary boilers.

Improvements in flare-gas recovery include installing recovery compressors and collection and storage tanks, and this technology is commercially available. Improving process control equipment and installing new flaring technology are additional means to further reduce emissions. With new flaring technology, flared gas can be reduced with the development of ignition systems with low pilot gas consumption or ballistic gas consumption. Also, benefits from flare gas recovery (or zero flaring) include reduced air pollution, less negative publicity around flaring, and increased energy efficiency from fuel savings (PCRA; Worrell & Galitsky, 2005; Zadakbar, Karimpour & Zadakbar, 2006). Furthermore, John Zink Co. reports that the payback period for the installation of a flare gas recovery system can be in some cases as short as one year (Worrell & Galitsky, 2005).

Uncontrolled emissions can also lead to huge losses of VOC's to the atmosphere and this is caused by internal leaking equipment such as pressure relief valves, ball- and gate valves, in the absence of a through monitoring and maintenance program. These emissions are the most significant cause of losses of raw materials resulting from plant activities. Companies and organizations have more awareness to work on their flare emission monitoring programs from reasons such as:

- The visible flame at the flare stack
- The losses of raw materials
- Unreliable stream balances and
- The environmental aspect

(The Sniffers NV/SA, 2011)

The following table provides examples of opportunities implemented in refineries to reduce flaring and fuel gas leaks.

Table 8 Examples of Identified Energy Efficiency Opportunities in Flare- Gas Systems

Refinery and Location	Description of Opportunity	Savings
Tabriz Petroleum Refinery	A study identifies 630 kg/hr flare gas to be used as fuel gas.	A capital investment of $ 0.7 million corresponds to a payback period of approximately 20 months. In addition, approximately 85% of gas emissions will be decreased.
Shell Martinez refinery	Reduced flaring is achieved by installing dedicated back up compressors. Compressors capture excess gases which build up during the refining process and these gases are then re-routed back into the fuel-gas system.	Reduction of flaring by 74%.
Caltex Lytton refinery	Installation of a new smaller control valve which has better control of flow of fuel gas to the flare.	Estimated savings of 0.897 tonnes/hr of fuel gas relating to 400 000 GJ/yr in energy savings.
	Upgrade of seven identified leaking control valves, which vented fuel gas during emergencies of process upsets. Valves were upgrade to class v valves which give tighter seal.	Estimated energy savings of 4500 tonnes fuel gas/annum.

Source: (Australian Government, 2009; KTVU from Worrell & Galitsky, 2005; Zadakbar, Karimpour & Zadakbar, 2006)

Recovering fuel gas also brings potential opportunities to use the excess energy elsewhere. These opportunities include:

- Utilising an on-site cogeneration plant to generate additional electrical energy and reduce utility purchases; (see cogeneration section)
- Selling the gas to a nearby utility;
- Purchased gas, methane, can be somewhat replaced by isolating and utilising high hydrogen containing streams as feed to the hydrogen plant; and
- Utilising waste- heat driven absorption refrigeration systems to recover heavier hydrocarbons from the fuel streams (Petrick & Pellegrino, 1999).

6.2.2.2 ***Steam Systems***

Steam accounts for approximately 20-30% of energy use in a refinery and can be generated onsite from boilers, waste heat recovery from unit processes, and cogeneration. It is used throughout the refinery for a number of purposes most importantly process heating, drying or concentrating, steam cracking and distillation (Petrick & Pellegrino, 1999; Worrell & Galitsky, 2005). The US Department of Energy estimates that an energy savings of about 12% can be realised at most refineries from optimising steam systems (Hydrocarbon Publishing Company, 2011).

There are a number of opportunities for energy and cost savings within steam systems. In general these can be described to include *steam generation*, *steam utilisation and distribution*, and *heat recovery*.

Often *steam generation* occurs at higher pressures than needed or in larger volumes than needed at the required time, therefore steam systems should be evaluated on their production schedule and use of appropriate pressure levels. Through:

- *Improved process integration*, and
- *Improved management of steam flows*, this excess steam generation can be reduced.

Inefficiencies in steam systems can lead to the let-down of higher grade steam to lower pressures or even venting of excess steam to the atmosphere. If it is not possible to reduce steam generation pressure, it may still be possible to recover energy through a steam expansion turbine or turbo expander (Worrell & Galitsky, 2005). In addition, to reduce energy use, new generation more efficient electrical motors can replace steam driven ejector systems and condensing turbines (Petrick & Pellegrino, 1999).

In large boilers, *heat recovery* from flue gases is common practice by means of an economiser. To achieve additional savings there is often potential to further recover heat by preheating the feed water close to the acid dew point, before it enters the economiser. Savings are limited to 1% across all boilers, as exhaust temperatures are already quite low, with a payback of 2 years (IAC 1999 from Worrell & Galitsky (2005)). A rise in boiler feed water temperature of $6^{o}C$ by waste heat would offer about 1% fuel savings (Kumar, 2010).

In petroleum refining with direct steam contact processes, only about 60-65% of steam can be returned back to the boilerhouse (US DOE, 2006b). However, recovering and reusing hot condensate in the boiler can have substantial energy savings. The maximum energy savings are estimated at 10% by installing a condensate return piping system, with a payback of about 1.1 years. Additional benefits include: 1) reducing the need for treated boiler feed water and 2) reducing the blowdown flowrate from increasing feedwater quality (OIT 1998, IAC 1999 from Worrell & Galitsky (2005)). In addition, opportunities to recover low grade steam from blowdown, to preheat feed water or used in space heating, can save about 1.3% of boiler fuel use.[11] Payback periods may range from 1 to 2.7 years (IAC 1999 from Worrell & Galitsky (2005)).

Table 9 presents an example of savings from a condensate recovery opportunity at a refinery in North America.

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[11] This is for boilers below 105.5 GJ/hr (100 MMBtu/hr).

Table 9 Example of Implemented Opportunity for Condensate Recovery

Refinery and Location	Description of Opportunity	Savings
Refinery in North America	Changing the routing of the steam condensate streams enabled an enhanced overall condensate recovery. Implementation required operating instructions for some diverter valves within a thermal conversion unit and training of relevant operators.	Value of the change was estimated at some $200 000/year.

Source: (Heyman & Accattatis)

Within the *utilisation and distribution of steam*, optimisation of steam distribution can also realise energy savings and some of the most intense steam-consuming processes include steam cracking, distillation, and process heating (Hydrocarbon Publishing Company, 2011). Other opportunities such as rigorous maintenance and improving of steam traps, valves and insulation, as well as the rapid repair of steam leaks, will add up to significant energy savings. The savings from steam distribution opportunities are summarised by (Worrell & Galitsky, 2005) in Table 10.

Table 10 Summary of Steam Distribution Savings and Benefits

Measure	Fuel saved	Payback Period (years)	Other Benefits
Improved insulation in heat distribution system	3-13%	1.1	
Improved steam traps	na	na	Greater reliability
Steam trap maintenance	10-15%	0.5	
Automated steam trap monitoring	5%	1	
Leak repairs	3-5%	0.4	Reduced requirement for major repairs

Source: (Worrell & Galitsky, 2005)

The table above illustrates that monitoring steam traps and the following maintenance can be the most cost-effective opportunity when carried out effectively. Reduction in steam usage can be best accomplished in conjunction with the implementation and integration of state of the art cogeneration plant into the refinery (Petrick & Pellegrino, 1999). Steam generation, distribution, recovery and cogeneration can offer the most cost-effective opportunities in the near term (Worrell & Galitsky, 2005). Examples of savings from maintenance, optimisation and distribution opportunities within steam systems are highlighted in Table 11 .

Table 11 Examples of Implemented Energy Efficiency Opportunities for Steam Systems

Refinery and Location	Description of Opportunity	Savings
Flying J refinery (Utah)	Repairing leaking steam traps	Annual savings of $ 147,000 (in 2002)
Valero Refinery (Houston)	Optimisation of blowdown steam use	Annual savings of $213,500 (in 2003)
Sunoco Philadelphia refinery	A program was initiated to monitor steam turbine surface condenser efficiency. The monitoring indicates when condenser efficiency is dropping and heat exchangers are then scheduled to be cleaned. Maintaining a high efficiency reduces the amount of steam needed.	During 2005 the program reduced fuel consumption with a savings of approximately $170,000 per month.
Sunoco Eagle Point Refinery	A project connected the steam systems of two adjacent process units. This enabled the refinery to transfer surplus steam from one process unit to another	This saved an estimated 226 billion BTUs per year in fuel, which is a savings of approximately $1.7 million per year (in 2005).

Source: (Sunoco, 2011; Brueske et al from Worrell & Galitsky, 2005)

6.2.2.3 *Power Recovery*

Many processes run at high pressures allowing opportunity for power recovery from the pressure of flue gases, of which the fluid catalytic cracker (FCC) holds the most opportunity for power recovery. High volumes of high temperature gases define power recovery applications for FCC units. Typically modern designs use power recovery turbines or a turbo expander to recover energy from the pressure (Worrell & Galitsky, 2005).

In a study involving a 60 000 bbl/d FCC, a power recovery system was identified to realise significant energy efficiency savings. The flue gas was being used for steam generation via a waste heat steam generator. Compared to a base case, a power recovery turbine installed together with a steam turbine, were identified opportunities which would save $14 million per annum[12]. Electricity would be generated from the regenerator flue gas and also from HP steam let down to LP and MP steam required in the FCC unit (Sheehan & Zhu, 2009). (Opportunities for energy savings for fluid catalytic cracking are discussed further in section 6.2.6)

Power recovery can also be applied to other units at elevated pressure such as the hydrocracker where power can be recovered from the pressure difference between the reactor and fractionation stages. Table 12 presents three examples of energy savings from power recovery opportunities implemented in refineries.

[12] Base case uses a condensing steam turbine to drive the main air blower and does not include a power recovery turbine.

Table 12 Examples of Implemented Energy Efficiency Opportunities in Power Recovery

Refinery and Location	Description of Opportunity	Savings
Petro Canada Edmonton refinery	Replacement of old turbo expander by a more efficient unit.	Energy savings of approximately $1.9x10^6$ GJ/year (18 TBTU/ year)
Valero Houston refinery	Power recovery train was designed and constructed to recover energy from flue gases from the FCC. A regenerator air blower (24,000 hp) is driven by this recovered energy, avoiding the need to install a separate electric motor.	Energy savings of up to 22MW and sales of up to 4MW through occasional excess power generation.
Total Vlissengen refinery (Netherlands)	A 910kW power recovery turbine was installed to replace a throttle at the hydrocracker, operating at 160 bars.	Generated approximately 7.3kWh/year, and resulted in a payback period of 2.5 years with an inital investment of $1.2 million (in 1993).

Source: (Valero Energy Corporation, 2003; Worrell & Galitsky, 2005)

6.2.2.4 *Cooling Water Systems*

Cooling water and boiler feed water makeup account for 40-45% of water usage in refineries. The main purpose of water use on refineries is to transfer heat, and cooling water systems play a very important role in rejecting heat from process streams (Seneviratne, 2007). Therefore opportunities for saving energy also lie in generating improvements in the cooling water systems and providing low-temperature cooling. By cooling water temperature, the lights ends which originate from towers can be substantially reduced. This, in turn, decreases the reboiler duty for a constant separation. Also A/C compressor electricity consumption may increase by 2.7% with a 1^{o}C increase in cooling water temperature. Conversely a 1 ^{o}C drop in cooling water temperature can give a heat rate saving of 5kCal/kWh in a thermal power plant (UNEP, 2006) .

Similarly, the amount of light hydrocarbons lost to fuel gas would be reduced by lowering the operating temperature of absorbers. Other benefits of improved cooling include knock out of additional liquid product and reduced energy consumption by cooling feed to the suction of the compressor. However, even if no liquid is removed, the lowering of suction and intercooler temperatures will also improve efficiency.

Typically revamping cooling water towers with a modern fill material was the traditional method of lowering cooling water temperature. A new generation of waste-heat-driven absorption chiller systems can further enhance cooling capability by further reducing the temperature of cooling water streams or directly cooling process streams. Excess low grade heat from stack gases of process units such as crude distillation, catalytic reforming, fluid catalytic cracking and boilers provide opportunities for use in absorption chiller systems. The benefits of applying chilling in refineries include reducing energy requirements for distillation and improving product yield (Petrick & Pellegrino, 1999).

6.2.3 *Heat Integration and Fouling Mitigation*

One of the most effective means of reducing energy usage in a refinery comes from heat integration and process heat recovery. The potential for energy savings from heat integration far exceeds conventional techniques such as insulation, steam trap management and heat recovery from boiler flue gas(Worrell & Galitsky, 2005).

Energy efficiency can typically be improved by 4-8% through projects to improve process unit heat recovery. For a typical 100 000 bbl/day refinery, the CO_2 reduction that results from these projects is between 48 to 96 MMtons/year (Honeywell International Inc., 2011).

The application of pinch technology facilitates the identification of opportunities for heat integration. Pinch analysis involves identifying targets and following a systematic procedure for designing heat exchanger networks. In order to achieve these targets investment and energy are optimised to determine the optimum approach temperature. This is done by linking hot and cold streams but not crossing the 'pinch' (Worrell & Galitsky, 2005). Refineries have reported major fuel savings from heat integration derived from pinch analysis. Overall savings in energy consumption from 20 to 40% have been reported together with additional benefits such as reductions in waste products and pollutant emissions (Petrick & Pellegrino, 1999).

Separation systems, namely distillation columns, represent primary opportunities for heat integration (Petrick & Pellegrino, 1999). Older studies by Sunden (1996), Clayton (1994) and Lee 1989 (from Worrell & Galitsky (2005)) have indicated reductions in fuel savings from process integration for the CDU range between 10 and 19%. By integrating heat between the crude and vacuum distillation columns fuel savings from 10-20% can be achieved, compared to non-integrated units. This is at relatively short payback periods; however this will be highly dependent on changes in heat exchanger networks, fuel prices, and refinery layout (Petrick & Pellegrino, 1999; Worrell & Galitsky, 2005).

Heat exchangers, taking into account furnaces, are workhorses within a refinery. There are hundreds of heat exchangers found within a typical modern refinery and the overall energy efficiency relies heavily on heat integration achieved in feed/effluent heat exchangers that recover thermal energy from high temperature process. Due to heat exchanger fouling, energy savings achieved by heat integration can be readily lost unless aggressive fouling mitigation practices/programs are implemented. Fouling significantly reduces energy-use efficiency as it reduces thermal efficiency and heat transfer (Petrick & Pellegrino, 1999; Szklo & Schaeffer, 2007). Additional gas must be burnt to compensate for the lost energy, as well as increased capital and other operating costs. About 6.5% of total energy consumed within US refineries is lost due to fouling and is expected to become more problematic as heavier crude and residuum is processed in the future (Petrick & Pellegrino, 1999). A study by (Panchal, 2000) analysed the effects of fouling of a 100 000 bbl/day crude distillation unit. The analysis found an additional heating load of 13.0MJ/bbl due to fouling, amounting to a significant savings potential. The following table highlights savings from identified opportunities in refineries to mitigate fouling and to recover heat.

Table 13 Examples of Identified Energy Efficiency Opportunities for Heat Integration and Fouling Mitigation

Refinery and Location	Description of Opportunity	Savings
Petro Canada refinery	A heat recovery system was installed on a crude unit to recover waste energy and re-use fuel in feed furnaces.	The $750,000 project saved approximately $250,000 in fuel costs (in 2001).
Shell Martinez refinery	Regular cleaning of heat exchangers and maintenance of insulation (short term).	Estimated annual cost savings of over $14 million/year with an investment of $9.85 million (in 2002).
BP Bulwer refinery	Upgrade of crude furnace soot blower with new design for regular removal of tube fouling.	Estimated energy saving of 79 400 GJ/yr with reduction of CO_2 emissions by 4450 tonnes/yr and increased process throughput.
Refinery in North America (110 000 bbl/day)	An opportunity was found to add four heat exchangers to a vintage 1970s diesel hydrotreating unit to recover more heat from the process and also generate steam. This scheme reduced the product rundown temperature by 107°C and the temperature to the products condenser by 150°C which reduced the amount of heat lost in the fin fans.	Capital cost for this project was $3 million but resulted in energy savings of $4.5 million /yr. Other benefits included impact on operating flexibility, especially with respect to start-up, shutdown, maintenance and control.

Sources: (Australian Government, 2008; CIPEC, 2001b; Sheehan & Zhu, 2009b; US DOE- OIT, 2002b)

6.2.4 *Combustion Efficiency in Process Heaters/Boilers*

Most of refinery fuel is used in process heaters and furnaces. These units account for over 60% of energy used in refineries. Therefore a major target for energy savings is improvement in the efficiency of combustion systems of heaters and boilers. Even a 1 % fuel savings in a 10.55x 10^3GJ/day heater saves approximately 200 000 US $/year in fuel cost (Metso, 2010).

Most furnaces in industry have a thermal efficiency between 75% and 90%. The maximum achievable improvement in thermal efficiency of most furnaces can be approximately 10%. However, in this area, even a 5% improvement is a very large potential for energy and CO_2 emissions savings. Furnace thermal efficiency is restricted to a maximum of about 92% and this is attributable to unavoidable heat losses, economics and dewpoint considerations (Petrick & Pellegrino, 1999).

For maximum energy efficiency, fuel use must be minimised and heat recovery maximised. Complicating the problem of increasing efficiency however, combustion systems need to be fuel-flexible and meet stringent environmental emissions regulations. There are a broad range of efficiency opportunities from plausible to proven and varying in economic viability.

Air preheating offers an efficient way of improving efficiency of a process heater, especially for higher temperature processes. Flue gases are used to preheat air required for combustion with the use of recouperators. Typical fuel savings from air preheating range between 8 -18% and the typical payback period is estimated at 2.5 years. The cost of preheating may vary strongly depending on the layout of the refinery and furnace construction. In addition to this, an increase in NOx emissions constrains the use of this approach (Petrick & Pellegrino, 1999; Seebold, Waibel & Webster, 2001).

The table below (Worrell & Galitsky, 2005) summarises fuel savings and benefits from energy efficiency measures in boilers.

Table 14 Summary of Savings and Benefits from Energy Efficiency Measures in Boilers

Measure	**Fuel Saved**	**Payback period (years)**	**Other Benefits**
Improve Process Control	3%	0.6	Reduced emissions
Reduced Flue Gas*	2-5%	-	Cheaper emission controls
Reduced Excess Air*	1% improvement for each 15% less excess air	-	
Improved Insulation	6-26%	na	Faster warm-up
Boiler Maintenance	10%	0	Reduced emissions
Alternative Fuels	Variable	-	Reduces solid waste stream at the cost of increased air emissions

* Reducing excess flue gas can be achieved through fixing leaks in the boiler and the flue. This can be done by performing periodic repair based on visual inspection. The savings from this measure are from the same losses as flue gas monitoring (process control) and should not be double counted.

Source: (Worrell & Galitsky, 2005)

Table 14 indicates that boiler maintenance and improved insulation can have the greatest potential for energy savings for boiler operation.

Another opportunity to reduce fuel consumption for burners is to improve the heat-release profile. Heat- release profiling seeks to match heat release with load and the flame shape with the process tube configuration. It can be achieved with radiant burners which concentrate heat where it is needed upon design to match the shape of the load (Petrick & Pellegrino, 1999). New burner technology also reduces emissions dramatically and can be used instead of installing expensive selective catalytic reduction (SCR) flue gas treatment plants (Seebold, Waibel & Webster, 2001). Another opportunity includes enhancing flame luminosity with a variety of techniques, which has had varying success on improved heat-transfer characteristics. Potential efficiency gains of 5-10% can be achieved in process heater applications with the use of pulsed combustion (Petrick & Pellegrino, 1999).

The Table 15 following highlights two examples of opportunities for combustion efficiency within burners, and the achieved savings.

Table 15 Examples of Opportunities for Combustion Efficiency in Process Heaters/Boilers

Refinery and Location	Description of Opportunity	Savings
Paramount Petroleum Corporation Asphalt refinery (California)	Reduced excess draft air of burners by regular maintenance.	Cost savings of $290, 000 per year with payback period of about 2 months (in 2003).
Chevron Texaco refinery	New low NOx burners were developed achieving a reduction in emissions from 180 ppm to 20 ppm. The installation of the burners in a reforming furnace reduced emissions by over 90% and eliminated the need for a SCR.	The refinery saved $10 million in capital costs of the SCR and $1.5 million/year in operating costs (in 2001).

Source: (Seebold, Waibel & Webster, 2001; US DOE, 2003)

6.2.5 *Distillation*

Distillation is the largest energy consumer among process units in a refinery. Overall savings of up to 55% ($5.9MM/year[13] in a 100 000 bbl/day refinery) can be achieved by improving energy use in this unit through fouling mitigation, heat integration and novel technologies (Hydrocarbon Publishing Company, 2011). Detailed energy analyses can identify substantive opportunities for energy savings in distillation. The main developments in the medium term are improved integration using heat recovery technology and the integration of different distillation units (CDU and VDU) (Szklo & Schaeffer, 2007).

The greatest potential areas for improvement have been identified in an energy analysis as:

- The fired heater,
- Condensate reflux system,
- Crude preheating train and
- Effluent cooling train (Rivero et al (1989) from Petrick & Pellegrino (1999).

A 10% reduction in energy use in the distillation process would reduce overall refinery energy consumption by approximately 4- 7%. This highlights the importance of improving waste heat recovery and enhancing combustion efficiency. Modifications in distillation for energy efficiency improvement units have been summarised in Table 16 (Petrick & Pellegrino, 1999).

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[13] $5.9 Million

Table 16 Energy Efficiency Measures for Distillation

Improving fired heater combustion efficiency through modification of the burners, applying advanced control technology and using a recuperative air preheater.
Incorporating a staged crude preheat.
Replacing steam ejector vacuum pumps with efficient, electrically driven mechanical vacuum pumps.
Selectively introducing vapour recompression into the overhead reflux condenser subsystem (eg depropaniser column).
Improving heat recovery and integration between crude and vacuum distillation units with 10 -20% energy savings.
Substituting reboilers heated by the main column for the stripping steam in stripping columns.
Optimising number of trays or using more efficient packings.
Major revamping of towers to increase number of heat-integrated condensing steps, thereby reducing the loads on fired heater and main condenser.

Source: (Petrick & Pellegrino, 1999)

The following table gives examples of savings achieved through energy efficiency opportunities in the distillation unit.

Table 17 Example of Identified Energy Efficiency Opportunities in Distillation

Refinery and Location	Description of Opportunity	Savings
BP Kwinana refinery	Improved heat integration across the No.1 crude unit and replacement of the furnace.	Estimated energy savings of 303,000 GJ/yr although payback would exceed 4 years.
Sunoco Tulsa Refinery	Upgrading of insulation in the crude distillation unit.	Resulted in a reduction of 9.6 million BTUs per hour of heater fuel which was equivalent to a savings of $550,000 for the year.

Source: (Australian Government, 2009b; Sunoco, 2011)

6.2.6 *Fluid Catalytic Cracker*

Typically within a refinery, the FCC flue gas stack accounts for 15 to 25% of overall CO_2 emissions (Sheehan & Zhu, 2009b). The FCC produces the majority of the gasoline pool and therefore, with an increasing trend towards “white products”, is likely to be an attractive target of opportunity for energy savings. The increase in use of heavier crudes will increases coke (carbon) laydown on the FCC catalyst and thereby increase opportunities for heat generation from FCC (Petrick & Pellegrino, 1999). In the FCCU energy use can be reduced by 28% by minimising heat loss, and implementing power recovery operations and various other improvements (Hydrocarbon Publishing Company, 2011). Heat recovery from hot flue gas represents a large source of energy savings and the high level heat is recovered by flue gas coolers which generate superheated steam (Lucas, 2001).

Studies have shown that optimisation of the FCC unit can increase the yield of gasoline and alkylate from 3% to 7% by appropriate modification of equipment and operating conditions. Increasing product yields per barrel of crude processed can give a substantive reduction in energy usage per barrel by increasing process efficiency (Petrick & Pellegrino, 1999). The following table gives an example of savings from an energy efficiency improvement in the FCC unit at a refinery in Texas.

Table 18 Examples of an Implemented Energy Efficiency Opportunity for the FCC Unit

Refinery and Location	Description of Opportunity	Savings
CITGO Corpus Christi refinery (Texas)	Combined an online optimiser with existing control systems to improve operations of the FCC unit.	Cost savings of $0.05/bbl was achieved (in 2000).

Source: (Timmons, 2000)

6.2.7 *Cogeneration*

Combined heat and power generation (CHP) (otherwise known as cogeneration) is a suite of technologies that can use a portfolio of fuels[14] in generating electricity and useful thermal energy (Shipley and others, 2008). It is one of the most cost-effective methods of reducing CO_2 emissions as it reduces the carbon footprint of separately generated heat and power (IEA, 2008).

CHP has a long history with the petrochemical and chemical industry. This is due to the numerous processes that require a large amount of heat and power (Saygin and others, 2009). Heat that would normally be lost in the power generation process can be recovered to provide needed heating and/or cooling. This allows for much greater improvement in overall fuel efficiency, resulting in lower costs and CO_2 emissions (Shipley and others, 2008).

In general, the average efficiency for power generation is in the range of 35-40% whereas combined heat and power efficiency can approach 80%. For an average furnace installed in a refinery, efficiencies are estimated at 70-82%; where this is about 80% for state-of-the-art steam boilers. These efficiencies for utilities may be lower due to older units that were designed below current state- of- the -art efficiency ratings and/or these units have decreased in efficiency over time due to natural occurrences in service (ie fouling). When compared to generating utilities separately, combined heat and power generation can result in an overall efficiency improvement of 27% (Hydrocarbon Publishing Company, 2011).

When compared against current generation of grid power, cogeneration offers primary energy savings of 20%[15]. The primary energy savings of cogeneration, when compared to power generation from natural gas, are 4- 10% (Saygin and others, 2009). When comparing cogeneration to the separate production of electricity and heat, total energy savings of between 15- 40% of energy can be achieved. However, cost savings for a cogeneration project are dependent on the price of electricity and the cost of primary energy fuel. Generally, suitable heat requirement is a prime criterion for a

[14] These include fossil and renewable based – natural gas, coal, oil, biomass, wood, waste fuels (landfill and digester gas) (Shipley and others, 2008).

[15] Cogeneration compared to state-of-the-art power generation by coal fuel type leads to primary energy savings of 12%.

cogeneration project, as its success depends on using recovered heat productively[16] (UNEP). However if a refinery traditionally imports electricity then the attractiveness of cogeneration technology may not be as great. Thus, the sourcing of utilities may be a limiting factor for a refiner compared to one who generates all utilities onsite. The value of cogeneration technologies may also be limited by the ability of refiners to polygenerate additional utilities (eg hydrogen) and the ability to export excess electricity, heat, hydrogen, and chemical feedstocks to other consumers (Hydrocarbon Publishing Company, 2011; Sheehan & Zhu, 2009b).

Cogeneration plants operating life can span 20 years and under favourable conditions a payback period of 3 to 5 years can be achieved, although the total investment is dependent on the design and scale of the plant (UNEP). The systems comprise of a variety of configurations including topping and bottoming cycles or single-turbine systems (Petrick & Pellegrino, 1999).

Table 19 below gives examples of savings achieved by CHP plants in three US refineries.

Table 19 Examples of Identified Energy Efficiency Opportunities for Cogeneration

Refinery and Location	Description of Opportunity	Savings
Paramount Petroleum Corporation refinery (California)	A CHP plant would generate 6.5MW of electricity and 31.7GJ/hr steam in addition to reliability of electricity supply.	Cost savings of an estimated \$3.79 million annually. The project was estimated to cost \$9.48 million with a payback of 2.5 years (in 2003)
Tesoro Petroleum Corporation refinery (Salt Lake)	A 22MW CHP plant was installed for reliability of electricity supply and uses natural gas and refinery gas as sources of fuel. The plant provides 15MW peak load (14MW average load) and exports 7-10MW to the utility grid.	The project cost \$25 million which paid for itself in 4 years. It saves \$6 million annually (in 2006). In addition, it has reduced GHG emissions by more than 500 tons/yr.
Valero Houston refinery	A 34MW cogeneration plant was constructed in 1990 which supplied all electricity for the refinery and electricity could be exported to the grid.	Cost savings of approximately \$55, 000 per day.

Source: (US DOE- OIT, 2003; US DOE, 2006b; Valero Energy Corporation, 2003)

Other opportunities to provide power and heat include expansion turbines, natural gas fired turbines, coke fired fluidised bed steam generators and gas fired boilers. Developments such as advanced turbine systems and fuel cells have the future potential to increase overall efficiency in stand-alone simple cogeneration plants by up to 13 percentage points and 24 percentage points, respectively (Petrick & Pellegrino, 1999). In the table below, efficiencies of natural gas fired CHP systems are shown together with their nominal capacities and typical CO_2 emissions per MWh. These systems

[16] A fairly constant demand of at least 4500 hours/yr is a general guide.

have efficiencies which are greater than for current generation for grid power, however with lower capacities.

Table 20 Efficiencies of Natural Gas Fired CHP Systems

Prime Mover (fuel)	Nominal Capacity, MW	Effective Electrical Efficiency, %	Steam/Heat Output, MM Btu/hr (MW)	Power-to-Heat Ratio	CHP Efficiency, %	CO_2 Emissions kg/MWh
Gas Turbine w/HRSG (NG)	1-40	49-66	8.31 (2.4)-129.27 (37.8)	0.47-1.06	66.3-72.1	2379-4138
Microturbine	0.035-0.250	46.7-58.9	0.17 (0.051)-1.20 (0.351)	0.53-0.69	63.8-71.2	3036-3927
Reciprocating Engine (NG)*	0.1-5	67-78	0.61 (0.179)-15.23 (4.500)	0.56-0.79	73-79	2258-3095
Steam Turbine (chemical plant)	0.5-15	75.1-77.8	19.6 (5.7)-386.6 (113.2)	0.09-0.13	79.5-79.7	NA
Fuel Cell (PAFC)	0.2	81.9	0.850 (0.249)	0.8	81	0.077
Fuel Cell (PEM)	0.01-0.20	53.58-65.01	0.04 (0.012)-0.72 (0.211)	0.85-0.95	65-72	0.13
Fuel cell (MCFC)	0.3-1.2	56.48-56.67	0.48 (0.141)-1.90 (0.557)	2.13-2.16	62	0.044
Fuel cell (SOFC)	0.125	74.02	0.34 (0.1)	1.25	77	0.11

Source: (Hydrocarbon Publishing Company, 2011)

6.2.7.1 *Gasification*

The increasing demand for lighter products and processing of heavier crudes is giving rise to a growing stream of refinery residues and heavy bottoms. To deal with these by-products refiners can use gasification to process these heavy fractions, and coke, to synthesis gas. This synthesis gas can then be used as a feedstock for chemical processes, hydrogen production and generation of power in an Integrated Gasification Combined Cycle (IGCC) (Bailey & Worrell, 2005).

The IGCC is one cogeneration option, which can take advantage of a wide range of available feedstocks for the utility requirements of a refinery. Entrained bed IGCC technology was originally developed for refinery applications, but is also used for the gasification of coal. Low value residues and petcoke can be processed for the generation of power, steam and H_2. This will have an added significance in a GHG-constrained world.

IGCC is considered the most efficient conversion method to process solid feeds to yield electricity and offers a more cost-effective approach to reducing emissions than other abatement technologies. Reductions of up to 40% of CO_2 emissions and 80% of SOx, NOx, CO and particulate emissions can be achieved (Bailey & Worrell, 2005; Hydrocarbon Publishing Company, 2011). The efficiency of an IGCC using heavy fuel oil is estimated to be around 40%, whereas the efficiency for net power

production from 3,664 kWh/t petroleum coke is estimated at approximately 38.2% ((Marano, 2003) from (Bailey & Worrell, 2005))
In addition, a significant supply of hydrogen gas can be generated together with power and steam, by integrating large efficient IGCC plants into refinery facilities. Within a typical refinery, many processing units use large volumes of H_2 with hydrogen supply is becoming an increasingly important issue in hydrocarbon processing (Hydrocarbon Publishing Company, 2011).

6.2.8 *Hydrogen Management*

Hydrogen management is becoming more of a priority in refineries with increasing demands for hydrogen. These demands stem from reasons such as:

- *Additional hydrotreating capacity* required for processing heavier and higher sulphur crude slates,
- *Producing lower sulphur fuels* (gasoline and diesel) in the clean fuels environment,
- *Processing lighter fuel products* from cracking processes.

Hydrogen management implies being aware and in control of all issues and opportunities relating to the demand and supply of hydrogen (Phillips, 1999). It is becoming more of a priority to achieve higher hydrogen purities to boost hydrotreater capacity, achieve product value improvements, and to lengthen catalyst life cycles. Furthermore, in some instances less hydrogen is generated, as refineries may reduce naphtha reforming to meet aromatics limits (Bealing and others; Davis & Patel, 2004).

Typically a hydrogen management programme fits into either a catalytic reformer supplied network or an on purpose hydrogen supply. More complex refineries, especially those refineries with hydrocracking units, may have on-purpose H_2 production and a catalytic reformer supplying off gas H_2. Typically this would be combined with the use of a steam methane reformer (SMR) which utilises, as a feedstock, refinery offgas and supplemental natural gas (Davis & Patel, 2004).

Hydrogen production and distribution networks are often seen by refiners as similar to a utility system and hydrogen ‘pinch’ analysis can be employed for integration. Energy efficiency improvements during hydrogen production in steam methane reformers (SMR) can increase overall energy savings (Hydrocarbon Publishing Company, 2011). Opportunities for energy efficiency in large SMR based H_2 plants can be identified through *hydrogen management*. These opportunities may include:

- Reforming process optimisation (eg reduced steam/carbon ratio and new inlet/outlet temperature setpoints)
- Furnace optimisation (eg excess air control, higher radiant efficiency, and improved waste heat recovery)
- CO_2 removal system energy reduction
- H_2 PSA recovery enhancements

The benefit of a hydrogen management programme is that it quantifies the economic benefits for improvement options in recovery, purification, and production of H_2. And this can be done in categories of no, low and higher capital execution plans. The production and uses of hydrogen can also be made visible using the approach of composition curves used in hydrogen pinch analysis (Davis & Patel, 2004). The hydrogen pinch analysis approach identifies the optimum hydrogen network. The processing revenue in terms of hydrogen system operating costs and production benefits is maximised, while minimising capital investment. As a further benefit, minimising operating costs also reduces CO_2 emissions. Typical savings from hydrogen pinch analysis include:

- Hydrogen demand: up to 20%
- Hydrogen system operating costs: up to 15%
- Capital avoidance: up to 15%
- CO_2 emissions: up to 160 kg per 1000 barrels of crude (CanmetENERGY, 2003).

Hydrogen management has been proved to discover valuable benefits for refinery operations. Process optimisation improvements with minimum investment can reduce energy consumption by 0.373-0.745 MJ/m^3 [17]. This reduction results in savings of $0.7 to $ 1.7 million in energy bills a year. Furthermore, nominal capital investment could result in $2.1 - $2.6 million a year in savings from energy efficiency improvements of up to 1.12 MJ/m^3 H_2.

Another opportunity is the replacement of an aging H_2 plant because of poor efficiency and high maintenance costs. Up to 20% lower energy consumption can be used in a new high efficiency SMR plant at 1.4 million Nm^3/day as opposed to a conventional plant design. The annual savings for the new efficient plant can be between $4.5 to $5.5 million/year[18] (Davis & Patel, 2004).

6.2.9 *Advanced Process Control*

Multivariable predictive control and optimisation applications have been commonly applied to refinery and petrochemical processes. In most refineries, opportunities exist to operate unit processes more efficiently. With little or no capital investment, operational solutions can improve energy efficiency by 2- 4%. The achievable reduction in CO_2 emissions can range between 24000 - 48000 ton per year for a typical 100 000 bbl/day refinery (Sheehan & Zhu, 2009). Plants which do not have updated process control systems typically may achieve energy savings of approximately 5% or more. Many refineries may already have modern process control systems but are often not solely designed for energy efficiency, but rather for improved productivity, product quality and efficiency of a production line. By incorporating energy efficiency objectives into existing strategies, controllers can be used to minimise energy use and also to maximise throughput and yield (Sheehan & Zhu, 2009b; Worrell & Galitsky, 2005).

The benefits of modern control systems include:

- Reduced downtime,
- Reduced maintenance costs,

[17] For a conventional 1.4 million Nm^3/day plant with a current net efficiency of 18MJ/m^3 H_2.

[18] Using savings of 2.6 MJ/m^3 and typical energy costs a $4.2 to $5.3/GJ ($4 to $5 /MMBTU).

- Reduced processing time,
- Increased resource and energy efficiency, as well as
- Improved emissions control (Worrell & Galitsky, 2005).

Table 21 gives two examples of opportunities for advanced process control and achieved savings.

Table 21 Examples of Identified Opportunities for Advanced Process Control

Refinery and Location	Description of Opportunity	Savings
Refinery in North America	An opportunity was identified for improving steam usage of a naphtha feed fractionation column reboiler, and optimising its steam consumption. The reboiler steam rate was controlled by an APC system, and was targeted at 30% reduction for the prevailing column charge rate.	Total realised savings were approximated at $4 million/yr. This was due to processing credits for downstream units which included lower fuel use and a consequent reduction in steam production, as well as reduced steam usage.
BP Kwinana refinery	The catalytic reformer unit (CRU) operates at high severity to make motor spirit blending component. An opportunity was identified to reduce energy usage severity by improving the control system software used to blend and revamping of the model used to formulate the blends.	Energy savings of 47 000 GJ/yr with an expected payback of less than 2 years.

Source: (Australian Government, 2009b; Heyman & Accattatis, 2006)

6.2.10 *Electric Motor Systems*

Motor systems in a refinery include conventional motors and motor use in pumps, fans and compressors. They account for about 80% of electricity used in a refinery. Therefore the optimisation of the motor is a primary focus when optimising electrical consumption on the plant. Conversion inefficiencies and distribution problems cause about 55% of electricity used in motors to be lost. On average, motor efficiency can be improved by 12-15%, through various improvements. Novel vacuum generating technologies such as ejectors can also yield efficiency improvements as the process of creating a vacuum is often very energy-intensive (Hydrocarbon Publishing Company, 2011).

When considering an upgrade at the end of equipment life, there is opportunity for replacing it with an energy saving option as opposed to replacement in kind. Areas for potential improvement, with regard to the selection and operation of electric motors, in the medium term include: energy efficient motors, variable speed drives and correctly sized motors (US OTA, 1993).

6.2.10.1 ***Motor Systems***

Motors are used in pumps (60%), air compressors (15%), fans (9%) and other applications (16%) (Worrell & Galitsky, 2005). A systematic approach to analysing a motor system on a plant is optimal to matching supply and demand of energy services. This approach yields savings of 20 to 50% when compared to 3% to 15% with individual component efficiency improvement (CIPEC, 2001b). The best way to improve efficiency within this area is thus to use both a systems approach while also looking to improve individual components.

Areas of motor systems that can lead to energy inefficiencies include:

- Incorrect sizing of the pump
- Unnecessary operation of backup pumps
- Varying flow rate requirements
- Excessive noise, heat or vibration
- Inadequate piping systems (Hydrocarbon Publishing Company, 2011).

Dealing with these inefficiencies can lead to noteworthy accumulated savings. For example, correcting for motor oversizing saves 1.2% of their electricity consumption (on average for the U.S. industry), and this can be an even larger percentage for smaller motors (Xenergy Inc, 1998). The following table gives an example of correcting for motor oversizing, with savings of $22 106/year.

Table 22 Cost Comparison for Oversized Motor

Motor Size	**110 kW (68% loaded ie 75kW)**	**75kW (sized to match needs)**
Annual Energy Use (kWh)	694 737	473 694
Annual Energy Cost ($)	69 474	47368
Annual Energy Savings ($)	22 106	

Assumptions: Operating 2000hrs/year, electricity costs 10 cents/kWh, 95% efficiency, power factor not considered.

Source: (Queensland Government)

<u>High efficiency motors</u> (HEM) are also a noteworthy energy saving opportunity and use 1% to 4% less energy than standard motors depending on their size. They are generally more reliable, last longer and result in lower transformer loading. A standard motor costing $2400 may consume over $144000 in electricity costs over a 10 year period. An equivalent HEM may save over 600% of its initial incremental cost[19] over the same period, although it may cost 15% to 20% more than a standard motor. This relates to a payback of approximately 1.5 years or less (CIPEC, 2001). Although typically high efficiency motors are not economically feasible when replacing a motor that is still working (CADDET, 1994).

<u>Variable speed drives.</u> Many refineries use constant speed motors and mechanically regulate process flow through throttling valves, dampers, fluid couplings or variable inlet vanes. These devices generally do not control flow efficiently as energy is dissipated across the throttling device.

The installation of adjustable speed drives reduces motor energy consumption by adjusting the motor speed continually to match the load of equipment such as pumps, fans and compressors (Queensland Government). Effective speed ranges are from 50% to 100% of maximum speed which can give

[19] The incremental cost is the premium paid over that of a lower efficiency component.

substantial energy savings (CIPEC, 2001b). The installation of adjustable speed drives also improves overall productivity, control and product quality (Worrell & Galitsky, 2005).

Variable speed drives have reduced maintenance in comparison to DC systems and reduced noise levels, however they have increased cost and complexity. In addition, they tend to be more economically viable on large motors (CIPEC, 2001b; Queensland Government). However in cases where a VSD is too expensive or when a motor is oversized (so much so that the variable speed controller would operate at very low speeds) there are two options which can be considered:

- Use of a multi- speed motor (which operates on a number of different speeds), or
- Installation of several smaller motors with controls to switch on the required number of motors to meet the demand.

Energy efficient belts can be installed such as cogged belts. They can be more efficient than smooth belts due to less slippage. The energy consumption can be reduced by 3-5% with an added benefit of a longer service life (Queensland Government).

Power factor correction can decrease power consumption and hence decrease electricity costs. Improved power factors through correction can prevent extra current flows, decrease the chance of cables overheating, increase equipment reliability, reduce supply costs and reduce greenhouse gas emissions (Queensland Government).

The power factor can be corrected by minimising:

- idling of electric motors,
- avoiding operation of equipment over its rated voltage,
- replacing motors by energy efficient motors (see above) and
- installing capacitors in the AC circuit to reduce the magnitude of reactive power in the system (Worrell & Galitsky, 2005).

With better motor management practices and improved selection of motors, 10-25% of motor energy costs can be saved (Queensland Government). The following table below describes an opportunity for electricity savings within a US refinery's motor system.

Table 23 Example of Identified Opportunity for Motor Systems

Refinery and Location	Description of Opportunity	Savings
A West Coast refiner (US)	An industry-government partnership identified near-term gains by adopting existing technologies with the OIT's Motor Challenge. The program used a 'systems approach' for motors, drives and motor-driven equipment.	Annual electricity savings of over \$700 000 and 12 million kWh.

Source: (US DOE- OIT, 2001)

6.2.10.2 *Pumps*

A pumping system is made up of a pump, driver, pipe installation and controls. As mentioned above the pumping system should be evaluated using a systems approach over the entire motor system of pumps, compressors, motors and fans. This is recommended for optimal savings and performance.

Significant opportunities exist to reduce pump system energy use though smart design, retrofitting and operating practices (US DOE- OIT, 2004). Maintenance and operations can give typical savings of 2 to 7% of pumping electricity with a payback period of immediate to one year (Xenergy Inc, 1998).

Electricity use in pumps makes up approximately 60% of energy use in motors and 48% of total electricity use in refineries. The initial choice of a pumping system should consider the energy cost over its lifetime, as energy costs may make up to 95%. The initial capital cost makes up a modest 2.5% of the total cost (Xenergy Inc, 1998).

Variable speed drives are suitable for pumping systems in which the pump is sized for an intermittent maximum flow rate but runs mostly at a reduced (but variable) rate (US DOE- OIT, 2004). The following table gives two examples of energy efficiency opportunities for pumps.

Table 24 Examples of Identified Opportunities for Pumps

Refinery and Location	Description of Opportunity	Savings
Replan refinery (Brazil)	An opportunity for variable speed drive installation was identified after an analysis of 5 fixed speed pumps of an atmospheric distillation column was carried out. The distillation column operated at capacities ranging from 125hp to 200hp.	Electricity savings potential of 2.6 GWh per year.
A San Francisco refinery	A variable frequency drive (VFD) [20] was installed on a primary feed pump (2250 hp) and on a product transfer pump (700 hp).	Each VFD saved $220 000/yr and $120 000/yr respectively (in 2004) with additional benefits of reduced vibration an elimination of mechanical seal and bearing failures.

Source: (Szklo & Schaeffer, 2007; US DOE- OIT, 2004)

6.2.10.3 *Compressors and Compressed Air Systems*

Considerable savings can be achieved by reducing energy consumption in compressors and compressed air systems as typically, within a time frame of 10 years, the cumulative costs of a compressed air system are made up of 10% maintenance cost, 15% capital cost and 75% energy cost (Energy Research Institute).

The largest single waste of energy associated with compressed air usage is air leakage. Air leakage can account for 20% of total air usage in a typical industrial plant, and can be as high as 50% (CIPEC,

[20] There are several types of variable speed drives (VSD). The most energy-efficient option for control in applications that require flow or pressure control, particularly in systems with high friction loss, is an electronic VSD. This is referred to as a variable frequency drive (VFD).

2001b). A properly managed compressed air system can save energy, reduce maintenance, decrease downtime, increase production throughput, and improve product quality. Addressing both the supply and demand sides of the system (and the interaction of the two) is important in improving and maintaining peak compressed air system performance (US DOE, 2003).

An average savings of 35% has been obtained when variable speed drives have been used to control air compressors (CIPEC, 2001b). A VSD equipped compressor maintains a target pressure level of an exact and constant pressure. It does so by varying air compression flow in response to changes in detected air system pressure (Control Techniques, 1999). The following table gives an example of an opportunity for a compressed air system.

Table 25 Example of Implemented Opportunity for Compressed Air System

Refinery and Location	Description of Opportunity	Savings
Mobil lubrication plant (California)	The retrofit of the compressed air system included installing a new 50 hp air compressor and fixing air leaks in the system.	Annual cost savings of $20, 700 with a reduction in plant energy consumption by 517 000 kWh. The $23, 000 investment paid for itself in just over a year (in 2002).

Source: (US DOE- OIT, 2002)

6.2.10.4 *Fans*

Fans often experience varying demand because air flow rates often change according factors such as production level, occupancy, temperature, and boiler load. The most efficient control option to adjust a fan's output is a speed control mechanism such as a VFD. The inherent soft-start capabilities of a VFD can also limit starting currents.

When loads vary over time by 30% of the full load, adjustable speed drive (ASD) retrofits offer good opportunities for cost savings. Energy savings of 50% or more may be available when fixed speed systems are modified to match variable loads requirements of a centrifugal fan or pump (US DOE, 2008).

In addition, fan system designers often tend to be conservative and specify oversized fans greater than the system requirements. Oversized fans increase operating costs, noise levels and operating costs (US DOE, 2008). Table 26 shows an example of an opportunity for energy savings at a Californian refinery for fan motors.

Table 26 Example of Identified Opportunity for Fans

Refinery and Location	Description of Opportunity	Savings
Paramount Petroleum Corporation refinery (California)	Six evaporative cooling towers supply cooling to process equipment. An opportunity was identified for variable speed fan motors to replace fixed speed fan motors ranging from 40 hp to 125 hp which were properly sized for summer conditions but oversized for cooler months. VSD's would be installed on all 6 motors and drives would be set to maintain cold water temperature design set point.	Cost savings of approximately $46,000/yr could be achieved with electricity savings of 1.2 million kWh and payback period of 5.8 years[21].

Source: (US DOE- OIT, 2003)

[21] Annual savings varies with the cost of natural gas. The payback period ranges from 4.2 to 7.7 years.

6.3 Long Term Opportunities

Long term opportunities require novel breakthroughs in research and development projects for refinery processes. Increasing refinery complexity and energy use for processing heavier crudes will require new approaches to refining to counteract these pressures. Table 27 below summarises research and development opportunities for reducing refinery energy use in the long term. These are not considered further in this study.

Table 27 Long Term Research and Development Opportunities for Energy Consumption and CO_2 emissions

Technology Developments	Savings and Benefits	Negatives
Distillation		
Thermal Cracking Process	Potential net energy savings of 65MJ/bbl crude processed.	High- cost option & drastic technological change.
Progressive distillation unit	Savings of up to 30% of total energy use for CDU and VDU.	Applicable to distillation units to be constructed.
Dividing-wall distillation	Savings of up to 30% in energy costs and lower capital costs compared to conventional columns.	Further development in petroleum refining industry still needed.
Hydrogen recovery		
Membrane separation technology	Recovery yield of 85-95% and purity 95%. Lowest cost option for low product rates	Hydrogen content must be at least 25% for economic recovery. Not lowest option for high flow rates. Development still needed for low cost membrane and lower requirement of hydrogen content.
Hydrotreating		
Olefin alkylation of thiphenic sulphur (OATS) process	HDS process no longer necessary. Reduces hydrogen and energy use. Takes place under mild conditions. Hardly influences octane.	Further studies required.
Oxidative desulphurisation process (ODP)	The combined approach of less severe HDS and ODP, for diesel desulphurisation, would imply energy savings of 40% when replacing severe HDS units.	Process still under development with prospects for gasoline not as good as for diesel.
Catalytic distillation (CD) process	Saves 52% of energy use in HDS and reduces hydrogen consumption by 81%. Avoids drop in FCC gasoline octane number. Long catalyst life cycle (5 years). Octane loss less than 1% and null gasoline yield loss. Already a commercial option.	
Biodesulfurisation	Estimated decreased CO_2 emissions by 70-80% compared to conventional hydrodesulphurisation. Mild processing conditions and reduced need for hydrogen make-up. In mid to long term, biodesulphurisation would achieve 15-25% lower operating costs and 50% lower capital costs.	Still in research and development stages. Further research is still needed in biological mechanisms of biocatalysts and economically suitable method for large scale preparation of biocatalysts.

Source: (Szklo & Schaeffer, 2007)

According to (Szklo & Schaeffer, 2007), with stricter sulphur regulations in the future, the most promising desulphurisation alternatives for the mid to long term appear to be the ODP process for diesel treating, and the CD process for gasoline treating.

Other opportunities for the long term include the development of improved catalysts for key energy-intensive processes such as hydrotreating and catalytic cracking. This area of research can improve product yields or lower activation energies leading to significant improvements in energy use and therefore CO_2 emissions reductions (Petrick & Pellegrino, 1999).

7 REVIEW OF DRIVERS AND BARRIERS TO ENERGY EFFICIENCY IMPROVEMENT

The previous chapter provided an in-depth discussion on opportunities to improve energy efficiency in the refining industry. In addition, there are studies which identify a variety of energy efficiency opportunities across different sectors of industry (Hasanbeigi, 2010; Martin and others, 2000; Worrell, Martin & Price, 2001). These opportunities also include low-cost or no-cost options for reducing fossil fuel energy use. However, there is a realisation that a significant number of these opportunities are not undertaken in industry, despite the numerous opportunities to invest in cost-effective, energy efficient technologies (Brown and others, 1998). This gap, between the level of energy efficiency actually achieved and the theoretically optimum level of energy efficiency provided cost effectively for the same products, is identified as the 'energy efficiency gap' (Brown, 2001; Jaffe & Stavins, 1994b; Levine and others, 1994).

There are numerous challenges to increasing energy efficiency and, in addition to technical and economic aspects, consumer behaviour is very much central to understanding the efficiency gap (World Economic Forum, 2010). The paradox of why profitable energy-saving investments are not undertaken continues to provoke debate and research indicates there is a reluctance to adopt proven technologies that can significantly improve the process. It is often argued that 'transaction' costs and other hidden costs reduce the seemingly high returns that can be realised from energy efficiency investments (DeCanio, 1998; Sanstad & Howarth, 1994). There are two contrary views as to the potential of cost-effective improvements for energy savings or the existence of the 'energy efficiency gap' in industry. One view is based upon the assumption that all managers make rational, cost-minimising, decisions. Analysts with this view argue that companies are already as efficient as the market demands. Managers minimise all costs by undertaking all improvements which are cost-effective. All unimplemented energy savings must therefore, by definition, not be cost-effective. They find that additional energy savings will be expensive and harmful to competitiveness as industry is already economically efficient.

Analysts, who take the counter viewpoint, are generally more optimistic of the level of cost-effective savings which can be achieved in industry. In this viewpoint, companies, in practice, do not minimise total costs, and are therefore economically inefficient. The cost-effective improvements are not implemented because of impediments such as general aversion to change, lack of information on technologies, capital constraints and budgeting methods. These manifest due to disparate goals of stockholders and managers, and manager's personalities as they relate to organisational culture, managerial inertia and external competitive pressures (US OTA, 1993).

In this chapter, barriers (which aid an explanation to the existence of an energy efficiency gap) and drivers to improving energy efficiency in industry are reviewed.

Sorrell and others (2004) defines a barrier to energy efficiency as "a postulated mechanism that inhibits a decision or behaviour that appears to be both energy and economically efficient". To build on this definition, within the context of this project, *barriers* are defined as factors that negatively affect a firm's intention for energy efficiency improvements, and *drivers* are defined as factors that positively impact on a firm's intention for energy efficiency improvements.

To reiterate, consideration is given here to both technology and best practices/house-keeping; these improvements are distinguished when presenting the results.

7.1 Drivers for Energy Efficiency Improvement

Tapping into energy efficiency is challenging and requires a significant, if unconventional, infrastructure. Energy efficiency requires “soft” elements like public policy support, education and awareness and innovative financing tools. In addition to the development of a wide-scale support infrastructure, deploying energy efficiency also requires the investment of capital (World Economic Forum, 2010). It is the motivating forces for improving energy efficiency that are as important to understand as ‘barriers’. Understanding consumer’s decision-making behaviour and preferences, as well as those of other stakeholders, would also give a better comprehension of the drivers that push energy efficiency measures (Reddy & Assenza, 2007).
Drivers for energy efficiency improvement include:

Decrease in Technology Price Levels - The price of a technology is an important factor in penetration of energy efficient technologies into the market. Competition can lead to a decrease in the cost of a technology (Reddy & Assenza, 2007).
Increase in Energy Prices - According to Reddy & Assenza (2007) a continuous and predictable increase in energy prices affects purchasing and investment decisions for energy efficient equipment, where the direct cost savings in energy bills through reduced energy consumption is a motivation to adopt energy efficient equipment (Reddy & Assenza, 2007).
Awareness - The high level of awareness created by a stimulant, such as an advertising campaign by a technology manufacturer, is an important driver for energy efficiency (Reddy & Assenza, 2007).
Technology Appeal - Non economic motivators, such as the impression that energy-efficient equipment gives, is a factor worth considering. Technologies ‘smartness’, such as it looks ‘appealing’, 'fashionable', and ‘modern’, can be a dominating factor in high-income groups, where technology appeal is a major driving factor (Reddy & Assenza, 2007).
Non-Energy Benefits - From an end-user perspective, non-energy benefits can also motivate energy efficiency. These can be direct or indirect economic benefits such as from i) downsizing or elimination of equipment, ii) labour and time savings, or iii) increased reliability, convenience and productivity (Reddy & Assenza, 2007).
Environmental Regulations - In the absence of environmental regulations, energy producers or consumers do not bear the societal costs of electrical generation and do not see the true costs for their consumption or production decisions. However, regulations can drive internalised environmental costs which can make energy efficiency investments more financially attractive (Reddy & Assenza, 2007).
Values and Culture - An organisation’s culture may be seen as the sum of individual’s values. The values of workers who have influence within the organisation, such as executives’ values, may have more impact on the organisations culture than workers in ‘lower status’ positions (Sorrell and others, 2000). Concern for the environment, helping others, and a moral commitment to using energy more efficiently are examples of values which influence individuals to adopt energy efficiency measures (Stern & Aronson, 1984).

Credibility and Trust - Credibility and trust in an information provider aids in the effective spread of information for energy efficiency investments (Stern & Aronson, 1984). Information providers or energy actors such as energy consultants or sector organisations may be important intermediaries in industry. Their trustworthiness can be a driver for energy efficiency improvement (Rohdin, Thollander & Solding, 2007; Stern & Aronson, 1984).

7.2 Barriers to Energy Efficiency Improvement

Challenges or 'barriers' to improving energy efficiency have been identified and discussed in several studies (de Groot, Verhoef & Nijkamp, 2001; DeCanio & Watkins, 1998b; Reddy, 1991; Sardianou, 2008; Sorrell and others, 2004). These barriers can be categorised in a number of ways. In this study, energy efficiency barriers are loosely categorised into i) financial, economic and market barriers, ii) institutional, organisational and behavioural barriers, iii) technological barriers, and v) uncertainty.

7.2.1 *Financial, Economic and Market Barriers*

Financial, economic and market barriers to investment in energy efficiency include:
Availability of Capital - When considering energy efficiency improvements and improvements in general, businesses do not have unlimited funds, although, in theory, firms might be able to borrow capital when a profitable investment presents itself. There is also competition for available capital, as capital is a scarce resource. Organisations impose internal limits through capital rationing, therefore energy efficiency investments compete with other investment priorities such as projects that achieve company goals and against familiar technologies. Consumers can only invest in some, and not all, of the investments that promise a positive return. Mandatory investments, such as those required to meet environmental regulations, and those central to the product line are often made first as a result of capital rationing (Canepa & Stoneman, 2004; National Academies, 2010; World Economic Forum, 2010).
Competition for capital is one of the main concerns for industrial energy efficiency investments, particularly large, capital intensive projects. Even energy efficiency improvements through making operating changes may also require investment in retraining of personnel. Due to this competition for potential uses of capital, energy projects must be "investment grade" (World Economic Forum, 2010).
High Hurdle Rates - Corporations often require high internal hurdle rates for investment to be undertaken, which are set at greater levels than the cost of capital (DeCanio, 1993). Investment decisions are subject to budget constraints. It is typical for a corporation to specify a hurdle rate for new investments as refining assets are capital intensive and long- lived in nature, and are thereby subject to considerable financial risk. It is a complex decision to invest in new refinery processing capacity as the decision is highly dependent on present asset performance and expectations about the future (Marano, 2007).On the other hand, Hassett & Metcalf (1993) argue that "what appears to be myopic behaviour, ie a high discount rate, may simply reflect an optimal investment strategy in the face of uncertainty", and therefore the high hurdle rate is simply a manifestation of future uncertainty.
The payback period is a financial tool that can be used to inform investment decisions and it is generally termed as the time required recoup the investment cost through energy savings. Energy

consumers generally insist on relatively short payback periods of approximately 2 years (Reddy, 1991). Some energy efficiency improvements have a relatively short payback period, however "deep retrofits" which save the most energy, require a longer time to pay back (World Economic Forum, 2010). According to Sorrell and others (2004), short paybacks required for energy efficiency investments may represent a rational response to risk. This could be a result of business and market uncertainty which encourages short term horizons, or because energy efficiency investments represent higher technical or financial risk than other types of investment.

Consumers often fall back on simpler first- cost rules of thumb, even while recognising the importance of life-cycle calculations and many energy efficient products cannot compete on a first-cost basis (Brown, 2001). Even if a consumer is fully knowledgeable about the net benefits from an energy efficiency improvement, it does not necessarily follow that an investment will be made (Reddy, 1991).

In addition, although an energy efficiency project might be technically feasible it does not mean it will be automatically undertaken. Most projects with a higher rate of return out-compete other lower return projects for capital financing, therefore giving a partial account for the efficiency gap (World Economic Forum, 2010).

Competing Investment Priorities - Firms may have competing investment priorities. Spending on mandatory environmental projects can detract from investments in the core business, which yields flexibility and reliability improvements as well as providing capacity growth (Szklo & Schaeffer, 2007). Moreover, most capital goods have no alternative applications and therefore capital investments are mostly irreversible (Hassett & Metcalf, 1993).

A company's core business may focus on market and production expansion as this may be more effective than efficiency improvements to generate profit maximisation (Worrell & Price, 2001b). Capital investment in new capacity can lead to a higher internal rate of return and more sales, and therefore are often first to receive available funds (Ren, 2009). Typically, projects which introduce new products into the market or increase capacity have priority over energy cost-cutting investments (National Academies, 2010). Figure 16 below highlights the African oil and gas industry's focus for capital expenditure on exploration and production in the next three years.

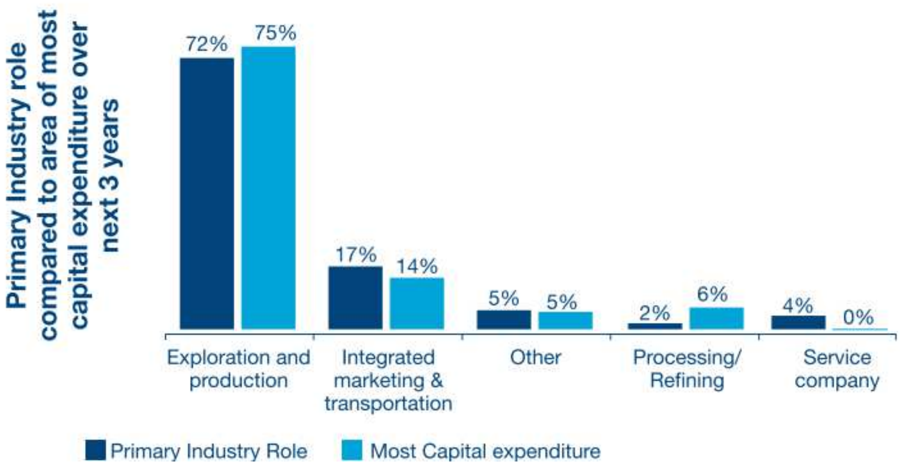

Figure 16 The African Oil & Gas Survey 2010

Source: (PricewaterhouseCoopers, 2010)

Economic Trend or Market Situation - An important obstacle for energy efficiency investments to take place is the external risk of the economic climate or market situation, such as an economic downturn. If a firm has difficulty raising additional funds through borrowing or share issues, energy efficient investments may be prevented from going ahead due to lack of available capital (Sorrell and others, 2004). In a stagnating market situation, investment in new technologies may be overshadowed by maintenance and minor improvements to extend the lifetime of existing technologies (Curras, 2010).

Delayed Investment Decision - A firm may also 'hold' an option to invest by waiting for new information that could affect the timing or attractiveness of the expenditure. This "ability to delay irreversible investment expenditure can profoundly affect the decision to invest". The investor holds an option not to invest, prior to making an investment decision. This option of not investing is valuable because once the investment is made, the option is lost, as the investment cannot be undone (irreversibility of the investment). This option then becomes more valuable with increasing uncertainty in future energy costs (Hassett & Metcalf, 1993). Due to a lack of confidence consumers will see an adequate return on their investment, volatile energy prices can cause consumers to delay purchasing more efficient technologies (National Academies, 2010).

Perceived Cost of Energy Saving Measures - Generally, a higher initial cost is incurred for higher energy efficiency equipment (Reddy, 1991). There is a perception that these first costs are too high for energy efficiency measures. Despite the possibility of long term savings, these high upfront costs can deter investment (National Academies, 2010). The decision maker has to decide whether to minimise upfront costs or minimise energy costs in the future (Reddy, 1991).

In addition, energy saving projects rarely rank equal with projects to capture new markets or increase production in fast growing economies. The main financial benefits of energy efficiency investments are focused on energy cost savings, as opposed to visible new production assets. The slow rate of return of investments and uncertainty about future energy prices, especially in the short term, can result in higher perceived risk and this risk leads to more stringent investment criteria associated with projects (Sardianou, 2008; Taylor, la Grange & Gous, 2000).

Transaction Costs - Small incremental opportunities in energy efficiency can lead to big savings, although as opposed to one large investment, these actions have transaction costs (World Economic Forum, 2010).

Collecting relevant information and researching new technology uses valuable time and resources, where many industries may prefer to focus financial and human capital on other investment priorities (National Academies, 2010). These transaction costs are often omitted in cost evaluations without justification. They mostly comprise of information costs such as search costs, data collection costs, negotiating and monitoring costs. These costs depend on the organisational set-up and the routines for making and implementing decisions. Transaction costs are sometimes confused with hidden costs although in the true sense, transaction costs are a subset of hidden costs (Ostertag, 1999).

Hidden costs are generally referred to in energy economics literature as any costs which are not conventionally included within engineering-economic models (Sorrell and others, 2004). The various types of neglected or 'hidden'[22] costs can include 'production' type costs such as the cost of possible production disruption or the embedded cost of specialist personnel for installation or maintenance due to energy efficiency measures (Ostertag, 1999).

Significance of Cost of Energy - Companies may be knowledgeable about energy efficiency benefits and in a position to afford upfront costs, although may still be indifferent to investing in energy efficiency improvements. This may stem from the fact that, relative to total expenditure, the savings made by energy efficiency improvements are not significant enough to motivate improvement. Similarly, a consumer has multiple factors to consider when purchasing energy-consuming equipment, of which, energy cost is often not the most important (Reddy, 1991).

Regulation and Financial Incentives - Regulation may be an important driver to innovation although it may sometimes, indirectly, be a barrier to greener practices. For example, cogeneration may be hindered by lack of clear policies for buy-back of excess power for the national grid or other users (Casten, 1998). Supply monopolies[23] are seen as barriers to energy efficiency improvement. Often, there are laws which prevent the production of energy by other producers. Incentives, which reward and encourage independent power producers to produce energy carriers, have been recommended to overcome this barrier type (Reddy, 1991). However, a strong regulatory and enforcement regime in addition to incentives to make energy conservation efforts profitable, are generally lacking (Niederberger & Spalding-Fecher, 2006).

Government regulated prices of energy carriers such as electricity, coal and petroleum products can discourage investments in the efficiency of utilisation of energy. The rate-setting formulae are often biased towards the supply of energy. This is the result of profits being coupled to sales so that if investments are made on demand-side programmes, revenues can be lost. It not only loses revenues due to decreased sales, but also returns on investments by demand reduction (Reddy, 1991).

In addition, government can place constraints on energy saving initiatives, which should be planned and implemented according to set standards, which may be a barrier in some instances (Govender, 2008).

7.2.2 *Institutional, Organisational and Behavioural Barriers*

Lack of Skilled Personnel - It has been suggested that the number one issue with increasing end-use efficiency is the "shortage of qualified energy managers and analysts" (Brown and others, 2008). In many industrial firms there is often a shortage of trained technical staff, with the development towards 'lean' firms (Ren, 2009; US OTA, 1993). Information collection and processing requires time and resources, where most personnel are busy maintaining production. This can lead to difficulties selecting and installing new energy efficient equipment when compared to simply buying energy (Reddy, 1991).

Lack of Staff Awareness - Many decision makers (consumers) are simply unaware of the cost-effectiveness of efficiency measures and the possibilities of improvement (National Academies,

[22] Refers to any costs which are not conventionally included within engineering- economic models(Sorrell and others, 2004).

[23] A market where there are many buyers and only one seller.

2010). Additionally, the rapid technological change in the field of energy efficiency improvement does not assist in fostering awareness (Reddy, 1991). Industrial decision makers can be overwhelmed by numerous products and programs which facilitate energy efficiency (Brown and others, 2008).

Bounded Rationality - Decision makers do not always behave ‘‘perfectly rational’’ in the sense of economic theory. The related notion of ‘‘bounded rationality’’ is closely linked to the cost of information. To avoid further information cost, it may seem rational to take a ‘satisficing’ option rather than a theoretically optimal decision. Simon (1979) argues that utility maximization in economic theory is not essential in the search of decision alternatives and ‘approximation must replace exactness in reaching a decision’.

Simon (1957; 1979) describes bounded rationality as decision making which deems satisfactory outcomes acceptable. This notion acknowledges the cognitive limitations of decision-makers in complex situations. An aspiration level of how good an alternative which should be found is formed by the decision maker and the search would end once that aspiration level has been met. This mode of selection is referred to as satisficing. This is one procedure of ‘bounded rationality’, to choose satisfactory choices instead of optimal ones. A second procedure is to subdivide abstract and global goals into tangible sub goals, whose achievement can be observed and measured. A third procedure can be to divide up the decision making task among specialists.

In the face of complexity and uncertainty, this individual bounded rationality is conflicted with the firm’s aggregate behaviour of profit maximisation. The notion of bounded rationality is a barrier to energy efficiency as the decision maker will choose ‘satisfactory’ alternatives, instead of optimal ones. A business can only approach profit maximising behaviour because of complexity of the environment and limitations on decision making resources they command (DeCanio, 1993; Simon, 1979).

Lack of Specialised Knowledge - According to Tonn & Martin (2000) and de Groot, Verhoef & Nijkamp (2001), the lack of knowledge by decision makers is one of the main causes of market failure to implement energy efficiency opportunities . The inability to account for the economic benefits of energy efficiency improvements is an additional information challenge and adequate management techniques, tools and procedures are often lacking within companies (Worrell & Price, 2001b).

Lack of Credibility and Trust - The energy user may not undertake energy efficiency measures due to a lack of confidence in information. They cannot always easily gain accurate information about the ultimate comparative cost of different investments, and therefore will rely on the most credible information available (Reddy, 1991; Rohdin, Thollander & Solding, 2007). The perception of credibility of the information source depends upon the expertise and trustworthiness in the information provider (Sorrell and others, 2004). For example, industrial sectors may distrust energy services companies (ESCOs) although they specialise in energy efficiency technologies. This is because these companies may not have industry- specific knowledge as a basis for providing accurate estimates to the company (Brown and others, 2008).

Split Incentives - According to Sorrell and others (2004), if actors cannot appropriate the benefits of an investment, energy efficiency opportunities are likely to be forgone. An example which is given is the lack of incentive to improve energy efficiency by individual departments within an organisation if they are not accountable for their energy use.

In addition, within businesses, operating and capital budgeting are often handled separately in the accounting and budgeting process. There may be split incentives or a disconnect between the party who makes the initial investment or procurement decisions and the party who pays the on-going operating costs. Therefore projects may still be rejected in the capital budget even though they provide investment-grade returns to the operating budget (World Economic Forum, 2010). This fundamental contradiction in incentives can lead to inheritors of inefficient equipment (Reddy, 1991).

Furthermore, according to DeCanio (1993) the interests of managers and shareholders may also not always coincide. Managers are induced to act in a manner as consistent as possible with the interest of the shareholders of the corporation, through the organisational design. Due to this principal agent problem many profitable investments might not be undertaken (Statman & Sepe, 1984).

Short Term Thinking and Planning of Owners - Underinvestment in energy saving technologies has been frequently claimed to stem from short-sightedness of management. This short-termism is considered to manifest in very short payback periods required of investments (DeCanio, 1993). Often short run earnings, earnings per share or sale growth are rewarded, and may encourage management to forego investment in the maximization of long run value of the firm (Pinches, 1982).

In addition, investment in human capital for energy conservation expertise ie retraining, will be low if the compensation and prestige of the managers responsible for energy use (facilities personnel) are less than the rewards for other positions (DeCanio, 1993).

Energy Management not Core Business Activity - The behaviour of individuals within the industrial firm affects the decision making process for investment decisions. Investment in energy efficiency improvement is thus linked to managerial attitudes towards energy conservation. With this in mind, there is a common view that energy efficiency is often overlooked by management because it is not a core business activity, thus it is not worth much attention (Sardianou, 2008).

Bureaucratic Procedures to get Governmental Financial Support - If a firm has difficulty raising additional sources of funding, energy efficiency investments may be prevented from going ahead (Sorrell and others, 2004). Financial incentives like tax breaks and interest subsidies are important tools in encouraging investment; however, administrative procedures to get government financial support can be preventative (Sardianou, 2008).

7.2.3 *Technological Barriers*

Technical Risks - Reliability and operational risks represent major concerns for industry, where decision makers can be averse to new technology and practices. Their preferences for familiar technologies and the status quo can sometimes sway them against energy efficient choices. This aversion can be attributed to risk, knowledge, motivation and also their ability to implement new technologies and procedures (National Academies, 2010; World Economic Forum, 2010). Commercial business managers, as opposed to industrial business managers, are more likely to adopt new technologies although both face knowledge barriers. The main energy efficiency improvements in the commercial sector are related to common technologies such as air-conditioning and lighting, whereas firms in the industrial sector often use very specific energy consuming technologies which are not necessarily “off- the -shelf” (Brown and others, 2008). Lengthy and larger scale field testing of new technologies, a slower pace of technology diffusion[24] and more stringent investment criteria are as a result of the perceived technical risks associated in industry (National Academies, 2010).

Technology Fitting into Process - Old equipment can add to the difficulties of incorporating new technology into the existing production process (Zilahy, 2004). When retrofitting new equipment, the process layout often may not allow for retrofitting e.g. there are spatial restrictions (limited space). Therefore, this often leads to the use of new 'already known' equipment rather than achieving the full benefits from installing new technology in existing configurations (Curras, 2010).

Resistance to Replacing Existing Machinery - The resistance to replace existing machinery is an important obstacle to energy efficiency improvement (de Groot, Verhoef & Nijkamp, 2001). The long life time of energy intensive industrial equipment can hamper replacements for new technology (Worrell & Price, 2001b). In many cases, equipment would be used as long as their functioning can be preserved by regular maintenance (Zilahy, 2004).

When a company invests in a new technology, it takes into account the depreciation costs of the existing machine that is not fully depreciated. This influences the payback period of the new technology as these costs for early depreciation need to be added to the operating costs of the new technology (Masselink, 2008).

Fear of Losing Flexibility in Process- When considering the adoption of new technologies, particularly in large integrated plants, small technology changes can lead to major changes in process and product performance. Therefore the uncertainties of the impacts and benefits on existing processes can be significant (National Academies, 2010). Integrating new technologies with existing technologies in operation may add complexity to the process and reduce flexibility (Curras, 2010).

Irreversibility of Technology Change- Due to the irreversible nature of an investment, if the long term benefits of a better technology can be enjoyed in the future, the investment may be postponed (Rogers (1995) from Curras (2010)).

7.2.4 *Uncertainty*

Uncertainty in Energy Price - Energy efficiency decisions involve the analysis of future energy prices and potential energy savings. Understanding the potential for future savings can be difficult as the variation and unpredictability of future prices are significant areas of uncertainty (World Economic Forum, 2010). Energy prices, and therefore the returns from an investment (avoided energy costs), are subject to fluctuations. This uncertainty seems to be a particularly important barrier in the short term (Velthuijsen, 1995).

More stringent investment criteria are often the result of higher perceived risk from these uncertainties (Worrell & Price, 2001b). Investors tend to avoid investments by playing it safe, leading them to postpone the decision during times of economic instability when uncertainties are aggravated (Reddy,

[24] Research has consistently shown that diffusion of new economically superior technologies is never instantaneous and typically follows a sigmoid or s-shaped curve. This diffusion curve starts with slow initial rates of adoption, then faster rates and ending with slow rates as the saturation point of the technology is reached (Jaffe & Stavins, 1994).

1991). Hassett & Metcalf (1993) suggest that the slow diffusion of new energy technologies may be the result of rational cost minimising behaviour in the light of uncertain future conservation savings, rather than the result of consumer/investor ignorance.
Uncertainty Related to Policy such as Future Subsidies or Environmental Requirements - Uncertainty related to policy such as uncertainty about future subsidies or environmental requirements is a barrier to investing in new technologies (de Groot, Verhoef & Nijkamp, 2001).
Uncertainty about Future Technologies - Fears that future technologies will be significantly better or cheaper can be a rational reason for decision makers to delay an investment in energy efficient technology. Delaying an investment means short term energy savings may be foregone. But due to the irreversibility of an investment, a firm with better technology options in the future may benefit (van Soest & Bulte, 2001).

This chapter has provided a base summary for barriers and drivers- these barriers and drivers have been synthesised to generate the questionnaire used in this thesis. The questionnaire can be found in the appendix.

8 RESULTS AND DISCUSSION

In the following sections, the results of this thesis are presented, ending with a synthesis of the findings. This Chapter begins with an overview of the energy efficiency performance in the refining industry. This is followed by the outcomes of the study as they relate to opportunities, drivers and barriers, in regards to energy efficiency improvement, from both interview and questionnaire results.

As a general comment it is noted there was a limit to access of numerical energy data due to the limitations set by the regulated price of fuel in the country. In addition, respondents of a lower seniority were more cautious to discuss energy efficiency performance, where more candid views surfaced through questionnaire responses. This was also shown by very few respondents adding comments to questionnaires. Therefore it was important to have both the qualitative and quantitative aspects in the method of research.

8.1 Energy Efficiency Performance of South African Crude Oil Refineries

The Solomon's Energy Intensity Index (EII) is a common benchmark used to compare energy performance across refineries worldwide. Solomon's "World's Best" is a weighted average of six of the best individual refineries from three grouped regions[25]. The composite World's Best EII in 2008 was 73.5 (Proops, 2010). South African crude refineries are placed within in the bottom 25% of the world's refineries when comparing energy performance (Anonymous, 2010). The average EII for South African refineries in 2008 was around 120 (as seen in Figure 19).

In order to further demonstrate the poor performance of the South African refining industry, the figure below shows the EII 10th and 90th percentile and average for different regions. The figure highlights that Asia export has the lowest average EII compared to all regions (below 100). In 2008, if the RSA value, of approximately 120, was to be compared to the regions in Figure 17, South Africa would have the second highest average EII, with the former Soviet Union having the highest.

[25] Two each from: 1) North and South America, 2) Europe, Africa and Middle East, and 3) Asia/Pacific/Indian Ocean, respectively.

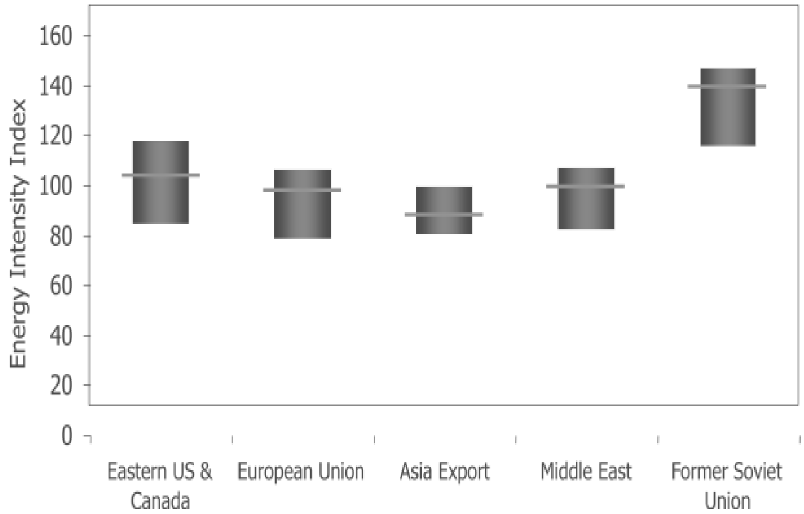

Figure 17 Solomon Energy Intensity Index (EII)- 10th +90th Percentile & Average 2008.

Source: (Beddoes, 2010)

Various reasons for inefficiencies in existing refineries worldwide have been highlighted in the literature review (section 5.3.1). South African refineries are 40+ years in age, whereas the best individual refinery in the world today has an EII of approximately 60. These newer state-of-the-art 'mega' refineries have greater economies of scale, and therefore benefit from better energy efficiency.

Referring to the literature review (section 4.1.1 Energy Challenges for South African Refineries), stricter sulphur regulations of Clean Fuels upgrades have had a marked adverse effect on refinery energy intensity, and this is also true in South Africa. This can be seen in the figure below, with refineries producing Euro 2 standard fuels by 2006 (Clean Fuels 1).

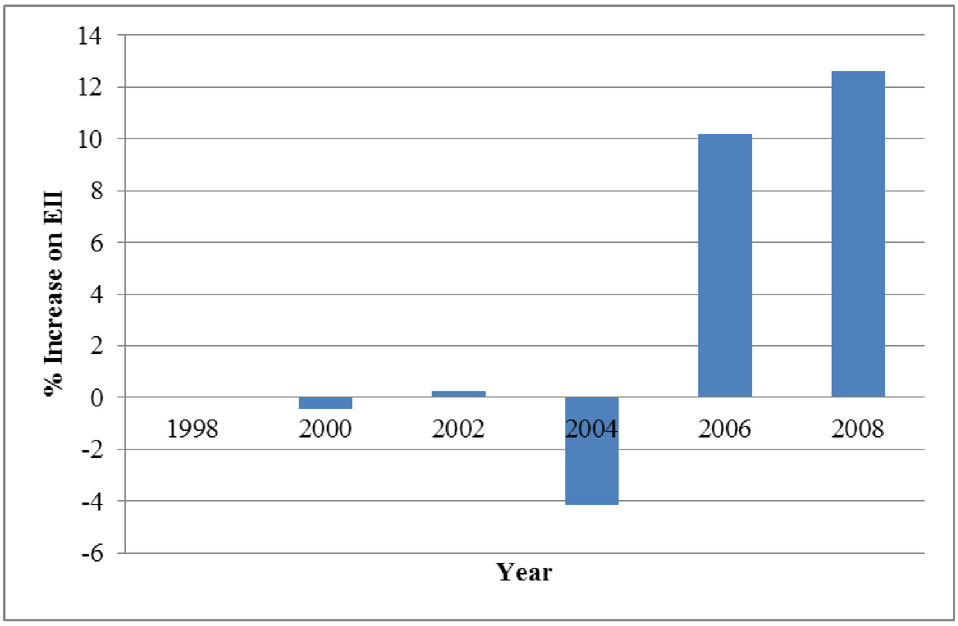

Figure 18 Percentage Increase on RSA Average EII (base year 1998)

The graph shows a 10 % increase in EII in 2006 compared to the base year (1998). This large incremental increase in refinery energy intensity can be mainly attributed to the Clean Fuels 1 upgrade, whereby sulphur limits for diesel and petrol were reduced to 500 ppm. The average performance of refiners in a similar grouping was however superior to South African refiners when comparing average EII. The following graph shows this increasing trend of EII in comparison to South Africa's competition.

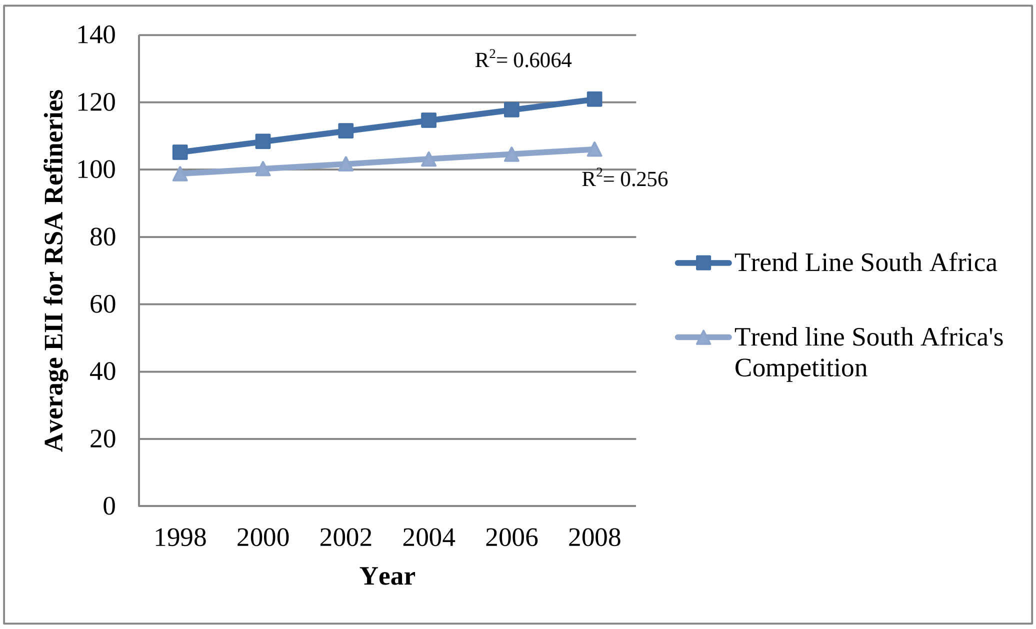

Figure 19 Trend Line for Average EII of South African Refineries

Figure 19 shows an increasing trend in energy intensity from both regions (South Africa and refineries in a similar grouping) over the period 1998 to 2008. Both regions were exposed to making higher quality fuel; however, South Africa deteriorated more than its competition, making the region more inefficient and consequently less competitive. This can be attributed to the approach of South African refiners to investments over the last ten years, where they have tended to be more capital constrained and to an extent have done the minimum required to comply with legislation. Competitor refiners on the other hand have taken the opportunity of larger upgrades such as clean fuels to also improve energy efficiency. In 2008, the South African average EII was 14 points above its competition. This is a notable difference, as an EII reduction of one point is worth approximately $1.7 million/yr (2007) at $4.74/GJ fuel price[26] in a typical 100 000 bbl/day refinery (Zhang and others, 2007).

With refinery energy intensity increasing, the next section unpacks the findings from the interviews conducted as part of this thesis of opportunities for refiners to improve energy efficiency.

8.2 Opportunities for Energy Efficiency Improvement

The literature review of opportunities for energy efficiency improvement (Chapter 6) discussed means of achieving energy savings through capex and non capex improvements in refineries. This review serves as a backdrop for the findings in this study.

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[26] This is equivalent to a fuel price of $5/MMBTU.

This section is laid out as i) findings from interviews (qualitative) (8.2.1), and ii) findings from questionnaires (quantitative) (8.2.2).

8.2.1 *Qualitative Results from Interviews*

8.2.1.1 ***Opportunities through Capital Projects***

Expansion projects were identified as having the potential to give the largest step changes in energy efficiency performance. Upgrades or increase in capacity projects are multi million, sometimes billion rand projects. These projects could give some of the best opportunities to increase energy efficiency, by energy efficiency projects 'piggybacking' on the justification of the upgrades or expansions. One respondent said there were opportunities to add energy projects to Clean Fuels upgrades but this would make a serious restriction on resources (time, personnel available, financial etc).

Opportunities which were also identified include:

- *Replacement of End of Life Equipment*- The replacement of end of life equipment as this can be one of the biggest or cheapest opportunities of gaining large savings. With term replacement, one does not have to apply for new capital. Term replacement is replacing 'like for like' and this is accounted for in a different way, and money is budgeted for in the lifecycle of equipment. When making a change which requires new capital, a project gets put onto the budget, after which, the project competes with other investment priorities.
- *Advanced Process Controls*- An opportunity identified which could be used in whole industry was the application of advanced process controls. 'Once the technical side and flow schemes are right then APC can make a big difference'.

8.2.1.2 ***Opportunities through Energy Management***

Energy management consists of the 'soft skills' such as awareness, taking ownership etc. These opportunities allow personnel to use the existing refinery structure but in an optimal way.

Opportunities for improvement through energy management which were highlighted by respondents include:

- *Organisational culture change* in terms of energy efficiency- 'constant focus' is needed to meet and sustain targets, ultimately to sustain improvement. The energy efficiency focus needed to be driven from the top down to reach the bottom levels.
- Greater operator *awareness* - there is room for improvement.
- *Responsibility* for energy efficiency by personnel is required- with energy efficiency being defined in individuals' job scopes.
- *Training* would have a significant effect on energy projects; this would be mostly at the operational level.

Respondents highlighted areas for improvement potential as:

- *Utilities* - 'low hanging fruits' can be attained here.
- *Flare and loss* - the elimination of hydrocarbons in the flare is an activity which is on-going. However operating problems increase flaring, and this is linked with operating know-how.

8.2.2 *Quantitative Results from Questionnaires*

Respondents were asked to rate the improvement potential on the current energy performance associated with various energy efficiency interventions. (This being 0% for no room for improvement, and 50% meaning a refinery can improve by 50% on its current situation). Results from respondents showed a large variation in opinion and this can be seen by the standard error bars shown in Figure 20.

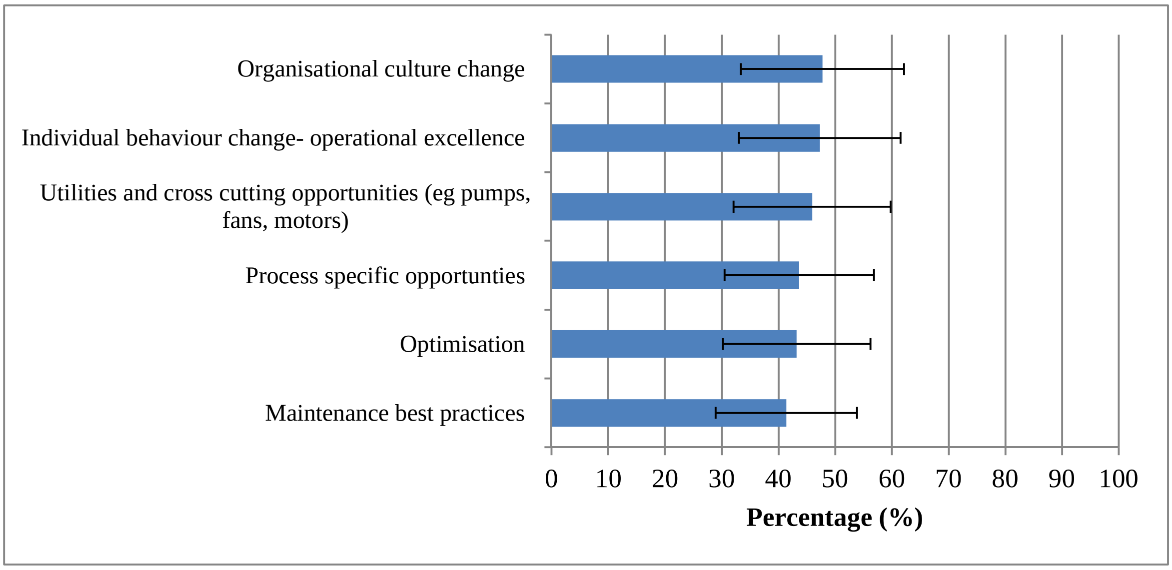


Figure 20 Average Improvement Potential for Energy Efficiency Measures

The most notable finding is that refineries can improve on the individual energy efficiency measures listed in Figure 20 from between 41.4- 47.7 %. When taking into account the standard error tolerance, this ranges between 28.9- 62.1%. This large improvement potential of at least 28.9% is in agreement with the 4th quartile performance of South African refineries as described in section 8.1. The percentage rating used has been used a guideline to give a perceived improvement potential. This is indicative only, as for example a 41.4% improvement in implementing maintenance practices does not correspond to a 41.4% improvement in overall energy performance.

Organisational culture change was found to have the greatest improvement potential of 47.7% (+-14.4). Following closely, individual behaviour change (47.3% +-14.3), and utilities and cross cutting opportunities (45.9% +-13.8), respectively, were the next highest measures for the potential to improve. Optimisation and maintenance best practices were found to have the lowest averages of 43.2% (+-13.0) and 41.4% (+- 12.5). This could be attributable to refiners being more involved with these measures at present, and perhaps indicates that these opportunities are more easily accessible/prominent. This measure also had a greater agreement by respondents for improvement potential, as seen by the lowest standard error of 12.5%.

The next section unpacks drivers for the increased uptake of energy efficiency measures, as found in the study.

8.3 Drivers for Energy Efficiency Improvement

This section is presented as i) qualitative findings from interviews (8.3.1) and ii) quantitative results from questionnaires (8.3.2).

8.3.1 *Qualitative Results from Interviews*

An analysis of the outcomes of the interviews identifies two main drivers or influences for energy efficiency in the industry. These are:

1) Legislation - It is vital that the regulatory/environmental requirements are met for a refiner's license to operate. In general, companies tend to take a precautionary approach and stay ahead of regulatory requirements.

2) Competitiveness - Cost is a chief determinant for a refinery to stay in business versus better efficiency, and thus competitiveness. As part of competitiveness, particularly for energy efficiency, the cost of technologies is important.

Further drivers for energy efficiency improvement on the plant include:

- *Corporate Support* - The endorsement of energy efficiency at a high level with energy guidelines driven to lower levels was highlighted as one of the most important drivers, if not the most important, for energy efficiency improvement, by a majority of respondents.
- *Operations Excellence* - The main aim is to cut costs as South African refineries are in the 4th quartile in terms of energy efficiency. Operating 'excellently' cuts costs and achieves other benefits such as quality assurance etc. On the level of the operator and engineer, there are rewards and initiatives to realise higher standards of performance. Rewards and performance management act as drivers for operational excellence, including energy efficiency improvement. However, this is linked to the support from corporate for energy efficiency initiatives. Key performance indicators (KPI's) are generally used for monitoring refinery operations.
- *Energy Efficiency Information* - At the refinery they have many knowledge sources. Information is abundant for energy efficiency improvements and best practices. The challenge is to implement opportunities without increasing cost, as some projects need downtime to implement which increases costs. In addition, subscribing to forums works very well for 'best practices' across the industry. Refiners can get information of tried and tested opportunities that have been implemented elsewhere. By belonging to technology alliances or having an agreement with a technical design house, refiners can be informed of opportunities implemented by other world leading refineries. This 'benchmarking' or comparing with other refineries would inform them of commercially used technologies that have been implemented elsewhere.
- *Increasing Energy Prices* - The steady increase in electricity prices was found to be driving implementation of electricity saving projects in the refinery environment, as Eskom prices are set to increase at roughly 25% for the next 3 years.

- *Financial Incentives* - Return on investment (ROI) is the biggest driver for approvals, although projects must meet the hurdle rate. Energy prices should further increase in the future to get the ROI required for project uptake, and incentives will help this. In addition, although the tax incentives (35-55%) for large industrial projects have a short life span until 2015, it was seen as a driver as it 'gives a basis which was not there before'. Also the awareness of opportunities such as Clean Development Mechanism (CDM), tax incentives etc, was said to be critical.
- *Reporting* - Other important drivers which were mentioned during the research which would promote energy efficiency improvements included reporting of sustainability and initiatives to reduce greenhouse gas emissions.

Within the refinery environment, opportunities for energy improvement are driven by several instruments; however the involvement of actors in the uptake of energy projects is important to understand. An energy coordinator/manager or team responsible for energy performance are important to energy efficiency improvement on the plant. Typically, team members have other responsibilities and roles on the plant, in addition to energy performance improvement.

According to interview respondents, the plant engineer and his/her team of operators are in the best position to identify energy saving opportunities where this can include the plant energy coordinator/manager. However in the short term, the operations and maintenance personnel are generally more involved in identifying gaps and opportunities. Process engineers/ technical staff look at projects for the medium to long term. The engineer will work up an idea and apply for money to do a preliminary study. One respondent said 'it comes down to how you motivate the project, if you have technical skill you can propose the idea in such a way to get buy in'.

The individual, together with the team and vendor are combined in the process for implementing a project. Benchmarking would be the first step when working on the concept for a project; they would compare equipment with similar products elsewhere. Companies would generally implement something that has been used elsewhere before. It was a common theme that refineries took a very precautious approach in South Africa, and generally used proven technology quickly. This stemmed from the age of the plants, and the high risk nature of the industry. Information sources would be used to come up with a concept, and from there they would go to vendors for solutions. On occasion, higher level or management level could identify opportunities, for example from attending a conference, but this is less so than from the operational level.

The following section presents the results from the questionnaire which aims to quantify the significance of some of these drivers to the uptake of energy efficiency projects in a refinery.

8.3.2 *Quantitative Results from Questionnaires*

The significance of drivers for the uptake of energy efficiency projects is presented in Figure 21, with ratings between 1 (completely insignificant) and 5 (very significant).

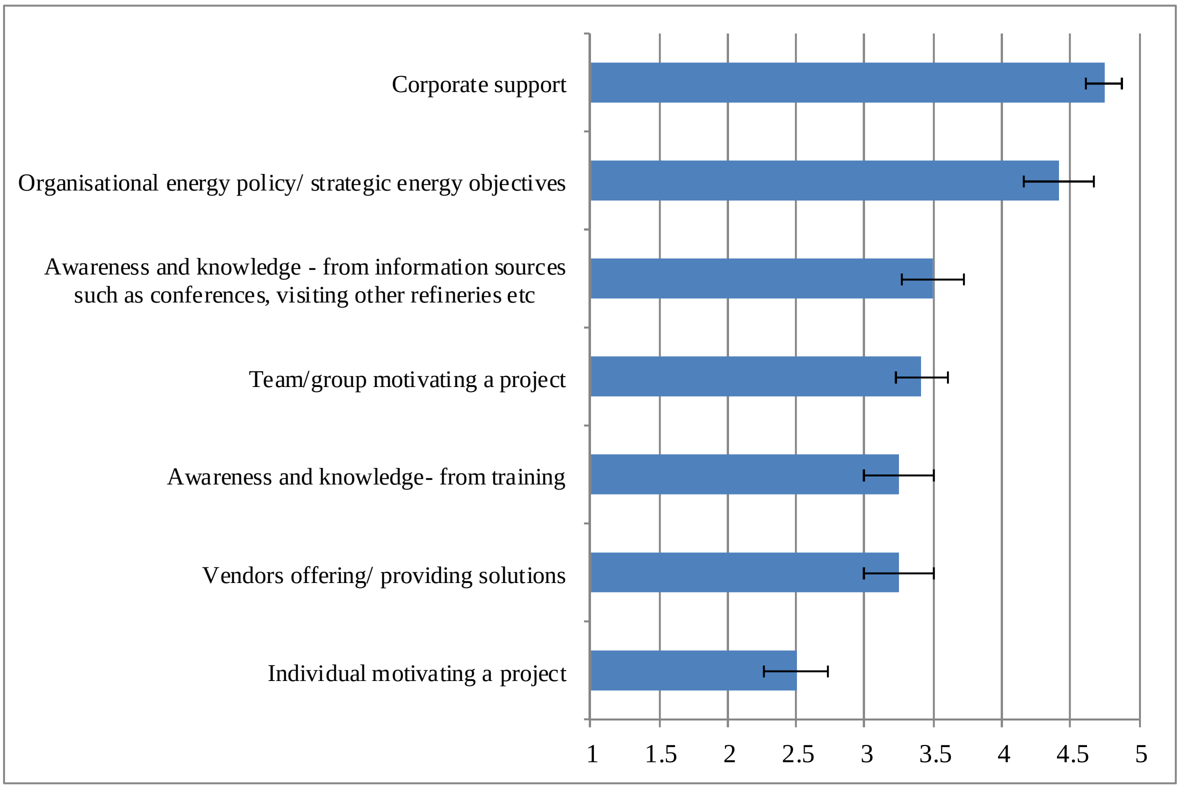


Figure 21 The Significance of Drivers for the Uptake of Energy Efficiency Projects

Corporate support was the greatest driver for the uptake of energy efficiency projects at a rating of 4.75. This driver also showed the highest agreement from respondents with a standard error of 0.13. Corporate support was essential to implementing a project because of the financial means to make the final investment decision. The organisation's energy policy or strategic energy objectives were also found to be very important to driving the uptake of energy efficiency projects, with an average score of 4.42. Essentially, a fundamental alignment of business objectives with that of energy efficiency objectives is a priority for driving a sustained uptake of energy efficiency projects.

Awareness and knowledge of energy efficiency opportunities from external sources such as conferences and visiting other refineries were viewed as a marginally more significant driver than awareness and knowledge from training, with averages of 3.50 and 3.25 respectively.

The figure also shows that from an actor perspective, a team or group, followed by vendors providing solutions are more significant in driving an energy efficiency project than an individual trying to motivate a project. Findings from the interviews indicate that individuals such as operators and engineers are the best position for identifying opportunities. However from the surveys it is distinguished that corporate support is required for these opportunities to be fully attained.

Therefore in summary, from these results from South African refineries, driving an energy efficiency project is a top-down approach. Corporate support and enforcement of organisational strategic energy objectives are crucial for the enhanced uptake of energy efficiency projects.

8.3.2.1 *The Role of Policy and Institutional Instruments*

The objective of this section of the questionnaire was to quantify the significance of policy and institutional instruments as additional means of driving energy efficiency improvement, through the increased uptake of energy efficiency technologies. The following table shows the grouping of instruments explored via this questionnaire.

Table 28 Grouping of Policy and Institutional Instruments for Driving Energy Efficient Technologies

Grouping	*Policy and Institutional Instruments*
Regulation	Energy performance standards for industrial technologies
	Mandatory targets for demand side management (DSM)
	Labelling of industrial technologies such as premium efficiency or standard motors
Financial	Financial instruments such as subsidy schemes, tax incentives
	Energy tax deductions
Information	Training/ information/knowledge transfer
	Energy Audits
Voluntary Agreements	Voluntary agreements to improve energy efficiency

Source: (Curras, 2010)

The two instruments within the information group are training and energy audits, where these may be carried out internally or externally to a refining company. The remaining groups of instruments (financial, regulation and voluntary) in the table are considered in this study to be external drivers for energy efficiency technologies.

Respondents rated the significance of policy and institutional instruments to driving the uptake of energy efficiency technologies both currently, and in the future. The following figure shows the results from this section of the questionnaire. This is rated from 1 (completely insignificant) to 5 (very significant).

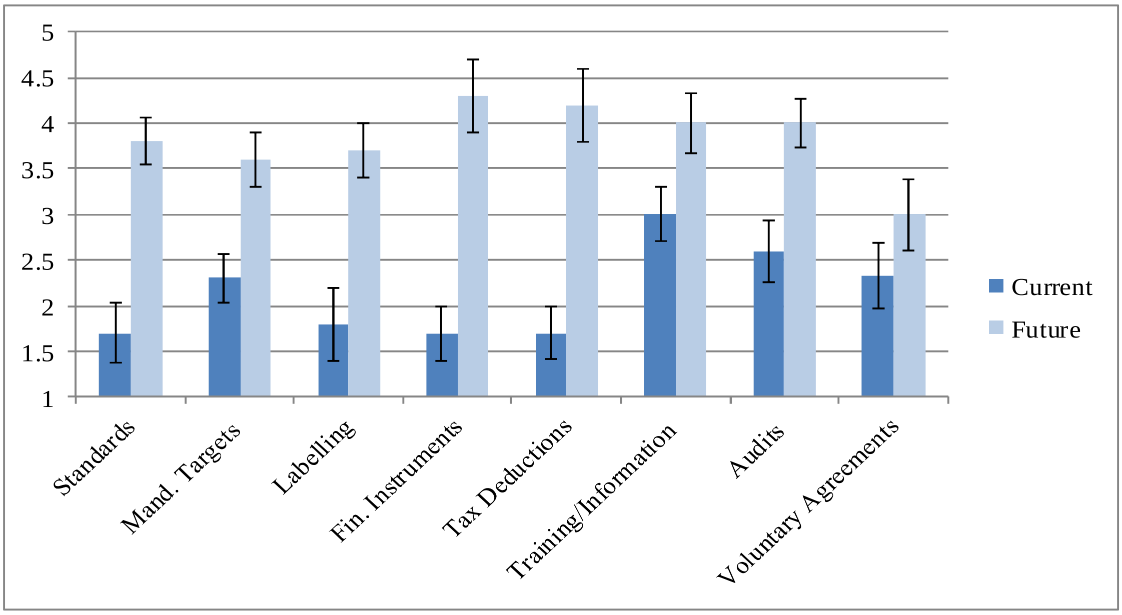


Figure 22 The Significance of Policy and Institutional Instruments on the Uptake of Energy Efficient Technologies

The most significant to the least significant policy and institutional instruments, currently, are as follows:

1) **Information**

   Training and/or information - refiners find that training and/or information from policy and institutional measures were the most significant influence currently to adopting energy efficient technologies. However this was only moderately significant with an average score of 3.

   Energy audits - firms do internal energy audits to evaluate energy performance. This is in addition to an external energy audit by Solomon's Associates every 2 years. This performance is benchmarked using the Energy Intensity Index (EII), discussed previously. Currently however the significance of audits on uptake of energy efficient technologies is relatively low, at 2.6.

2) **Voluntary Agreements**

   Voluntary agreements, such as the Energy Efficiency Accord, currently have a lower significance (at 2.33) to influencing the uptake of energy efficiency projects than information instruments.

3) **Regulation**

   The significance of influence of *mandatory targets* for demand side management (DSM) on the uptake of energy efficiency projects are shown to be fairly low at an average of 2.3. Mandatory requirements are prioritised in a refinery, and are 'must do' projects. Therefore regulatory requirements for a refiner's license to operate would need to be met. Currently from an energy perspective there are no mandatory requirements to reduce energy consumption. Eskom's power conservation program (PCP) requires energy intensive users to reduce electricity use by 10%, however this is not mandatory, Eskom only threatens to cut off a user's power supply.

   Labelling and energy performance standards of industrial technologies are found to have a very insignificant role in the uptake of energy efficiency technologies, with average scores of 1.8 and 1.7 respectively.

4) **Financial**

   Financial instruments such as tax incentives and subsidy schemes were found to be somewhat insignificant currently, to influencing the uptake of energy efficient technologies in refineries with an average of 1.7. This was also found for *energy tax deductions* (such as tax breaks for energy efficiency in the Industrial Policy Project, Section 12-I of Income Tax Act No. 58)

In the future, however, respondents indicated a marked increase in the significance of policy and institutional instruments to driving the uptake of energy efficient technologies. This could be due to a number of reasons including: i) an increasing trend of regulatory requirements for the industry in recent years, ii) an increased focus on energy improvement and GHG mitigation by government and institutions, and iii) an increasing trend in the cost of energy.

The most to least significant future policy and institutional drivers have been found to be:

1) **Financial**

   Respondents viewed *financial instruments* and *energy tax deductions* as the most significant in the future to driving energy efficient technologies, with an average of 4.3 and 4.2 respectively. It is interesting to note how this has changed from the current situation, as these measures were the worst ranked drivers for current policy and institutional instruments.

2) **Information**

   Training and/or information in addition to *energy audits* were rated as significant to driving technologies in the future, both of which have an average score of 4.

3) **Regulation**

   The future use of regulatory instruments is seen to be a significant driver, with *energy performance standards*, *labelling of industrial technologies* and *mandatory targets* having an average score of 3.8, 3.7 and 3.6, respectively.

4) **Voluntary Agreements**

   Voluntary agreements were ranked as the lowest influence for the effect of instruments in the future. Although it is ranked last it is still perceived to have a moderately significant effect (average score of 3.0) in driving energy efficient technologies in the future.

The following section unpacks findings from interviews and questionnaires of barriers to energy efficiency improvement.

8.4 Barriers to Energy Efficiency Improvement

While keeping in mind the opportunities for energy efficiency improvement, and what drives these opportunities to be adopted, what is equally as important is to understand the different factors which act as barriers to improving energy efficiency in a refinery. This section presents results from interviews, followed by results from questionnaires. A quantitative perspective is provided on the relative significance of barriers from the responses to the questionnaire. However, there is a tendency for barriers to interact and thereby reinforce each other which is difficult to capture within a survey (Sorrell, Mallet & Nye, 2011). Therefore a more qualitative approach is given by a discussion of findings from interviews to supplement the quantitative questionnaire results.

8.4.1 *Qualitative Results from Interviews*

Findings from interviews draw attention to a number of barriers to the adoption of energy efficiency measures. Once again, measures are defined here as to include both technologies and best practices. The focus within this section will be on projects requiring capital. However, mention is given to maintenance or best practice opportunities which were highlighted during interviews.

- <u>*Operating Stability*</u> - A number of respondents indicated that operating stability of the plant can be a serious problem, and this is linked to the experience of managers and engineers. Within the refinery, plant upsets can divert resources away from energy improvement. Operational instability leads to a greater focus on daily production problems, and to a certain extent this is tied into a lack of technical skills. Any energy improvements that have been made can be overshadowed or masked by operational instability, and achievements will not be truly reflected in performance results. Resources (financial and personnel) can be shifted to focus on production problems. Moreover, when resources are limited, the focus will always be on the immediate urgent item. This would be resolved in the medium to short term by personnel, and consequently less time is left for energy improvement.
- <u>*Availability of Skilled Personnel*</u> - According to the interviewees, staff resources are scarce and this was due to focus on daily production problems and a tendency towards leaner firms. During periods of recession in the market, refiners target reductions on fixed and variable costs to improve on profitability. Staff costs are the next highest operating costs, after energy costs, and personnel numbers are usually first to be targeted when reducing fixed costs. This leaves personnel with less discretionary time for improvements that are not an immediate priority.

  Technical availability at the operational level can be a concern. Several respondents have pointed to other 'compliance' projects that use up the plant's technical resources. Regulation or environmental 'must do' projects for licence to operate leave fewer resources for other areas of improvement on the plant. In recent years the refining industry in South Africa has been 'overwhelmed' with regulatory requirements. The amount of technical energy and time required for clean fuels has overshadowed the energy arena. 'There is limited capacity to implement new technology mainly due to clean fuels and environmental regulations. There is never enough time for process engineers to sit down, investigate and work on energy projects'. This comes back to company energy policy and guidelines and how these are prioritised and put into effect. 'Personnel are always in a rush and when it comes to the crunch, energy improvement is last on the list, if at all'. Some companies had a dedicated 'energy coordinator' with other personnel (not on a full time basis) supporting his/her role. However, companies might only have one person looking at both plant support and energy improvement ideas, and problems on the plant can distract from energy efficiency optimisation.
- <u>*Experience and Technical Skill*</u> - Interviews revealed that in the industry in South Africa in general technical skill was lacking at the operational and technical level.

  As mentioned in the first point, operational stability is influenced by a lack of technical skill and experience. Two respondents said that within the industry, a large number of experienced managers and engineers had retired, and this had an impact on operations, as 'the new generation is not experienced enough'. One respondent also explained that the skills gap is becoming a bigger challenge as experienced personnel leave for opportunities in the Middle East, which highlights a greater necessity to maintain experienced people within the industry. In addition, one respondent said that there needed to be integration between theoretical and practical knowledge. 'Inexperienced graduates are placed onto the plants who have limited practical experience to identify these things'.

In addition, during the formulation of concepts by engineers at the beginning of a project, a lack of technical skill is a concern as engineers need to make numerous assumptions due to uncertainties in measurement. The identification of the energy gap is the biggest factor in making improvements, and older refineries have a limited number of meters on the plant. This lack of measurement equipment gives rise to difficulty in determining the baseline for energy. The assumptions made by engineers and the correctness of those assumptions are therefore very important as mass and energy balance deviations can have a significant impact on the entire refinery analysis.

When it comes to seeking outside support on a technical level, technical skill is not readily available in South Africa, for example, refiners need to go to the big licensing technology companies abroad for large energy projects such as pinch/heat integration etc.

The skills gap is also becoming a bigger challenge with respect to maintenance and operations technical personnel. The external maintenance skills have dropped substantially, for example the weld failure rate is up to 25% whereas it should be 2%. Tank cleaning, welding etc should be straightforward but the skills are not there to do the job properly, or in the required time. This has a knock-on effect on operational excellence and stability, and hence energy improvement.

- *Availability of Baseline Data* - As mentioned, measurement of energy forms the basis for engineering assumptions, and uncertainty in energy information provides an uncertain baseline.

  Several respondents said that in terms of measurement, there was poor information quality, the reason being that 'for many years energy was considered free'. It is very expensive to put in measurement equipment throughout the plant, 'they need to draw the line, as energy savings might not be justified'. However, 'to manage energy properly you need the equipment. There is no return initially, but it's required to run the business responsibly'.
- *Enforcement of Energy Guidelines and Corporate Support* - Energy is a key area in terms of supporting sustainable improvement, and sustainable profitability. Although times have changed in the energy arena, with rising energy costs and a growing emphasis on greenhouse gas emissions, for many firms the focus on energy improvement was 'not serious enough'.

  Several respondents indicated a lack of corporate support for energy improvements. Energy was considered at executive levels and provisions had been made, but this was not really a driver in the lower levels. There was a notion that putting a focus on energy projects and objectives may be expensive and efforts may not warrant as much return. One company had recently put a particular focus on energy related operating expenditure and gross margin improvement that was driven from corporate, although there was room still for improvement as part of continuous improvement on the plant.

One respondent indicated that there are efforts on energy focus but the minute the focus goes away they would be back to where they started. Therefore management support is central to sustained energy improvement, and one respondent indicated that many initiatives are driven from the top down, therefore ‘if it’s not a key activity, you won’t get buy in’. The endorsement of energy efficiency at a high level was highlighted as an important prerequisite by majority of respondents, for most firms to improve on current energy performance.

- *Available Capital and Investment Priorities* - Findings from interviews indicate a lack of capital available for energy investments. Refinery projects compete for capital allocated through budgeting, as well with as other downstream investments. Capital is required for ‘stay in business’ projects in order to meet the requirements for licence to operate. Mandatory ‘compliance’ projects are first on the list e.g. environmental requirements, this impacts where capital is spent and ‘energy efficiency can be put on the backburner’. Energy investments compete with investments in line with product diversification and quality, reliability etc. In addition, energy efficient equipment has a greater upfront cost and ‘in general, there is not as much return from energy efficiency projects as opposed to yield improving’. ‘Projects which save money are generally not as lucrative as profit generating projects’.

  Several respondents had the view that capital availability was a barrier, as energy efficiency comes down to priorities, and ‘there is only so much capital’. Largely, business cash flow determines capital availability, and this is driven by the commercial world. Other areas of the business might also compete for funds, which may leave less for the refinery. Different areas of more promising investment opportunities in the downstream, like retail networks, might get more investment.

  Several respondents said the greatest influence on funding of capital projects is that of refining margins, particularly in South Africa where there is a regulated margin. Companies have to cut back on capital investment when refinery margins are reduced; they then eliminate certain projects from the budget list. ‘It’s all about margins’ and this has its short falls in the short term thinking and planning of owners.

  On the other hand, if an improvement made financial sense, then resources outside the budgeting protocol could be assigned quickly. However, large capital projects would have to wait for an improved economic climate, as there was no access to vast amounts of capital.

- *High Hurdle Rate for Investments* - A consequence of capital rationing is that projects must meet a high hurdle rate in order to be approved for implementation. Many projects are proposed, and are nice to have, but they are not economically justifiable. ‘Even mandatory compliance projects are still about making money’. On the other hand, projects that mitigate high risk will still go ahead, even though they may not meet the hurdle.

  During project selection, senior personnel will scrutinize projects and go for the economically justifiable ones. There is a tendency towards ‘more value and instant gratification’.

  Within three out of four companies in this study, hurdle rates varied roughly between 14-17% for weighted average cost of capital (WACC) or return on capital employed (ROCE). One company had more recently made capital available for small energy efficiency projects for up to R20 million. This allowed for implementation of energy projects which may not meet high hurdle rates of competing investments. The maximum typical payback period was generally no more than 5 years as a rule of thumb.

- *Economic Situation and Market Trends* - The economic downturn was found to have an impact in availability of capital. Large investment projects were on hold until the economic climate improved as there was 'no access to huge funding currently'. Opportunities were implemented with resources available, but the key driver was to maintain production flow during periods when the market slumps. 'Low cost ideas can come in e.g. optimization to reduce the gap, but all high level investment will be halted- not just energy efficiency ones'.

  The economic climate affected factors such as crude price and rand dollar exchange rates however sales or demand for finished product was affected very little, if price increases were made in small increments. Furthermore, the uncertainty in the economic climate affected the thinking and planning of owners which was geared towards a shorter horizon.
- *Significance of Cost of Energy* - According to the interviewees, the relatively low cost of energy in South Africa historically 'did not create a burning platform for improvement'. In the past, 'energy did not get much attention'. This is because plants were designed when energy was very cheap, the design optimised piping costs etc. 'Energy cost in the past was not significant, but now this is different- the cost of energy, especially electricity, is significant' and 'it makes incentive sense to implement energy efficiency nowadays'. However, several respondents said that there was a notion that since energy is reasonably cheap and because there was no access to a vast amount of funding currently, they were not going to spend capital on large projects e.g energy integration, but rather go for the low-hanging fruits.

  In addition, energy costs fluctuate vastly, this uncertainty in the cost of energy was a barrier to energy efficiency investments, and 'when the cost of energy is low they look at other more promising investment opportunities'. For example, energy costs can vary from R180 million/month to R20 million/month for natural gas at the equivalent GJ consumption.

  Many respondents indicated that although energy prices were uncertain on the short term, in the longer term it was the end of 'cheap energy'. Power costs were increasing, but no improvement can offset the increases. Energy (crude) prices did not have as much of an impact on the refinery as 'to some extent it's still in your control'.
- *Old Design/ Brownfields* - According to the interviews, the biggest challenge with energy efficiency improvement is inherent in the design. The refineries are old 1960s designs and you 'cannot compare existing vs. new designs in terms of energy efficiency; there is a big gap between the two'. There are difficulties to adding on refineries 40+ in age (brownfields). They are 'really stretching the limits, as infrastructure has been added on so many times'. The biggest challenge would be to retrofit the old plant where stand-alone energy efficiency projects are often difficult to integrate with an old design. One of the biggest challenges is instrumentation- many older systems are not designed to incorporate new technologies easily. New retrofit designs need to incorporate the old control system with the new equipment.

  One respondent said there is a large gap between new and old technologies for refiners. The old refineries in the country are at least three or four technology generations behind. For example, one refiner's furnace efficiency went up 28% after replacement- that is how big the gap is.

In addition, the level of energy integration feasible is limited at a plant that has been around some time. The configuration is the net outcome of revamps throughout its lifetime. Therefore, there is a trade-off between integration and flexibility on the plant. 'There is very little process recovery between units- and they are constrained by the old design'.

- *Limited* Space - Findings indicate two of the refineries had limited space for expansion/modification however, in the other refineries the space limitation was not significant. Site congestion, together with technical risks of the old 1960s design, has an effect on the level of energy integration between units.
- *Financial Incentives* - Financial incentives for energy efficiency can be a significant driver for improvement; however limitations may exist in the implementation of the financial incentives therefore hindering their uptake by industry. Findings from interviews identify one of the main concerns with the tax incentives is spending before a major upgrade, namely Clean Fuels, which could lead to regret capital. The tax incentives for brownfields projects (Industrial Policy Project, Section 12-I of Income Tax Act No. 58) will be around until 2015, whereas Euro 5 specifications and standards for cleaner fuels should be implemented by 2017. With respect to electricity-based incentives, companies do factor in demand side management (DSM) savings from Eskom. However, they are cautious to implement these arrangements as it sets a threshold level for energy consumption. Eskom penalises if the quota is exceeded.
- *Resistance* - Several respondents said that there was a difference between resistance to and awareness of energy efficiency measures. The lack of staff awareness was not seen as a significant barrier but more so resistance. 'I think people are aware, but doing something about it is another thing'. 'In practice, people on the plant prefer to be pushed than proactive'.
- *Uncertainty* - According to the interviews, there are a number of aspects of uncertainty with regards to energy efficiency investment and energy cost. As discussed above, the cost of energy or crude is highly uncertain due to the nature of the economic market. There are large fluctuations in energy prices (crude); however the cost of electricity is more certain with steady increases within the next several years. In addition, in terms of a carbon tax, 'they are not ready to factor in a cost of carbon into appraisals as there is no certainty yet'.

  Several respondents agreed there was uncertainty in clean fuels investment. 'Shall we do it, or shall we just import it'. Clean Fuels is driven by the need for lower sulphur requirements, however changes in fuel specifications require immense investments for upgrading refineries and 'there is no economic incentive'. 'Why go ahead unless its regulation'. As an alternative to Clean Fuels upgrades they could spend money on infrastructure e.g. tanks for importing. Importing finished product from Middle East 'mega' refineries could be an option, as they have economies of scale (up to 1 million bbl/day). A viewpoint was that this depends on how significant government sees refineries as being for energy security.

  Similarly, several respondents shared the same view of the uncertainty in the future of the respective refineries. This comes back to return on investment, it might make more sense to shut the refinery down and build one which is totally new technology and energy efficient.

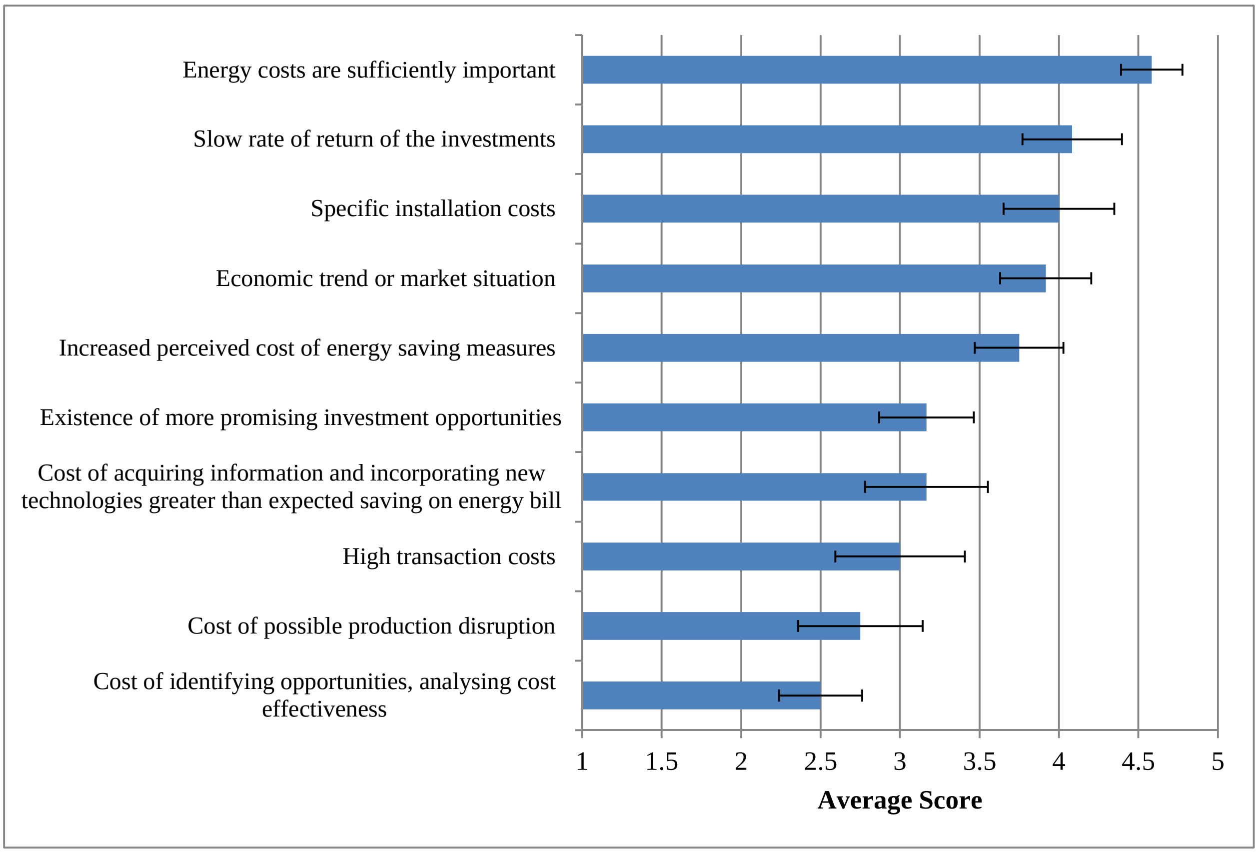
The following section presents findings from questionnaires for the significance of barriers within the refinery environment, to adopting energy efficient technologies.

8.4.2 *Quantitative Results from Questionnaires*

This section of the questionnaire was developed based on the grouping of barriers and drivers from literature. These barriers have been rated by respondents on a scale of 1 (completely insignificant) to 5 (very significant) for their influence on the uptake of energy efficient technologies.

8.4.2.1 *Financial, Economic and Market Barriers*

The following figure presents the results from the questionnaire given to respondents in the refining industry.



Note: Refineries are energy intensive and energy costs are substantial at between 40-50% of operating costs. A typical barrier to the improvement of energy efficiency from literature is that '*Energy costs are not significant*', particularly for non-energy intensive companies. Therefore in this circumstance, as this barrier was not suitable, this statement was adapted in the questionnaire to '*Energy costs are significant*'.

Figure 23 The Significance of Financial, Economic and Market Barriers

'Energy costs are sufficiently important' was the most significant result with a high average rating of 4.58, in addition to showing strong agreement between respondents (standard error of 0.19). The slow rate of return for energy efficiency investments was also a significant factor in the decision to invest, with an average rating of 4.08. Compared to other projects, investments in energy efficiency have a slow pay out. In addition, specific installation costs were seen as a significant barrier with an average rating of 4.00. However, this had a large standard error (0.35) as respondents noted these costs are accounted for in the initial project cost estimations. Projects must meet the hurdle rate, and would be filtered out if they are not economically viable.

The economic trend or market situation is a considerable factor in the decision to adopt energy efficient technologies with an average rating of 3.92. This factor is noted to affect all investment decisions, as funds available for companies are generally restricted in a recession. In addition, high upfront costs, or the increased cost of energy saving measures compared to other profit generating projects, are a significant barrier to adopt energy efficient technologies. This is seen by an average rating of 3.75.

The following barriers were ranked in descending order of significance (from 3.17 to 3.00): i) existence of more promising investment opportunities, ii) cost of acquiring information and incorporating new technologies greater than expected saving on energy bill, iii) high transaction costs.

The least important barriers seen from the figure are finally: iv) cost of possible production disruption (2.75), v) the cost of identifying opportunities and analysing cost effectiveness (2.5).

8.4.2.2 *Institutional, Organisational and Behavioural Barriers*

The following figure presents the findings for the influence of institutional, organisational and behavioural barriers to the uptake of energy efficient technologies.

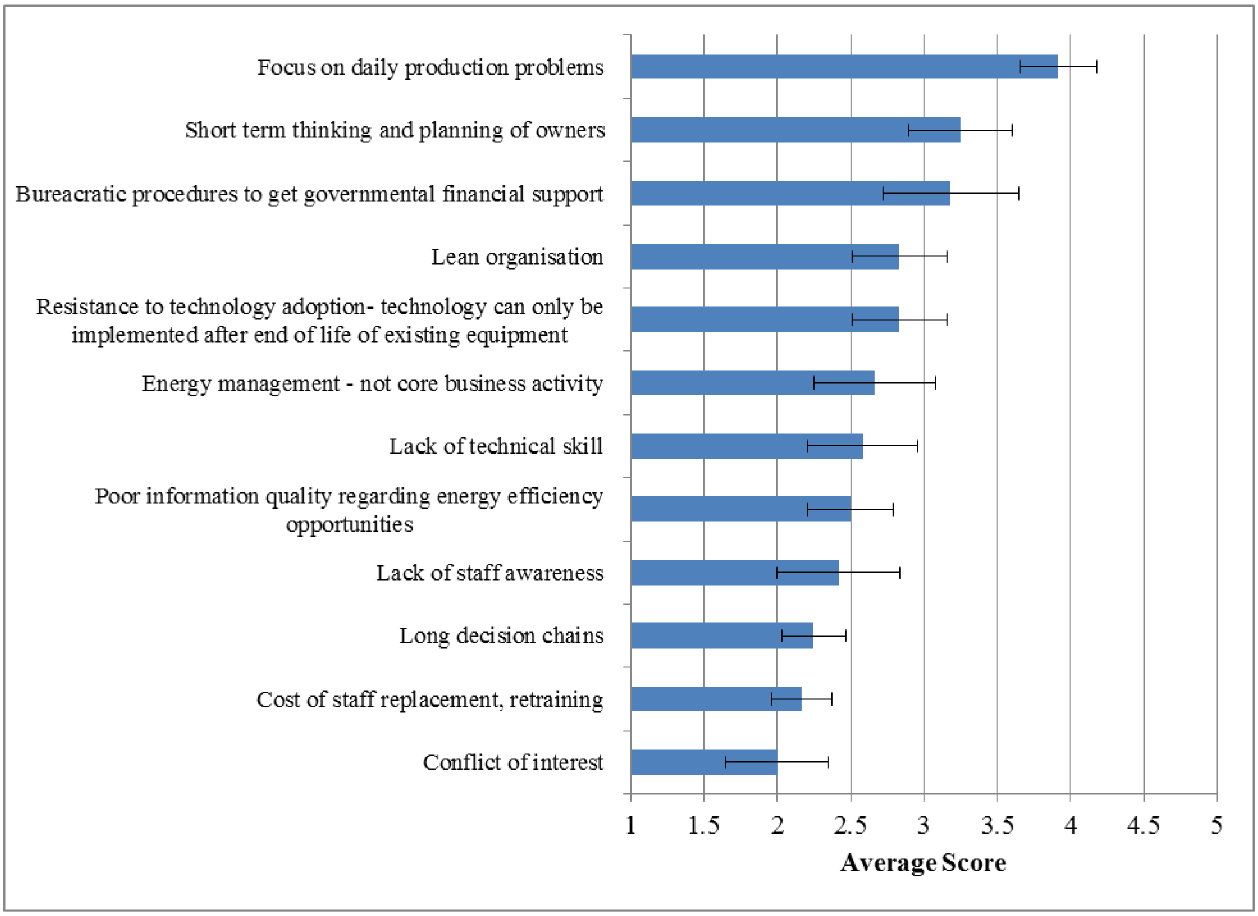


Figure 24 The Significance of Institutional, Organisational and Behavioural Barriers

The most important finding from this category of barriers is the significance of the focus on daily production problems, having an average rating of 3.92. This is linked to the availability of personnel on the plant as discussed in 8.4.1. The barrier of short term thinking and planning of owners, and bureaucratic procedures to get governmental financial support, were also found to be moderately significant with a rating of 3.25 and 3.18 respectively.

There was a large difference in viewpoints from respondents for barriers: bureaucratic procedures to get government financial support, lack of staff awareness, and energy management as not a core business activity. This is shown by the standard error of 0.46, 0.42, and 0.41 respectively in the appendix. These barriers were rated with a moderate to low significance in influence.

8.4.2.3 *Technological Barriers*

The following figure presents the results of the significance of technological barriers on the uptake of energy efficient technologies.

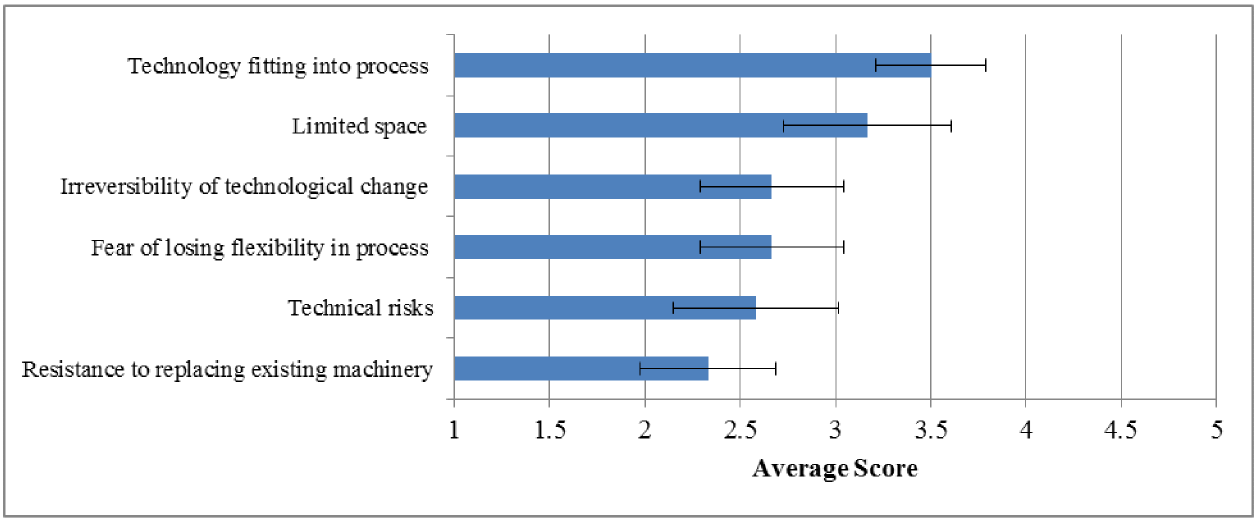


Figure 25 The Significance of Technological Barriers

The technological barrier with the most significant influence on the uptake of energy efficient technology is technology fitting into the process. This had a moderately significant influence with a score of 3.50. South African refineries are 40 years and above in age, and many units have older technology. Incorporating new technology with old technology is technically challenging, and many older refiners tend to be fast followers with technology that is proven, as opposed to 'on the cutting edge'.

As mentioned in the previous section of interview findings, limited space was a concern for two out of four refineries. This is reflected quantitatively here, with a moderately significant influence (3.17) and with the largest standard error of 0.44 for this category.

The findings also present the barriers of irreversibility of technological change, fear of losing flexibility in process, technical risks and resistance to replacing existing machinery with a moderate to low significance of influence. The barrier of technical risk however has a large standard error of 0.43. This can be assumed to be owed to the fact that technical risks are very important when considering implementing technology; however risks are generally managed during the project development and technology selection.

8.4.2.4 *Uncertainty*

The figure below presents the results for the significance of four uncertainties to the uptake of energy efficient technologies. This is presented on a scale of 1 (completely insignificant) to 5 (very significant).

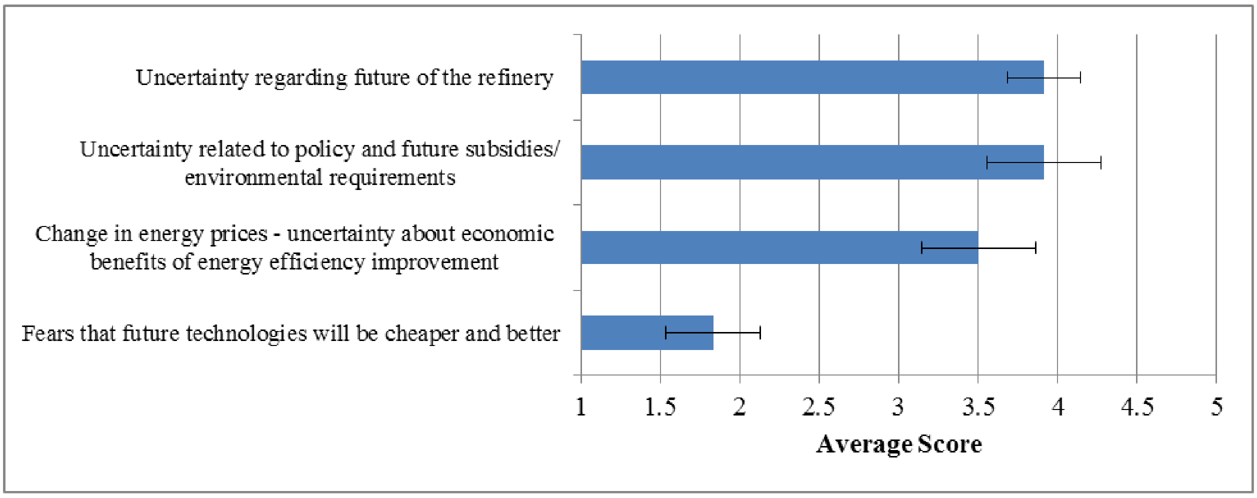


Figure 26 The Significance of Uncertainty to the Uptake of Energy Efficient Technologies

The uncertainty regarding the future of each of the refineries was seen to be an important barrier to the adoption of energy efficient technologies. This uncertainty could manifest in the delay of further investment. Similarly, uncertainty related to policy and future subsidies or environmental requirements was also very significant with an average of 3.92. Respondents noted there was little uncertainty about the economic benefits of energy efficiency investments and energy prices were increasing (the ‘end of cheap energy’). However in the short term, energy prices, particularly crude prices, fluctuate substantially.

8.5 Discussion

The study revealed noteworthy results to support an explanation of the energy efficiency gap in the refining industry in South Africa.

8.5.1 *Integrating Qualitative and Quantitative Findings on Barriers and Drivers*

Barriers are categorised in this study as: i) financial, economic and market barriers, ii) institutional, organisational and behavioural barriers, iii) technological barriers, and v) uncertainty. The following figure presents the overall significance of each of the different barrier categories from a scale of 1 (completely insignificant) to 5 (very significant). This is specifically for energy efficient technologies.

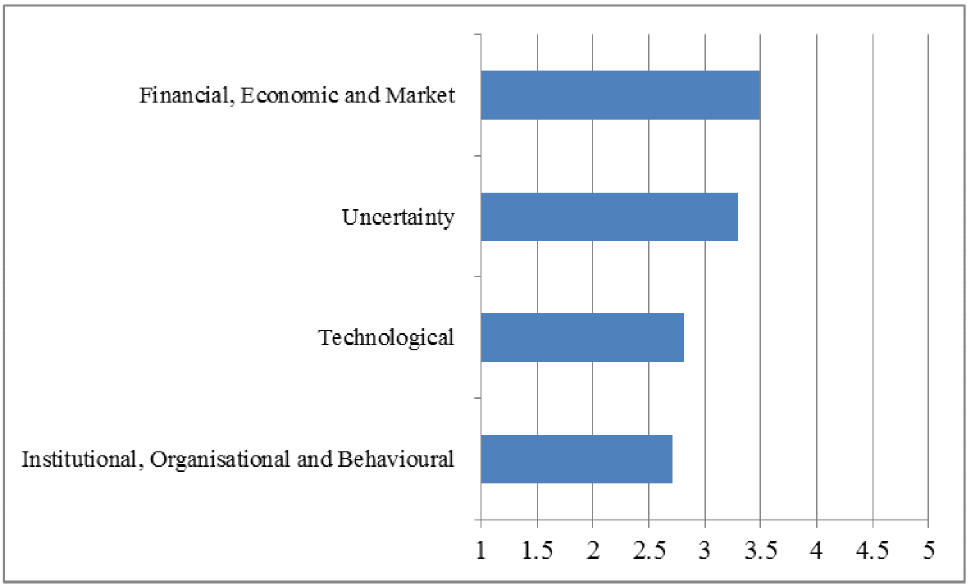


Figure 27 The Average Significance of Barrier Categories

Figure 27 shows the most significant group of barriers as *financial, economic and market* barriers, with an average rating of 3.46. This observation is in agreement with findings relating to the most influential policy and institutional drivers in the future- which are the *financial* instruments (such as subsidy schemes, tax incentives) and energy tax deductions. Furthermore, these findings are in line with de Groot, Verhoef & Nijkamp (2001) and Sardianou (2008) who find that policy instruments, such as subsidies and fiscal arrangements, may be supportive in steering investments towards higher energy efficiency.

The questionnaire results for *current* institutional and policy drivers supplement the interview findings for drivers. The most significant institutional and policy driver currently was *information*. This was firstly from training and/information sources, and secondly, through energy audits. Interviews highlighted the actions for obtaining information are related to dealings with refining industry experts, such as by belonging to technology alliances or having an agreement with a technical design house. In addition, energy audits were carried out every two years by Solomons Associates, and refiners utilised the Solomons EII methodology to perform internal energy audits on a more frequent basis. According to Sorrell, Mallet & Nye (2011), large energy intensive firms are typically better informed about energy efficiency opportunities than small and medium-sized entities (SMEs). This is in line with findings from this study, that information for energy efficiency improvement opportunities is abundantly available for refineries.

Closely following the financial, economic and market barriers category is the category of *uncertainty*, with an average significance rating of 3.29. The uncertainty about the future of refineries and energy prices has its effect in the long term decision making of refiners into energy efficiency investment, and whether refiners invest or divest in current assets. These two uncertainties are tied into the fluctuating nature of the global economy. In alignment with recent literature, findings by (Ren, 2009) specify two areas with the highest uncertainty, which are analogous to uncertainties found in this study, being firstly, the costs and supply of energy or feedstocks and secondly, the prospects of economic growth and market demand.

Another uncertainty particular to the South African situation is that of South African policy, financial incentives and/or environmental requirements. This uncertainty can be more so controllable through adequate government planning and support.

In summary, these findings indicate that financial and government policy support would stimulate energy efficiency investment further. This parallels one of the conclusions from a study by (Hepbasli, 2003). According to this study, in Turkey and as well as Asia, the two most important features behind successful policies and programs, which have been created to promote energy conservation, are i) government policy support and ii) long run self-sustainability of financial support to the programs (Hepbasli, 2003).

In the results of this study, an important dynamic that emerged is that although financial incentives were found as a driver for energy efficiency improvement, they could be a barrier in some instances. For example, spending on energy efficiency before a major upgrade with Clean Fuels could lead to regret capital. Also incentives which set a threshold limit such as Eskom demand- side-management savings for electricity consumption reductions can be a barrier. Companies are cautious to enter into agreements where penalties might be incurred for operating above a threshold.

8.5.2 *Discussion of Specific Drivers, Barriers and Opportunities*

Certain individual barriers and drivers are more significant than others, and making a distinction between these assists in the forming a holistic understanding of energy efficiency improvement. In this section, the significant drivers and barriers are presented and discussed. Lastly in this section, the findings of opportunities and potential for improvement are discussed.

8.5.2.1 ***Significant Barriers***

The following table presents the ten most significant individual barriers to the adoption of energy efficient technologies.

Table 29 Most Significant Barriers to the Adoption of Energy Efficient Technologies

Significant Individual Barriers	Average	Std Error
Energy costs are sufficiently important	4.58	0.19
Slow rate of return of the investments	4.08	0.31
Specific installation costs	4.00	0.35
Uncertainty regarding future of the refinery	3.92	0.23
Focus on daily production problems	3.92	0.26
Economic trend or market situation	3.92	0.29
Uncertainty related to policy and future subsidies/ environmental requirements	3.92	0.36
Increased perceived cost of energy saving measures	3.75	0.28
Technology fitting into process	3.50	0.29
Change in energy prices - uncertainty about economic benefits of energy efficiency improvement	3.50	0.36

The table shows the three most significant factors to energy efficient technology adoption as the financial, economic and market barriers of:

- *Energy Costs are Sufficiently Important* - This is the most prominent result. For refineries, energy costs are between 40 to 50% of operating costs, and therefore a major business expense and driver for energy improvement. However, it must also be noted, that in practice, energy that is derived from crude is usually not reported as an operating cost and typically shows as a yield loss or loss in gross margin. Thus, the true cost of energy is often hidden in the reports and typically only the imported energy cost (mainly electricity) is reflected in the cost report. As a result, although energy costs are large, the energy costs may not seem as important as they are often not fully reported.
- *Slow Rate of Return of Investments*- According to respondents, compared with other investment opportunities, energy efficiency (‘profit saving’) investments typically gave a slower pay-out than ‘profit generating’ investments. Also investments in other parts of the business may take priority such as retail networks.
- *Specific Installation Costs*- The specific costs of installing technologies is a noteworthy barrier and these add to high upfront costs which companies must provide for energy efficiency projects.

The following barriers are equivalent in significance to the uptake of energy efficient technologies:

- *Economic Trend or Market Situation* - The economic climate has a large impact on the availability of funds for large capital investments.
- *Focus on Daily Production Problems* - The shortage of staff and time on the plant is a notable factor in energy efficiency improvement as resources are focused on daily production problems. This is more so if available capital is restricted, as the focus will be towards the immediate urgent item.
- *Uncertainty Future of the Refinery* - This is linked to the old age of the refineries in South Africa, increasing regulatory requirements in the country and the global economic market.
- *Uncertainty Related to Policy and Future Subsidies/Environmental Requirements* - There has been an increasing trend in regulatory requirements for the refining industry in recent years. However findings show a high significance for the uncertainty in policy, future regulatory requirements and access to external financial incentives, such as subsidies.

The following barriers decrease in order of significance to the adoption of energy efficient technologies:

- *Technology Fitting into Process* - The age of existing refineries in South Africa makes energy integration difficult between units, due to the old designs. In addition, older technology makes up a large contingent of existing equipment, which increases the difficulty of integrating newer technology into the process.
- *Increased Perceived Cost of Energy Saving Measures* - The higher cost of energy saving measures was found to be a significant barrier, and this is reflected in the slow rate of return of energy efficiency technologies, compared to other investment opportunities.
- *Change in Energy Prices*- There is also uncertainty about the precise future returns from energy efficiency improvement which arises from fluctuating energy prices.

Coherent with findings from this thesis, Sorrell, Mallet & Nye (2011) state that large energy intensive firms typically still face important barriers to improving energy efficiency, most notably in relation to the hidden costs of staff time and the risk of production interruptions. Findings from this thesis point out that personnel available for working on energy efficiency projects, are limited, as there is a *focus on daily production problems*. More importantly, this lack of available personnel is driven by operating instability of the plant (which requires staff resources), and a decline in technical experience.

Moreover, a study by Ren (2009) on improving existing processes in petrochemical plants specifies the shortage of staff and time as an important barrier. Troubleshooting often occupies the valuable time of engineers in petrochemical plants. This leaves little time for understanding current energy use or collecting information on innovative energy efficient technologies. Also within larger firms, not many (no more than 10) personnel are specialised in energy efficiency improvement related coordination and management and finding experienced engineers to replace retired personnel or to meet labour demand is often difficult (Ren, 2009).

Additional barriers found in this study were in line with the study by Ren (2009). These are: i) existing configurations (*old design/brownfields*) and ii) competition from other prioritised projects (*available capital and investment priorities*). According to Ren (2009) and references therein, applying widely commercialised technologies and engineering, are generally focus activities for improving existing processes, as opposed to R&D. The disruptions and shutdowns of a plant can create economic losses which are usually in the range of hundreds of thousands to millions of dollars per month (Burchmore and others (1993) from (Ren, 2009)). Therefore relying on proven configurations and operation control, are considered to be more important than the potential benefits of energy savings from implementing energy efficient technologies. Also integration within the refinery adds complexity. Increasing complexity reduces plant flexibility. This can sometimes cause upsets, as when units are linked (directly or indirectly), an upset in a unit can cause unexpected disruptions in one unit or shut down of the whole plant (Ren, 2009). Secondly, competition for capital is an important barrier. According to Ren (2009), priorities such as capital investment in new capacity are often first to receive investment funds. Investments such as these give a higher internal rate of return and more sales than those which improve energy efficiency. From this thesis, must-do projects which refiners require to meet the requirements for license to operate, and maintain the running of the plant, are priorities for capital. These must-do/mandatory projects include projects to meet environmental, health, safety, and plant security requirements, and maintenance (Marano, 2007). Budget funds which are remaining are therefore prioritised for investments which are more lucrative and meet investment hurdle rates. Ren (2009) indicates that improving energy efficiency in existing processes is appreciated as giving a competitive advantage, although it is not always a top priority.

Furthermore, in unity with the findings from this thesis of barriers: *investment priorities* and *change in energy prices*, Szklo & Schaeffer (2007) re-iterate the view that capital needs in the refining sector compete with capital needs in other petroleum segments of a corporation. Therefore refiners tend to present risk aversion for investing in technological innovations, whose return depends on the uncertain premium price of oil products (Szklo & Schaeffer, 2007).

8.5.2.2 ***Significant Drivers***

Major drivers for energy efficiency projects which have emerged from this study are *corporate support* and *organisational energy policy or strategic energy objectives*. These both have a very high significance rating for the influence on the uptake of energy efficiency project (4.75 and 4.42 respectively, on a 5 point scale). This is consistent with Sorrell, Mallet & Nye (2011) where a company-wide energy policy, with prominent support from senior management, is the foundation for an energy management system (EMS). This is in addition to dedicated energy management personnel. Likewise, according to Ferland (2005) and Zarker (2005) (from Ren (2009)) commitment from the top leadership or a leading coordinator in energy savings can also be important.

In terms of actor dynamics, findings in this thesis highlight that opportunities are mainly identified from the bottom-up (at the plant level), however an endorsement of energy projects from the top-down, via *corporate support*, is the most significant influence to improving the implementation rate of energy efficiency projects. Furthermore in this thesis, the barrier of resistance was highlighted more so than lack of awareness of opportunities on the plant. As highlighted previously in the review on opportunities, a study by Mckinsey & Company (2009) indicates that the driver of building increased *awareness* of the importance of energy conservation and CO_2 emissions reductions, for large companies, will take time and continued reinforcement. Behavioural changes are always gradual, and high level management attention will be required for this focus to remain effective.

Two key drivers which were highlighted from interviews are i) *legislation* and ii) *competitiveness*, with cost as a very important part of business competitiveness. This is in agreement with Reddy & Assenza (2007) who discusses a decrease in the price of technology as an important factor in the penetration of energy efficient technologies into the market. Similarly, Ren (2009) states the most important driver for improving existing processes is *cost savings* as a result of reducing process energy use per ton of product. Business earnings before income tax, a key indicator of performance, are increased directly by the reduction of energy costs (Strohrman (2005) from Ren (2009)).

Lastly, the findings within this thesis highlight a prominent difference between the current and future significance of instruments to adopting energy efficient technologies. Refiners view the stimulus of policy and institutional instruments as drivers to increase overall in the future, compared to the current situation. This outlook can be assumed to be drawn from the increasing trend of regulatory requirements in the country in recent years.

8.5.2.3 ***Potential and Opportunities for Improvement***

From the literature review presented, a study by UNIDO (2010) gives an estimate of potential for energy efficiency improvement at between 40-45% for the refining industry in developing countries. This is somewhat in agreement with the findings in this thesis for the potential for energy efficiency improvement in the South African crude oil refining industry as South African refiners are in the fourth quartile in terms of energy performance (EII rating). Different energy efficiency measures (such as optimisation, organisational culture change, utilities and cross cutting opportunities etc) were found to have an improvement potential in the range of 41-47% (29-62% when including standard error). In contrast to this, other literature discussed presented values of approximately 13% overall improvement potential (or in the range of 10-20%) from cost-effective energy efficiency opportunities, for the refining industry world-wide (developed countries included).

Opportunities which could be implemented were from both energy management and investment in capital projects. Capital projects provide the largest step change for improvement; however improved energy management practices (i.e. 'soft skills' such as awareness and behavioural change) are required to sustain an energy focus, and thus energy savings. This is driven from the top-down, by corporate support and strategic energy objectives, as discussed earlier in the findings.

Findings which arose from interviews highlight opportunities from capital projects to be: i) the *replacement of end of life equipment* for energy efficient alternatives, ii) energy efficiency projects to 'piggyback' on the justification of *restructuring renovations* such as expansion projects and iii) application of advanced process controls. As discussed in the literature review, the energy savings achievable from applying *advanced process controls* can range between 2-4%. Plants which do not have updated process control systems can typically achieve energy savings of approximately 5% or more (Sheehan & Zhu, 2009; Worrell & Galitsky, 2005).

Findings from interviews and the questionnaire also highlight opportunities from advancing energy management. These were *behaviour* based opportunities of: awareness, responsibility, training and organisational culture change, in addition to improvements in utilities and for flare and hydrocarbon loss.

Behavioural changes offer no-low cost opportunities for CO_2 abatement; however it requires support from upper management. Building increased awareness of the importance of energy conservation and reduction in CO_2 emissions will take time and continued reinforcement (Mckinsey & Company, 2009). From the review of literature for opportunities for energy efficiency improvement, estimates of energy savings from *behavioural* changes that can be realised range from 1- 4%. This is by promoting energy efficiency stewardship in the form of energy management programs (Petrick & Pellegrino, 1999).

It is interesting to note that these opportunity findings correspond with the study by (McKinsey & Company, 2009). This study highlights that energy efficiency from *behavioural changes*, *improved maintenance* and *process control*, and energy efficiency requiring *capital expenditure* at process unit level, to have the highest cost savings potential for reducing GHG emissions (negative GHG abatement costs) in the downstream segment (refining). Refer to Figure 14, Global GHG Abatement Curve for Petroleum and Gas Sectors.

Furthermore, organisational, institutional and behavioural barriers have been found in this thesis to be the least significant grouping of barriers from surveys (rating of 2.71 seen in Figure 27, section 8.5.1). However, this is in contrast to the largest potential improvement for measures of organisational culture change and individual behaviour change, which are approximately 47% (as seen in Figure 20 in section 8.2.2.). This suggests that cultural change and operational excellence (individual behaviour change) are seen as *key steps* to identify and realise other (technical) opportunities for energy efficiency improvement in the industry.

9 CONCLUSIONS

This thesis explored current opportunities to improving energy efficiency in a refinery, and established an understanding of the influences which promote or inhibit the implementation of energy efficiency opportunities in the refining industry in South Africa. The aim of this thesis was motivated by increasing challenges faced by refiners such as stricter sulphur regulation of Clean Fuels 3, the IMO marine fuel standards, and an increasing shift towards middle distillates, which all contribute to increasing refinery energy intensity. Furthermore, challenges of increasing energy costs, in particular electricity costs in the context of South Africa, substantiate the need for mitigating some of these impacts on South African refiners, who are currently 4^{th} quartile with respect to energy efficiency performance .

Although energy costs are significant in refineries, and are therefore a major driver for energy improvement, the study has identified a range of barriers to improving energy performance. These include available capital and investment priorities, availability of skilled personnel and baseline data, old design/brownfield refineries, operating stability and uncertainty of the future of refineries, to name a few. There are many opportunities which refiners would like to implement, however the two biggest challenges are found to be firstly, available capital, where energy efficiency projects typically have a slow rate of return compared to competing projects, and high specific installation costs. Secondly, the availability of skilled personnel is reduced due to a focus on daily production problems which leaves less time for non-urgent items. From the synthesis it is established that the most significant categories of barriers that arose were firstly financial, economic and market barriers, and secondly, uncertainty barriers.

Understanding the drivers, barriers and opportunities for energy efficiency improvement from this thesis contributes to understanding future industry action required for mitigating GHG emissions and rising energy costs. These results have important implications since they suggest that future energy policy can improve on the situation within industry, by providing long term financial incentives. In addition, increased certainty in financial instruments, and campaigns should promote energy efficiency measures. This includes increased corporate support for energy efficiency objectives, one where energy improvement is one of the top priorities, as improvement is strongly driven by a top-down approach.

The opportunities which were emphasised include improved energy management practices, where energy efficiency is a constant focus. In addition, improvements in utilities, including flare and loss, and cross cutting opportunities were also highlighted. A larger step change in energy performance can be achieved through investment in capital projects when replacing end-of-life equipment, and during restructuring/expansion renovation projects. Advanced process controls were an additional opportunity which could be implemented in the future. It was noted that there was a large potential for organisational culture change and individual behaviour change (operational excellence), in the industry and these were key steps to achieving technical and energy management opportunities for energy efficiency improvement.

9.1 Recommendations

To ensure the achievement of the greenhouse gas emissions targets set out in the National Climate Change Response White Paper in addition to the targets set out in the national energy efficiency accord, government and industry need to deliver a step-change in energy demand trends, of which industry is a key energy consumer. Companies should incorporate programme design strategies that work to remove near- and long-term barriers to energy efficiency improvement from motivations of cost reductions and greenhouse gas mitigation. Refining industry specific barriers have been identified in this thesis, and more importantly, the most significant drivers to improving energy efficiency should be taken into consideration to overcome these barriers.

The recommendations for government, based on the findings from future institutional and policy drivers, are to implement further: i) financial instruments (incentives, subsidies) and energy tax deductions, and ii) energy auditing and training and/or information initiatives.

Typically energy management has the greatest impact when organisations address the three dimensions of technical, organisational and human behavioural. These include aspects of awareness of energy efficiency as corporate priority, values and attitudes towards energy use, in addition to the skills and knowledge related to the management and use of energy consuming equipment and energy systems. But comparing different sectors, “there is no one size fits all” when it comes to energy management. A portfolio of industrial policies is needed to assist companies in developing a supporting context for energy efficiency improvements. However, if government provides technology based incentives in the absence of energy management it will not result in significant market shifts. An organisational context to respond and integrate the opportunity into on-going business practice is required (Christoffersen, Larsen & Togeby, 2006; McKane, Price & De La Ru Can, 2008). Incorporating organisational culture and individual behaviour change (including operational excellence) mechanisms into the refining industry are key steps to implementing improvements and realising energy and GHG emissions reductions.

A study which explores energy efficiency in the CTL and GTL plants within the oil and gas sector would add significant meaning to the findings of this study. CTL and GTL processes are more energy intensive than crude oil refining, where typical barriers to improving energy efficiency in CTL and GTL are likely to be around technological uncertainty as more complex technology is used in the process. To aid in bringing energy intensities of major industrial sectors into line with international standards and best practice, similar studies in the synfuel refineries in addition to other energy intensive sectors such as within the minerals and chemical industries, should be performed.

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11 APPENDIX

Fuel Quality Specifications

Table 30 Proposed Petrol Specifications

Petrol	Units	Current National Specification	Clean Fuels 2 (CF2)	Clean Fuels 3 (CF3)
Vehicle emissions standards – SANS specifications roughly equivalent to EU		"Euro 2"	"Euro 4"	"Euro 5"
Sulphur, max.	ppm (m/m)	500	50	10
Research Octane Number (RON), min.		95; 93; 91	95; 93; 91	95; 93; 91
Benzene, max.	vol %	5	2	1
Aromatic content, max.	vol %	50	45	42
Olefins, max.	vol %	-	24	21
RVP (summer), max.	kPa	75	65 (+5 ethanol)	65 (+5 ethanol)

Source: (SAPIA, 2011)

Table 31 Proposed Diesel Specifications

Diesel	Units	Current National Specification	Clean Fuels 2 (CF2)	Clean Fuels 3 (CF3)
Vehicle emissions standards – SANS specifications roughly equivalent to EU		"Euro 2"	"Euro 4"	"Euro 5"
Sulphur, max.	ppm (m/m)	500 / 50[1]	50 / 10[1]	10
Polycyclic Aromatic Hydrocarbons (PAH), max.	mass %	na	11	11[2]
T90, max. **T95, max.**	°C	362 na	na 360	na 360

Source: (SAPIA, 2011)

[1] Niche grade

[2] Currently being reviewed by EU

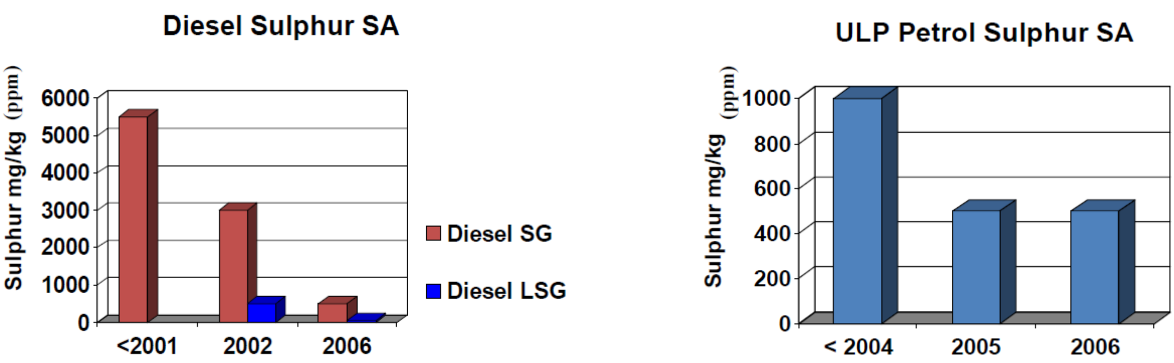

Figure 28 Sulphur Reduction in Petrol and Diesel

Source: (SAPIA, 2011)

Results

Table 32 The Significance of Drivers for Energy Efficiency Projects

Drivers for Energy Efficiency Projects	Average	Std Error
Corporate support	4.75	0.13
Organisational energy policy/ strategic energy objectives	4.42	0.26
Awareness and knowledge - from information sources such as conferences, visiting other refineries etc	3.50	0.23
Team/group motivating a project	3.42	0.19
Awareness and knowledge- from training	3.25	0.25
Vendors offering/ providing solutions	3.25	0.25
Individual motivating a project	2.50	0.23

Table 33 The Significance of Financial, Economic and Market Barriers

FINANCIAL, ECONOMIC AND MARKET	Average	Std Error
Energy costs are sufficiently important	4.58	0.19
Slow rate of return of the investments	4.08	0.31
Specific installation costs	4.00	0.35
Economic trend or market situation	3.92	0.29
Increased perceived cost of energy saving measures	3.75	0.28
Existence of more promising investment opportunities	3.17	0.30
Cost of acquiring information and incorporating new technologies greater than expected saving on energy bill	3.17	0.39
High transaction costs	3.00	0.41
Cost of possible production disruption	2.75	0.39
Cost of identifying opportunities, analysing cost effectiveness	2.50	0.26

Table 34 The Significance of Organisational and Behavioural Barriers on the Uptake of Energy Efficient Technologies

ORGANISATIONAL AND BEHAVIOURAL	Average	Std Error
Focus on daily production problems	3.92	0.26
Short term thinking and planning of owners	3.25	0.35
Bureaucratic procedures to get governmental financial support	3.18	0.46
Lean organisation	2.83	0.32
Resistance to technology adoption- technology can only be implemented after end of life of existing equipment	2.83	0.32
Energy management - not core business activity	2.67	0.41
Lack of technical skill	2.58	0.38
Poor information quality regarding energy efficiency opportunities	2.50	0.29
Lack of staff awareness	2.42	0.42
Long decision chains	2.25	0.22
Cost of staff replacement, retraining	2.17	0.21
Conflict of interest	2.00	0.35

Table 35 The Significance of Technological Barriers

TECHNOLOGICAL	Average	Std Error
Technology fitting into process	3.50	0.29
Limited space	3.17	0.44
Irreversibility of technological change	2.67	0.38
Fear of losing flexibility in process	2.67	0.38
Technical risks	2.58	0.43
Resistance to replacing existing machinery	2.33	0.36

Table 36 The Significance of Uncertainty to the Uptake of Energy Efficient Technologies

UNCERTAINTY	Average	Std Error
Uncertainty regarding future of the refinery	3.92	0.23
Uncertainty related to policy and future subsidies/ environmental requirements	3.92	0.36
Change in energy prices - uncertainty about economic benefits of energy efficiency improvement	3.50	0.36
Fears that future technologies will be cheaper and better	1.83	0.30

<u>**Raw Data**</u>

Barriers	Respondent Ratings											
Energy costs are sufficiently important	5	5	5	4	5	5	4	5	4	5	3	5
Increased perceived cost of energy	3	5	5	4	3	4	2	4	4	5	3	3
High transaction costs	2	5	4	3	1	1	2	4	4	3	2	5
Slow rate of return of investments	5	5	5	3	5	5	3	3	2	4	4	5
Existence of more promising investment opportunities	4	5	2	2	3	4	2	2	3	4	3	4
Long Decision chains	3	2	3	2	3	2	1	2	3	3	2	1
Lack of technical skill	2	3	5	1	1	3	1	4	4	2	3	2
Short term thinking and planning of owners	3	3	2	2	4	3	1	5	4	5	4	3
Technical risks	4	2	5	2	1	1	1	4	2	2	2	5
Resistance to replacing existing machinery	4	2	3	1	3	2	1	5	2	1	2	2
Irreversibility of technological change	4	5	3	3	3	1	1	4	2	3	2	1
Focus on daily production problems	4	5	4	4	3	3	2	4	4	5	5	4
Cost of staff replacement, retraining	2	3	2	2	1	2	2	1	3	3	3	2
Fears that future technologies will be cheaper and better	3	3	2	1	1	2	1	4	1	1	2	1
Uncertainty related to policy and future subsidies/environmental requirements	5	5	5	2	5	4	4	4	2	4	5	2
Conflict of interest within the company	4	1	2	1	1	4	1	3	3	1	1	2
Cost of possible production disruption	5	2	2	2	4	2	1	5	2	4	2	2
Bureaucratic procedures to get governmental financial support	4	3	4	1	1	1	3	5	4	4	5	-
Resistance to technology adoption- technology can only be implemented after end of life existing equipment	4	4	2	2	3	3	1	5	3	2	3	2
Lean organisation	3	4	3	2	2	3	1	5	4	2	3	2
Energy management not core business activity	1	3	4	3	1	3	1	4	5	2	4	1
Specific installation costs	4	5	5	4	4	5	1	5	4	5	3	3
Economic trend or market situation	4	5	4	2	4	3	3	5	3	5	5	4
Cost of acquiring information and incorporating technologies greater than expected saving on energy bill	2	2	5	2	5	3	2	5	2	2	4	4
Cost of identifying opportunities, analysing cost effectiveness	2	4	2	1	1	3	2	3	3	3	3	3
Lack of staff awareness	1	3	2	1	1	1	4	3	5	1	4	3
Poor information quality regarding energy efficiency opportunities	3	4	3	2	2	2	2	3	4	1	3	1
Fear of losing flexibility in the process	3	2	5	2	3	1	3	4	3	1	4	1
Technology fitting into process	4	5	5	3	4	2	2	4	3	4	3	3
Limited space	2	5	5	2	3	2	1	4	4	5	4	1
Uncertainty regarding future of the refinery	3	5	3	4	5	4	3	5	4	4	3	4
Change in energy prices- uncertainty about economic benefits of energy efficiency improvement	5	5	3	3	2	2	5	4	3	5	3	2

Opportunities	Respondents Ratings										
Maintenance best practices	30	30	50	80	20	35	80	20	50	10	50
Individual behaviour change-operational excellence	30	40	80	70	10	30	100	20	65	15	60
Organisational culture change	20	10	80	90	30	30	100	10	65	30	60
Optimisation	50	10	50	80	30	35	70	30	80	10	30
Utilities and cross cutting opportunities eg pumps, fans, motors	20	10	50	80	15	30	100	30	90	20	60
Process specific opportunities	30	30	50	90	15	25	100	50	50	20	20

Current		Respondent Ratings									
Regulation	Energy performance standards for industrial technologies	2	1	3	1	2	1	1	1	3	2
	Mandatory targets for Demand Side Management	1	3	3	2	2	1	2	2	4	3
	Labelling of industrial technologies	1	3	3	1	1	3	1	1	2	2
Financial	Financial instruments such as subsidy schemes, tax incentives	2	1	5	2	1	1	1	1	2	1
	Energy tax deductions	2	1	5	2	1	1	1	1	2	1
Information	Training/Information/Knowledge transfer	3	4	2	3	3	1	3	3	5	3
	Energy Audits	4	3	2	3	3	1	2	3	3	2
Voluntary Agreements	Voluntary agreements to improve energy efficiency	2	1	2	-	2	2	3	1	5	3
Future											
Regulation	Energy performance standards for industrial technologies	3	3	5	3	3	3	5	3	5	5
	Mandatory targets for Demand Side Management	3	3	4	4	4	2	4	3	5	4
	Labelling of industrial technologies	2	5	5	4	1	4	4	4	4	4
Financial	Financial instruments such as subsidy schemes, tax incentives	5	5	5	5	3	3	5	4	5	3
	Energy tax deductions	5	5	5	4	3	3	5	4	5	3
Information	Training/Information/Knowledge transfer	4	4	3	4	4	2	4	5	5	5
	Energy Audits	4	3	3	5	4	2	4	5	5	5
Voluntary Agreements	Voluntary agreements to improve energy efficiency	3	1	3	-	3	3	4	2	5	3

Questionnaire

Please rate the relative importance of identified factors towards the adoption of readily available energy efficient technologies.
(complete insignificance **1** - very significant **5**)

Energy costs are sufficiently important	
Increased perceived cost of energy saving measures	
High transaction costs	
Slow rate of return of the investments	
Existence of more promising investment opportunities	
Long decision chains	
Lack of technical skill	
Short term thinking and planning of owners	
Technical risks	
Resistance to replacing existing machinery	
Irreversibility of technological change	
Focus on daily production problems	
Cost of staff replacement, retraining	
Fears that future technologies will be cheaper and better	
Uncertainty related to policy and future subsidies/ environmental requirements	
Conflict of interest within the company	
Cost of possible production disruption	
Bureaucratic procedures to get governmental financial support	
Resistance to technology adoption- technology can only be implemented after end of life of existing equipment	
Lean organisation	
Energy management not core business activity	
Specific installation costs	
Economic trend or market situation	
Cost of acquiring information and incorporating new technologies greater than expected saving on energy bill	
Cost of identifying opportunities, analysing cost effectiveness	
Lack of staff awareness	
Poor information quality regarding energy efficiency opportunities	
Fear of losing flexibility in process	
Technology fitting into process	
Limited space	
Uncertainty regarding future of the refinery	
Change in energy prices - uncertainty about economic benefits of energy efficiency improvement	

Comments:____

Please rate the significance of the following on the uptake of energy efficiency projects.
(**1** complete insignificance **- 5** very significant)

Corporate support	
Organisational energy policy/strategic energy objectives	
Awareness and knowledge – from training	
Awareness and knowledge **-**from information sources such as conferences, visiting other refineries etc	
Individual motivating a project	
Team/group motivating a project	
Vendors offering/providing solutions	

Comments and or/other:____

Please rate the potential for improvement in the following: (%)

Maintenance best practices	
Individual behaviour change- operational excellence	
Organisational culture change	
Optimisation	
Utilities and Cross cutting opportunities – eg pumps, fans, motors	
Process specific opportunities	

Comments and or/other:____

(0% being operations excellence and no room for improvement. 50% meaning we can improve by 50% on current situation) Column does not have to add up to 100%.

Please rate the relative influence of listed policy instruments to the adoption of readily available energy efficient technologies.
(complete insignificance **1 -** very significant **5**)

	Policy instruments	**Rating**	
		Current	**Future**
Regulation	Energy performance standards for industrial technologies		
	Mandatory targets for Demand Side Management (DSM)		
	Labelling of industrial technologies *		
Financial	Financial instruments such as subsidy schemes, tax incentives		
	Energy tax deductions		
Information	Training/Information/Knowledge transfer		
	Energy Audits		
Voluntary Agreements	Voluntary agreements to improve energy efficiency		

*Example- high or premium efficiency motors

Interview Questions (Semi Structured)

1. *Organisational structure/decision processes*

- What is your role in the company? How do you fit into the organisation? What kind of decisions do you make?
- Who are the main decision makers of the company when making a major change in the refinery? (Large capital investment)
- To what extent does head office play a role? Does the company have complete autonomy or does head office (overseas) dictate what should be done(technology, mandatory targets etc)
- Are there any particularly influential people in the decision making process? For example stakeholders, CEO, head of finance? or key influencers with respect to personality or perhaps strong political connection that influence decisions towards a yes or no.
- How are the decision processes different for -1) large capital expenditure & 2) maintenance expenditure.
- Are there different classes of decision? Limits of authority? ie less than R5 million refinery manager should sign off, greater than R10 million CEO should sign off etc
- Are there company heuristics that should be followed when making a decision? - For example a gate stage model? What are the criteria that should be met when making a decision? Cost benefit analysis, payback , shutdown criteria ?

2. Investment

- Could you identify the top 3 or 4 factors that have a large impact on profitability? (for example crude price, Rand/dollar exchange rate, input cost) What are the main objectives for profitability of the business? (sales/yield etc)
- How does the availability of capital affect investment decisions? Are there any financing constraints? (for example source of funds , cash flow)
- How far in advance does the company plan investments?
- What is the preferred financial tool for analysing investments? (for example IRR/profits, payback, WACC)
- What are your internal hurdle rates? How do they differ for different investments?
  What are the hurdle rates for energy efficiency investments (as opposed to capital expansion)?
  How long is turnaround on a decision for large capital investment?
  In terms of uncertainty, what kind of uncertainties impact decisions made within the company? (Mthombo/Coega, peak oil, regulatory environment/policy, prices, economic climate)
  How is risk handled during decision making? Are there company guidelines? I.e. risk matrix
  How does carbon tax/ future GHG emission regulation affect investment decisions?
- How are capital budgets set up? (How is capital planned for)
- What internal procedures are in place to identify+ undertake capital projects (utility systems, heat integration, process controls, combustion efficiency)
- Who decides what projects are to be undertaken?
- How are projects ranked or prioritised?
- How many alternatives are designed for in the pre-feasibility stage? How is information about energy efficient technologies incorporated? vendors, energy tech company, internal database
- How are maintenance budgets set up? (How is maintenance planned for)

What internal procedures are in place to identify+ undertake maintenance projects/opportunities (How are opportunities identified?) motor systems, pumps, fans, blowers, fouling, leaking, insulation)

- Who sets the task of checks? Is this routine based or ad-hoc decision?
- Who decides when a piece of equipment (or unit) needs to be replaced or fixed? How are opportunities prioritised?

3. *Status Quo Energy Efficiency*

- Have there been any energy efficiency initiatives that have been adopted by your company? (energy management programs etc) What factors drive the initiative? Is this cost driven/emission driven/environmental image driven.
- Is there an energy manager? Who formulates energy objectives within the refinery? Who approves energy objectives?
- Is there a specific internal target for energy objectives? or energy efficiency accord driven (15%) ? Who sets the targets?
- Do you have an energy monitoring system?
- Are energy minimisation objectives are integrated into:
    - purchasing programs (for example ee motors)?
    - maintenance programs (maintenance checks such as steam trap leaks) ?
    - operating procedures (temperature, pressure optimisation) ?
- Are there incentives provided for energy savings within the refinery?
- What is the most recent energy saving a project that has been implemented in the refinery? What have you done so far in terms of energy efficiency, relative savings?
- Are there any technologies that you are considering that are out of the norm?
- How do you become aware of any new technologies (either industry specific or cross cutting) which have not been used before?

4. *Opportunities*

- What are some of the opportunities which could be implemented in the industry?

5. *Drivers*

- Are there any particular measures that would influence companies to invest more in energy efficiency?
- How much influence do engineers/staff have on motivating or driving a project?
- Do current and or anticipated regulatory requirements present any significant opportunities for the business?

6. *Barriers*

- What are some of the challenges that you or the firm experience concerning energy saving measures (investment or process improvements)?
- How significant is energy cost within the company?
- What role does uncertainty have in your decisions?
- Are there any challenges relating to shut down and priority of projects?
- How long is turnover of a decision? Does this impact efficiency?
- Can you talk me through challenges around reducing fuel gas use and flaring? excess fuel gas?