ENERGY EFFICIENCY MEASURES:
A STUDY ON INDIAN REFINERIES

By

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Submitted

IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY

TO

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, DEHRADUN

DECEMBER 2012

Acknowledgement

'I will bless the Lord at all times, His praise continually on my lips, I will praise God from my heart, let the humble hear and rejoice (Psalm 34:1-2) I thank you, Lord, with my whole heart, I recount all your wonders, I rejoice and delight in you, I sing to your name, Most High (Psalm 9: 1-2)'

Pursuing the Ph.D research is very demanding, yet an extremely enjoyable experience. It is just like climbing a high peak, step-by-step, accompanied with hardships, frustrations, encouragement and trust. When I found myself at the top enjoying the scenery, I realized that, in fact, it is teamwork that got me there. It is with great delight that I acknowledge my debts to those who have contributed immensely to the success of the project.

First of all, I would like to convey my heartfelt gratitude to University of Petroleum and Energy Studies for funding my entire research work. I am deeply indebted to the authorities of my university; especially, Mr. Sanjay Kaul the President 'Hydrocarbons Education and Research Society', Prof. S.J Chopra [Dr.] the Chancellor, Prof. Parag Diwan [Dr.] the Vice-chancellor, Ms. Deepa Verma the Director [HR], Prof. Anirban Sengupta [Dr.] the Dean, the previous deans and directors of the college, who have contributed greatly to the realization of my former MBA studies and the present Ph.D program.

I am highly indebted to my research guide Prof. Prasoom Dwivedi [Dr.] for his able supervision, guidance, constructive comments and encouragement. I was very lucky to benefit from his rich expertise and critical comments, and have motivated me to work hard because of his valuable input. He is very friendly, considerate and was always there for me when I needed motivation during the difficult stages of the Ph.D work, and was kind enough to advise me on my personal issues. I have learned a lot from him and without his help I could not have finished my thesis successfully.

Furthermore, I would express my appreciation to the Head of the Department of oil and gas, Prof. S. K Pokhriyal. I have benefited a lot from his keen supervision, critical comments and advice. He has been a constant inspiration to me and his support has contributed enormously to the success of this work. His office doors were always open to me when I needed advice and support; not only in my academic life but also dealing with my personal difficulties.

I also appreciate the advice of the FRC committee members, especially, Prof. D. K Punia [Dr.], Prof. Manvinder Singh Pahwa [Dr.], Prof. K. K Pandey [Dr.], Prof. K. V Mohana Rao [Dr.], Prof. T. Bangar Raju [Dr.], and Prof. Tarun Dhingra [Dr.], for their critical comments, which enabled me to make necessary improvements in my work.

I owe special thanks to Major General S. P. S Narang [Retd.] [Dr.] and Rev. Fr. Francis Fernandez [Dr.] for tirelessly reading my chapters and giving constructive ideas based on their experience and suggesting possible improvements.

The visits I made to Indian Institute of Technology, Roorkee and Indian Institute of Management, Bangalore were essential. I appreciate the support and encouragement of the staff members of those institutions. I would also like to express my heartfelt appreciation to all those companies and persons who have contributed me their time and efforts, during the collection of necessary data for the study.

My experience as a research fellow at the university would not have been so pleasant without the combined, daily sustained efforts of all my colleagues at the university. Thank you for being keen to share your knowledge with me.

A special thanks to my office mates, Karan, Namita, Neha, Shilpi and all Ph.D scholars, it was a pleasure to share the office with them. I really enjoyed the nice atmosphere and our short coffee breaks; they have also helped me in translating Hindi, when it was required. Thanks also to my students for the great discussions we had both within and outside classrooms. It has undoubtedly contributed a lot to my work.

My friends at Doon valley, Divya, Kriti, Parimal, Raj, Ritu, Sam, Shradha, Sujith, Surbhi and Swami, thanks for always being so cheerful and for all our nice conversations, the parties, movie nights, road trips and nice dinners. I am thankful to the families of Manikantan Vellachery and

Anisha Manikantan, Aju James and Leemol Aju, and Mrs. R. S Pal; I have enjoyed their company, delicacies, and friendship, thank you for taking care of me when I was feeling a bit down and when I was ill. They have made my stay in Dehradun memorable.

This research would have never been realized without the prayers and persistence of my grandmother, Mrs. Clara Fernandez. Her firm and kind hearted demeanor has affected me to be steadfast and never bend to difficulty.

Above all, no words are enough to thank my parents, Mr. George Fernandez and Mrs. Sherin Fernandez, whose love encouraged me to work hard and to continue pursuing the Ph.D. Their moral support and encouragement have made me feel confident to fulfill my dream and to overcome every difficulty I encountered. I am greatly indebted to my sister Sevarena and my brother-in-law Shatly, my uncles, aunts, cousins, nephew and niece for their support, prayers, unconditional love and forgiving me for forgetting/not attending important functions in the family.

Geo Jos Fernandez,
Dehradun
16-12-12

Declaration

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text."

Geo Jos Fernandez

18-12-2012

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on "**Energy Efficiency Measures; A Study on Indian Refineries"** by **Geo Jos Fernandez** in Partial completion of the requirements for the award of the Degree of Doctor of Philosophy (Management) is an original work carried out by him under my supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

Dr. Prasoom Dwivedi

Internal Guide

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Executive Summary

The demand for energy in India is expected to grow at an annual rate of three to four times over the next twenty years, assuming the GDP growth rate remains between 8 - 9%. It is a significant challenge for India to find enough energy to satisfy this enhanced demand. To overcome this demand and supply gap, the Government of India has adopted various strategies and policies to enhance energy supplies by identifying different conventional and non-conventional energy sources, and also by demand side management of various stakeholders in the society like, households, agriculture, industries, power sector etc.

Demand side management comprises of load management, load building, fuel substitution and energy efficiency. This study is limited to the study of energy efficiency measures in energy intensive industry in India.

Studies have pointed to the fact that the efficient use of energy could be the largest and most profitable way to reduce the costs. The prior studies and literature prove that there is a huge techno-economic opportunity for the cost effective energy efficiency investments in the industrial sectors. The major attraction of these studies were steel, fertilizer and cement industries. Even, studies were conducted in meat processing and food industry, but not in the Indian refining industry, which is a capital and high cash-intensive industry.

The emissions in the oil refineries also make energy efficiency an attractive opportunity to reduce emissions and operating costs. The governmental policies on energy efficiency have made Indian refineries a designated consumer, resulting in energy efficiency measures to improve competitiveness through increased energy efficiency and reduced environmental impact.

This study has been conducted to find the energy efficiency measures that have been implemented in Indian refineries and their economic effectiveness. This study also identifies various barriers and driving forces for the adoption of energy efficiency measures in Indian refineries.

The whole study is covered under seven chapters which are broadly covering energy efficiency policies in India, its impact on energy efficiency measures implemented in oil refining industries and barriers and drivers to the implementation of these measures, brief detail of the chapters is given below:

Chapter one outlines the concept of energy, their global scenario, their relationship with the environment and the energy characteristics of a developing country. This chapter discusses on demand and supply of different energy sources, which identified that the fossil fuels are dominating the global energy market with a market share of 87%, and the share of non conventional fuel growing every year, but only by a small percentage. This excessive dependence on these exhaustible energy sources has created a lot of environmental concerns. It is evident that the energy and environment concerns were local in nature initially, but it widened its scope to regional and global extend and has now become a major political issue. It also became important to understand the energy characteristics of developing countries to understand the concept of energy and its impact on various countries. This has brought out that even though the commercial energy source usage is increasing, noncommercial source of energy is still the major source of energy in these countries. These countries basically depend on energy imports, even though they have a great potential for harnessing renewable sources of energy.

India, being a developing country, has similar characteristics as discussed ibid. Hence, it became important to understand the Indian energy sector; its supply and demand, various regulatory/administrative agencies which regulate the energy spectrum in the country, etc. Chapter two, discusses the above mentioned and gives a complete picture of the Indian energy sector and various challenges being faced by the sector. This chapter outlines that India depends on coal and hydrocarbons, whose reserves are very limited. The low quality of coal in India and less reserves of hydrocarbons in the country has resulted in high imports of coal and hydrocarbon sources. In 1991, India imported about 17.85 % of the total primary commercial energy supply which have increased to 30% in 2005, and is also projected to increase much higher. These imports have not only raised the oil import bill, which not only reduced the foreign exchange resources, but also raised concerns on the energy security of the nation. This chapter showcase that the natural gas consumption grew over the last few decades, as it has become the fuel of choice for electricity generation, and other industrial and domestic sector energy consumption. It also portrays numerous challenges faced by various energy sectors, in which the availability and access of energy, continuous supply of commercial energy in a cost effective manner, energy security are a few to point out. As the energy demand and supply shows significant growth of each energy source, the need to understand the organizational and institutional efforts being made by the Government of India became important. The roles and responsibilities of various ministries [The Ministry of Petroleum & Natural Gas, the Ministry of Coal, the Ministry of Power, and the Ministry of New & Renewable Energy], and various statutory and autonomous bodies, who are responsible in taking decisions and making policies pertaining to the energy sector in India are also discussed in this chapter. It discusses in depth, the stages of development of Energy Conservation in India or initiatives taken up by the government in this regard and the reasons for the limited success in the implementation of conservation policies in the past.

Chapter three discusses about the Indian refining industry, where eight companies both public and private entities operate twenty two refineries with a capacity of 202.38 MMTPA. It's been noted that, India produces excess of petroleum products over the domestic demand, except for liquefied petroleum gas and exports these surplus petroleum products. This chapter portrays, the history of Indian refining industry and introduces various companies who are into refining in India.

Chapter four, reviews the various literature available to understand the research area. This chapter gives a backdrop on the importance of energy efficiency and has tried to define the term ‘energy efficiency’. This chapter discusses on various models on measuring the energy efficiency and various methods an organization could adopt to improve the energy efficiency, such as, technical measures, behavioural measures and the policy related measures. This chapter points out the need for studying energy efficiency measures in Indian refineries is important and reviews various energy efficiency measures implemented in refineries throughout the world and shows their economic effectiveness. This chapter identifies various energy efficiency measures which have huge potential for saving energy in Indian refineries, if it is being implemented better.

Chapter five discusses the importance of this study, its objectives, the methodology adopted by the researcher for the study purpose, the limitations of the study and the further scope of this study. This chapter suggests that to achieve the objective 'to identify various energy efficiency measures being adopted in refineries and to evaluate their economic effectiveness', empirical study has been conducted over a 10 years' time frame since 2000, and secondary data were collected. Various economic tools were used to evaluate the overall effectiveness of these measures in Indian refineries as a whole. The researcher has used a questionnaire 'to identify various barriers to and the driving forces for adoption of energy efficiency measures in Indian refineries' which was sent to various external stakeholders.

Chapter six showcases the analysis and findings of the study. This chapter discusses various energy efficiency measures being implemented in Indian refineries both in terms of improvement/continuous maintenance in operations as well as the development of new projects. It is clearly evident that the energy efficiency measures implemented by the refineries are audit based in most cases, where leakages, replacement of the equipments/processes with more efficient equipments/processes have been implemented. It was noted that, even though the output of Indian refining industry have increased by 178% with a CAGR 10.78%, the value of the output produced by the Indian refining industry increased by 457% with a CAGR 19% which could be attributed to the dismantling of the APM and also due to the changes in product mix. During the study period, the energy consumption only increased by 149% with a CAGR of 10% but the cost incurred by the Indian refineries on purchasing energy increased by 405% with a CAGR of 18% which could be attributed to the increase in the unit cost of the energy being used. During the study period of 2000 – 2010. It was noticed that the energy consumption per unit of crude processed decreased by 11% with a CAGR of -1 percent which showcases that the refineries in India has implemented energy efficiency measures effectively. It was also identified that the refining industry had saved

25937 trillion kcal of energy which corresponds to INR 15465 Crore and has identified RIL as the most energy efficient refinery in India and CPCL as the least energy efficient. The results of this research are contradictory to the assumptions that complex refineries are less energy efficient (Sathaye, Price, Can, & Fridley, 2005). This chapter identified twelve barriers which hinder the implementation of energy efficiency and nine driving forces which drives the implementation of energy efficiency measures in the Indian refining industry.

Chapter seven concludes the thesis and suggests that, in spite of various internal and external impediments, the Indian refineries have reduced the energy intensity by about 10%. It was noted that the companies in the Indian refining industry are considering the implementation of energy efficiency measures and are reporting as a legal obligation rather than an opportunity to save the costs. This chapter suggests a framework for reporting the energy efficiency measures by the refinery and recommends strategies to remove/minimize the identified barriers and for better implementation of energy efficiency measures in Indian refineries.

List of abbreviations

ABE	Advisory Board on Energy
AC	Air Conditioning
AHEC	Alternate Hydro Energy Centre
ALD	Acoustic Leak Detector
ALDS	Auto LPG Dispensing Stations
AMOCO	American Oil Company
APDRP	Accelerated Power Development and Restructuring Program
APH	Air Pre-Heating
API	American Petroleum Institute
APM	Administered Pricing Mechanism
APTEL	Appellate Tribunal for Electricity
ARU	Aromatic Recovery Unit
ASD	Adjustable Speed Drive
ATF	Aviation Turbine Fuel
ATU	Amine Treating Units
AU	Atmospheric Unit
bcm	Billion Cubic Meters
BEE	Bureau of Energy Efficiency
BFW	Boiler Feed Water
BIS	Bureau of Indian Standards
bls	Barrels
BPCL	Bharat Petroleum Corporation Limited
BPRL	Bharat Petro Resources Limited
btu	British Thermal Unit
BWT	Bridge Wall Temperature
CAGR	Compounded Annual Growth Rate
CASE	Commission for Additional Sources of Energy
CCO	Coal Controller Organization
CCR	Crude Catalytic Reformers
CCTV	Closed Circuit Television
CCU	Catalytic Cracking Unit
CDU	Crude Distillation Unit
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CFL	Compact Fluorescent Lamps

CHT	Centre of High Technology
CIAL	Coal India Africana Limitada
CIL	Coal India Limited
CLPS	Cold Low Pressure Separator
CMIE	Centre for Monitoring Indian Economy
CMPF	Coal Mines Provident Fund Organization
CO_2	Carbon Di-oxide
CPC	Calcined Petroleum Coke
CPCL	Chennai Petroleum Corporation Limited
CPP	Captive Power Plant
CPRI	Central Power Research Institute
CRS	Condensate Recovery Scheme
CRU	Catalytic Reforming Unit
CTU	Central Transmission Utility
CVU	Crude/Vacuum Unit
C-WET	Centre for Wind Energy Technology
DCS	Distributed Control System
DCU	Delayed Coking Unit
DEA	Di-ethanolamine
DGH	Directorate General of Hydrocarbons
DHDS	Diesel Hydro-Desulphurization
DM	De-mineralized
DSM	Demand Side Management
DST	Department of Science and Technology
DUU	Diesel Unifying Unit
DWD	Diving Wall Distillation
E&P	Exploration and Production
EAS	Energy Accounting System
EC Act	Energy Conservation Act
ECBC	Energy Conservation Building Code
ECS	Electricity Certificate System
EMC	Energy Management Centre
EOL	Essar Oil Limited
EPC	Engineering Procuring, Commissioning
ERP	Enterprise Resource Planning
ETP	Effluent Treatment Plant
FCC	Fluid Catalytic Cracking
FCCU	Fluid Catalytic Cracking Unit

FD	Forced Draft
FDU	Fractional Distillation Unit
FEM	Fuel Efficiency Monitors
FPC	Fuel Policy Committee
FPU	Feed Preparation Units
FRP	Fiber Reinforced Plastic
GAIL	Gas Authority of India Limited
GDP	Gross Domestic Production
GMI	Gas Measuring Instrument
GRP	Glass Reinforced Plastic
GT	Giga Tons
GTA	Gas Transmission Agreement
GTB	Gas Turbine
GTG	Gas Turbine Generator
HCP	High Compressible Pressure
HCU	Heavy Crude Unit
HGU	Hydrogen Generation Unit
HMU	Hydrogen Manufacturing Unit
HP	High Pressure
HPCL	Hindustan Petroleum Corporation Limited
hr	Hour
HRSG	Heat Recovery Steam Generators
HSD	High Speed Diesel
HVGO	High Vacuum Gas Oil
HVU	High Vacuum Unit
IBP	Indo Burma Petroleum Limited
IIPEC	Indian Industry Program for Energy Conservation
IIT	Indian Institute of Technology
INR	Indian Rupees
IOCL	Indian Oil Corporation Limited
IREDA	Indian Renewable Energy Development Agency
IRR	Internal Rate of Return
kcal	Kilo Calories
KMO	Kaiser-Meyer-Olkin
kWh	Kilowatt Hours
LBS	Lube Base Stocks
LCGO	Light Cycle Gas Oil
LGO	Light Gas Oil

LNG	Liquefied Natural Gas
LOB	Lube Oil Base
LP	Low Pressure
LPG	Liquefied Petroleum Gas
LSHSD	Low Sulphur High Sulphur Diesel
LT	Low Temperture
MAB	Main Air Blower
MBOPD	Million Barrels of Oil per Day
mbpd	Million Barrels per Day
MDEA	Methyl Di-ethanolamine
MGC	Make-Up Gas compressor
MIS	Management Information System
Mkcal	Million Kilo Calories
MMT	Million Metric Tons
MMTPA	Million Metric Tons per Annum
MNES	Ministry of Non-Conventional Energy Sources
MNRE	Ministry of New and Renewable Energy
MoC	Ministry of Coal
MoP	Ministry of Power
MoPNG	Ministry of Petroleum & Natural Gas
MoU	Memorandum of Understanding
MP	Medium Pressure
MPCS	Multivariable Predictive Control System
MRL	Madras Refineries Limited
MRPL	Mangalore Refinery & Petrochemicals Ltd
MS	Motor Spirit
MSTU	Maharashtra State Transmission Utility
MT	Million Tons
Mtoe	Million Tons of Oil Equivalents
MW	Mega Watt
NECO	Nodal Energy Conservation Organization
NELP	New Exploration Licensing Policy
NGO	Non-Governmental Organisation
NHGU	Net Hepatic Glucose Uptake
NHT	Naphtha Hydrotreating Unit
NIOC	National Iranian Oil Company
NLCL	Neyveli Lignite Corporation Limited
NLDC	National Load Dispatch Centre

NMEEE	National Mission on Enhanced Energy Efficiency
NO_X	Nitrogen Oxides
NPC	National Productivity Council
NPTI	National Power Training Institute
NRL	Numaligarh Refinery Limited
NSU	Naphtha Splitter Unit
NTPC	National Thermal Power Corporation
OBSG	Out Board Steam Generator
OECD	Organization for Economic Cooperation and Development
OHCU	Once-Through Hydrocracker Unit
OIDB	Oil Industry Development Board
OIDF	Oil Industry Development Fund
OIL	Oil India Limited
OISD	Oil Industry Safety Directorate
OM&S	Operations Maintenance & Storage
ONGC	Oil & Natural Gas Corportaion
OOA	Online Oxygen Analyzers
OPEC	Organization of Petroleum Exporting Countries
PBT	Profit Before Tax
PCA	Principle Component Analysis
PCAG	Petroleum Conservation Action Group
PCD	Progressive Crude Distillation
PCRA	Petroleum Conservation Research Association
PFI	Petroleum Federation of India
PGCIL	Power Grid Corporation of India Limited
PGR	Propane Gas Recovery
PJ	Peta Joules
PPAC	Petroleum Planning and Analysis Cell
PRDs	Pressure Relief Devices
PRT	Power Recovery Turbines
PRU	Propelene Recovery Unit
PSA	Pressure Swing Adsorption
PSTCL	Punjab State Transmission Corporation Limited
PSU	Public Sector Undertaking
R/P	Reserve/Production
RBI	Reserve Bank of India
RFU	Reformer Feed Unit
RGC	Remote Gas Calibrator

RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
RIL	Reliance Industries Limited
RLDC	Regional Load Dispatch Centre
RLNG	Re-liquefied Natural Gas
RO	Reverse Osmosis
RPC	Raw Petroleum Coke
SAP	System Application program
SCR	Selective Catalytic Reduction
SEC	Solar Energy Centre
SERC	State Electricity Regulatory Commission
SKO	Superior Kerosene Oil
SLDC	State Load Dispatch Centre
Sq. Km.	Square Kilometers
SRU	Sulphur Recovery Unit
STG	Steam Turbo Generator
STU	State Transmission Utility
Tcf	trillion cubic feet
Tcm	trillion cubic meters
TPCES	Total Primary Commercial Energy Supply
UB	Utility Boiler
UK	United Kingdom
UNCED	United Nations Conference on Environment and Development
US	United States
USA	United States of America
VAM	Vapour Absorption Machines
VBU	Visbreaking Unit
VDU	Vacuum Distillation Unit
VGO	Vacuum Gas Oil
VPSTT	Vacuum Pipe Still Tower Trays
VR	Vaccum Residue
VSD	Variable Speed Drive
WEC	World Energy Council
WGEP	Working Group on Energy Policy
WSSD	World Summit for Sustainable Development
$	Dollar

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Chapter 1
Energy

Section 1.1: Introduction to Energy

The term energy derived from '*Energia*' a Greek term which means 'vigor of expression' was introduced by Aristotle, the great philosopher of his time (Harper, 2007). This word was introduced in English by the poet Samuel Taylor Coleridge in the nineteenth century. The term energy in India has a new dimension and is called as "Shakti". Various 'Vedic verses' praise, commend and pray the 'Shakti' which moves stars and earth, resulting in the winds, rains, tides etc.

The term energy is defined in various forms. The Bureau of Energy Efficiency [BEE] defines it as:

> "It is the ability to do work and work is the transfer of energy from one form to another" (BEE, 2002a).

Some of the other definitions of energy are as follows:

> According to Harper and Gregory; "In physics, energy is an indirectly observed quantity that is often understood as the ability of a physical system to do work on other physical systems" (Harper, 2007) (Gregory, 2005).

As per some of the online dictionaries, such as, business dictionary, reference dictionary and accurate and reliable dictionary, energy is being defined as follows:

> "It means the capacity for vigorous activity" or "it's an adequate or abundant amount of such power" (RD, 2011).
>
> "It means the internal or inherent power; capacity of acting, operating, or producing an effect, whether exerted or not; as, men possessing energies may suffer them to lie inactive" or "it is the power efficiently and forcibly exerted" or "it could be the capacity for performing work" (ARD, 2011).
>
> "It is the measure of the ability of a body or system to do work or produce a change, expressed usually in joules or kilowatt hours (kWh)" (BD, 2010).

To understand the term energy better the above definitions can be summarized as *"Energy is the capacity to do work".* Let it be the working of any machinery, the human body or it could even be the mind. However, we are not much concerned about the human energy but are concerned about the energy requirement that is external to human body and mind. In the earlier days, the requirement of the human beings were limited and was fulfilled with the effort of his body; but as humankind progressed from the primitive to the civilized state the need for more and more external sources [other than human energy] of energy became apparent. Also in the early days, some of the major sources of energy being used were firewood for heating purposes, animal power for mechanical purposes, wind energy for shipping transportation, and vegetable oils for lighting purposes. Later, coal has also taken its position for transportation. In the nineteenth century after the invention of internal combustion engine, the need for petroleum fuels has increased, and the requirement is now increasing at a faster pace.

Section 1.2: Classification of Energy

The energy sources being used today can be classified on the basis of their basic forms, in terms of the levels of energy flow, marketability [commercial or non-commercial] or in terms of renewability.

Classification of Energy in terms of Basic Form

The energy sources can be classified on the basis of their basic forms which are as follows (BEJ, 2012):

Potential Energy: These are any type of stored energy and is not shown through any movement. This energy could be chemical, nuclear, gravitational or mechanical type.

Kinetic Energy: It is the energy of movements. This energy could be electric, electro-magnetic radiation, thermal energy and temperature based or sound based energy.

Classification of Energy in terms of Levels of Energy Flow

The energy sources can be classified on the basis of their levels of energy flow which are as follows:

Primary Energy: These sources of energy are either found/stored under the earth's surface, such as, coal, oil and gas and these sources have only undergone separation and cleaning, or these could be the energy that could be captured from the flow of various resources on or above the earth's surface, such as, wind, water, sun (EOEARTH, 2011).

Secondary Energy: Once, the primary energy is converted to another useful form of energy, then those forms of energy are known as secondary energy. Some of the examples of secondary energy are petroleum products, electricity. etc. (ENS, 2009a).

Final Energy: The energy that is available to the consumer before its final utilization is termed as final energy (ENS, 2009b).

Classification of Energy in terms of Marketability

The energy sources can be classified in terms of their marketability and they are as follows:

Commercial Energy: These are that energy sources which could be bought from the market with a price. Coal, lignite, oil, gas, and electricity are some of the examples of commercial energy (BEE, 2002b).

Non-Commercial Energy: These are that energy sources which cannot not be bought from the market with a price, or, these are the energy sources which are not covered under the commercial energy. Cow-dung, firewood are some of the examples of non-commercial energy sources (BEE, 2002b).

Classification of Energy in Terms of Renewability

The energy sources can be classified on the basis of their renewability is as follows:

Renewable Energy: These are the energy sources that could be produced from various sources which are considered to be inexhaustible. Solar energy, wind energy are some of the renewable forms of energy.

Non Renewable Energy: These are the energy sources that are produced from various exhaustible sources. Crude oil, natural gas and coal are some of the examples of non-renewable sources of energy.

As discussed in the ibid. sections, the understanding of energy could only be possible if the energy scenario is being studied. Hence, the next section 1.3 discusses the global energy scenario to understand the development of energy demand and the supply of different energy sources.

Section 1.3: Present Global Energy Scenario

Most of the primary energy being consumed today is produced from fossil fuels which are depleting at a very fast rate. The uneven distribution of the fossil fuels around the world has various consequences in terms of energy access and energy security. Even though the energy access and energy security has emerged as the biggest concerns among various governments, still the fossil fuels dominate the global energy market with a market share of 87%.

Fig 1.1 illustrates the global energy mix, in which the crude oil dominates the energy consumption in the world. The scenario of various energy sources being used is further described below:

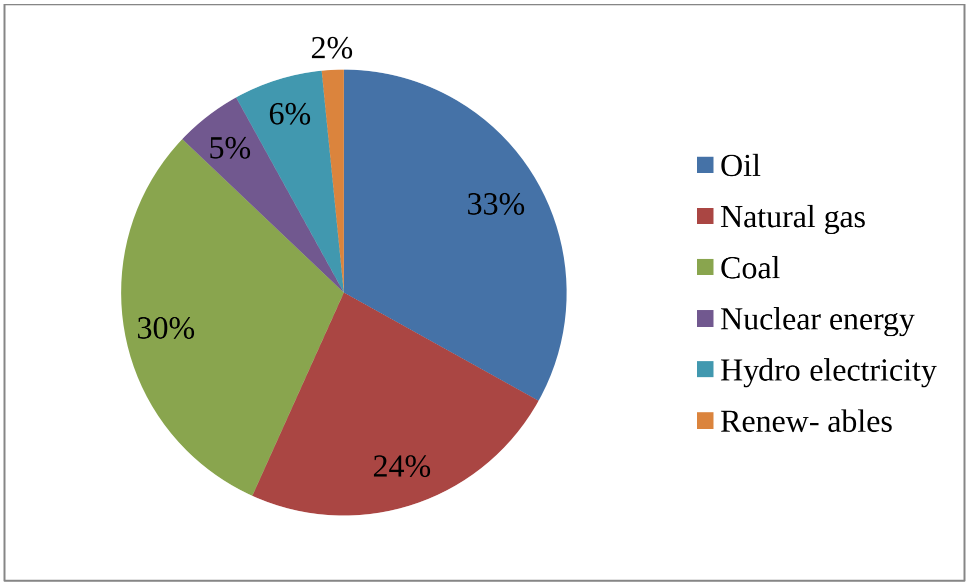

Figure 1.1: Global Energy Mix in 2011 (BP, 2012)

Crude Oil

The year 2011 is considered to be the year of disruption as there were a lot of instances where the global oil production had come down[1]. In the year 2011, the global crude oil reserves were about 1652.6 billion barrels [bls] with the Middle East having about 48.1% of the total reserve quantity, and as a single country, Venezuela has the highest reserves with about 17.9% of total world reserves (BP, 2012). Region wise oil reserves, available in the year 2011 are illustrated in fig 1.2.

[1] *Some of the major issues that has reduced the global oil production were the Libyan Crisis, Bahrain Crisis and various other smaller disruptions in various other countries.*

The crude oil production has seen a growth by 1.1 Million Barrels of Oil per Day [MBOPD] with the highest contribution from Saudi Arabia among the Organization of Petroleum Exporting Countries [OPEC] and by the United States of America [USA] among the non-OPEC. The global oil consumption for the year 2011 was about 88 MBOD, which has grown by 0.6 MBOD [which is about 0.7%] from 2010's oil consumption. This increase in energy consumption is considered to be one of the weakest global growth rates. The consumption in the Organization for Economic Cooperation and Development [OECD] countries had gone down, and even though the crude oil prices were high, the consumption growth rates of crude oil were below average in various oil producing countries (BP, 2012). It was noticed that various countries were depending on other oil producing countries for crude oil (BP, 2012). Fig 1.3 showcases the region wise oil production for the year 2011.

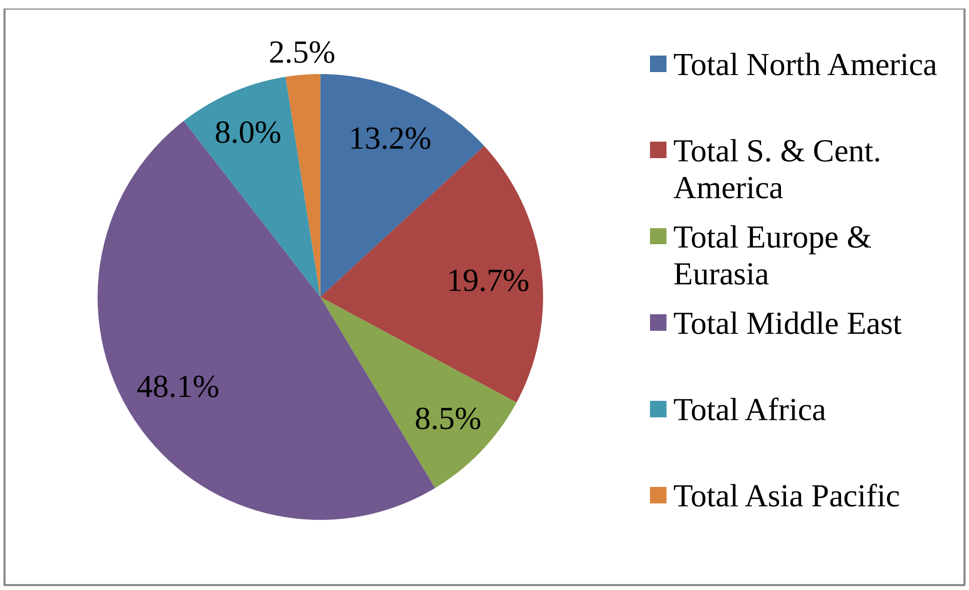

Figure 1.2: Region-wise Oil Reserves in the year 2011 (BP, 2012)

In the year 2011 the global refinery crude run[2] had increased by 0.375 MBOD, which is about 0.5% increase compared to the previous year. This increase in the refinery crude run was mainly contributed by the non-member countries of the OECD by about 0.685 MBOD. The global refining capacity has increased by 1.4, MBOD resulting in reducing the global refinery capacity utilization to 81.2% (BP, 2012).

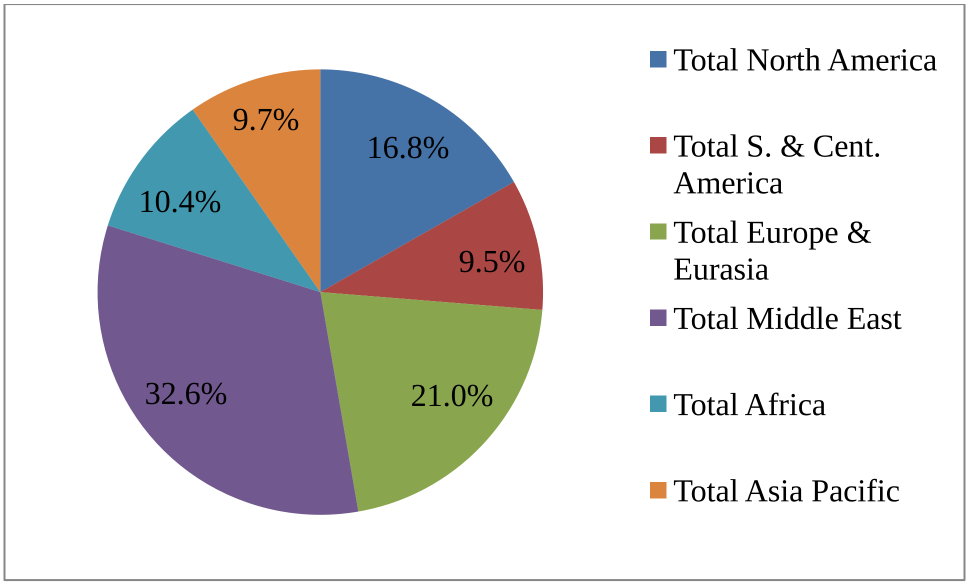

Figure 1.3: Region-wise Oil Production in the year 2011 (BP, 2012)

Natural Gas

In the year 2011, the global natural gas reserves were 7360.9 trillion cubic feet [tcf], in which the Middle East has about 38.4% of the total natural gas reserves, and as a single country, the Russian Federation has the highest gas reserve of about 21.4% of the total world reserve (BP, 2012). The global natural gas production has grown by 3.1% compared to the previous years which was contributed by USA, Qatar, Russia and

[2] *Observed refinery intake of crude oil*

Turkmenistan. The production has gone down in the countries, such as, Libya[3] and the European Union[4]. The global natural gas consumption has also seen an upward rise by 2.2%, in the region of North America contributing majorly[5] compared to other regions (BP, 2012). China, Japan and Saudi Arabia also have their own pivotal role in this increased gas consumption. The highest decline in the gas consumption was found in the European Union region[6] (BP, 2012). It was noticed that various countries were depending on other gas producing countries for natural gas (BP, 2012). Fig 1.4 and Fig 1.5 illustrate the regionwise natural gas reserves and its consumption in the world.

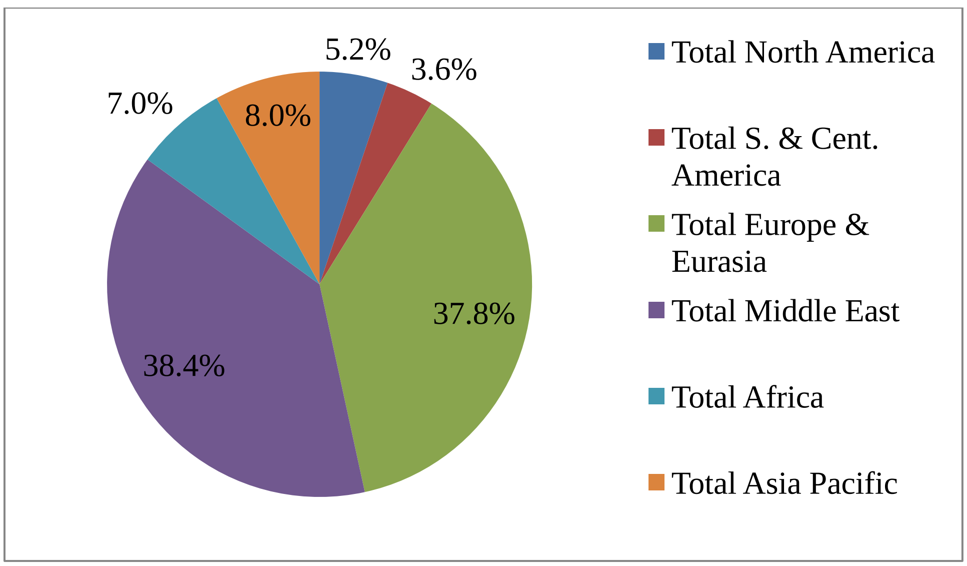

Figure 1.4: Region-wise Natural Gas Reserves in the year 2011 (BP, 2012)

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[3] *It was due to the internal unrest in the country resulting in stopping of production of Oil and gas from various wells.*

[4] *It was due to the combination of mature fields, Maintenance and weak regional consumption (BP, 2012).*

[5] *It was due to the low prices of natural gas in North America (BP, 2012).*

[6] *It was due to the warm weather coupled with weak economy, high gas prices and continued growth in renewable energy (BP, 2012).*

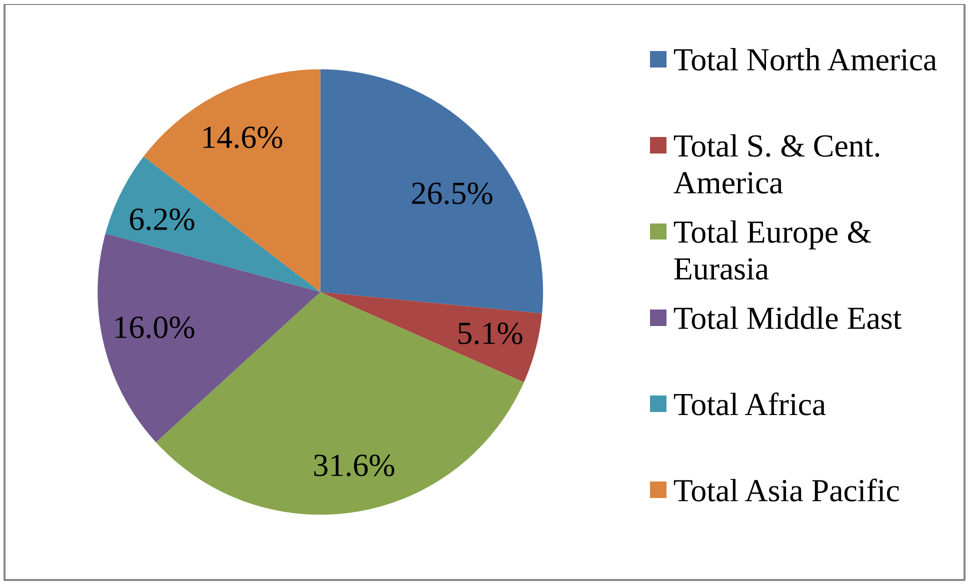

Figure 1.5: Region-wise Natural Gas Production in the year 2011 (BP, 2012)

Other Sources of Energy

The various other sources of energy being used today are coal and renewable energy sources in which coal has its own position. In the year 2011, the coal consumption had grown by 5.4% accounting for about 30.3% of the total energy being consumed in the world. The consumption of coal in the non-OECD countries grew by 8.4% and as a country China's consumption grew by 9.7%. The global coal production has also grown compared to the previous year by 6.1% with non-OECD countries and China playing the major role (BP, 2012).

The hydroelectric power output grew globally by 1.6% with an increased output from North America[7], but the output from Europe and China has decreased drastically[8]. The global nuclear output has also fallen by 4.3%,

[7] *It was due to heavy rainfall (BP, 2012).*
[8] *It was due to drought in those areas (BP, 2012).*

which was the largest decline till date which was due to the sharp decline in Japan and Germany (BP, 2012).

The global bio-fuel production has only grown by 0.7% due to the high decline in the output especially in Brazil[9]. The renewable energy being used for power generation has grown by 17.7% with wind energy contributing highly to this growth, which was more than half the renewable energy contribution to the global production (BP, 2012). The USA and China have contributed much to this wind energy generation. The share of renewable energy consumption in total global consumption has grown from 0.7% in 2001 to 2.1% in 2011 (BP, 2012). The excessive dependence on exhaustible energy sources has created environmental concerns in this regard. Hence, the next section discusses issues related to the energy and environment interrelation.

Section 1.4: Energy & Environment

The energy use and the environment are interlinked. The use of energy has made a greater impact on the environment compared to any other activity of humans. Even though, the energy and environment concerns were local in nature initially, it widened its scope to regional and global extend and has now become a major political issue. Most of the primary energy being used today is fossil fuels whose consumption results in the emissions of carbon dioxide [CO_2] and other polluting oxides into the atmosphere.

It was found that during the 20th century the average global surface temperature had increased by 0.6 ^{0}C, the ice extent has decreased and the average global sea level has risen (IPCC, 2007) (IPCC, 2001); which indicates that these emissions had led to global warming. This increase in

[9] *It was due to the poor sugar harvest (BP, 2012).*

temperature could result in changes in the climate such as cloud cover, precipitation, wind patterns and duration of seasons (BEE, 2002b). The further emissions of these air polluting oxides can have disastrous results (BEE, 2002b) as mentioned below:

- Severe storms and flooding
- Food shortages
- Dwindling fresh water supply
- Loss of biodiversity
- Increased diseases and
- Acid rain

Studies have showcased that in the year 2011, the global consumption of fossil fuels was about 87%, in which coal was the fastest growing energy source with its own consequences of carbon emissions. The options that are available for reducing the consumption levels of fossil fuels are, introducing renewable energy or by energy conservation, which could be achieved by the energy efficiency measures being adopted.

After analyzing the energy and environment linkages, it was found that these linkages differ from country to country. As the energy and environment concerns has now broadened its scope to regional and global extend, its important to understand the energy characterestics of various countries. As India is a developing country, the study is focused to understand the energy characterestics of India and similar developing countries, it became important to study the energy characteristics of developing countries. Hence, Section 1.5 discusses the energy characteristics of developing countries.

Section 1.5: Energy Characteristics of a Developing Country

Various developing countries differ from each other in their nature and economic characteristics as well as the energy characteristics. But some of the energy characteristics are common in various developing countries and they are as follows:

Rapidly Increasing Commercial Energy Consumption

The energy consumption of the developing countries compared to the developed countries is lower which could be because of less industrialization in these countries, lower income, etc. But the rate of increase of energy consumption is higher in these developing countries because of high energy requirement due to the development process initiation, and another reason is because of the substitution of non-commercial energy by commercial energy sources in these countries.

Non-commercial Energy still the Major Source

It is being noted that the non-commercial energy is one of the major sources of energy in the developing countries due to the low income of the people and the easy availability of the non-commercial energy. Another reason for non-commercial energy for being the major source is the lack of energy infrastructure in the remote [especially in rural] areas of the developing countries.

Unequal distribution of energy

In the developing countries, the distribution of energy is uneven with respect to geographical conditions, e.g., urban viz-a-viz rural, rich viz-a-viz poor, thus, resulting in some people getting energy for their requirement and some not getting the same.

Energy Dependence on Outsiders

Various developing countries in the world have very little or no reserves of fossil fuels, thereby resulting in their dependence on other countries for energy. Even though various developed countries are also dependent upon the energy imports, the economic impact of energy imports on the developing countries is more compared to the developed countries. These dependent developing countries, due to their ever increasing energy import dependence, will result in the short of foreign exchange, and are facing serious economic difficulties. For e.g., In 2011 India imported about 33% of natural gas and 75% of crude oil consumed (BP, 2012), and this dependency on hydrocarbon imports is expected to increase (IPC, 2006). In the year 1991, India imported about 17.85 % of the Total Primary Commercial Energy Supply [TPCES] which increased to 30% in the year 2005 (IPC, 2006) that was also projected to increase much more as the years roll by.

Great Potential of Renewable Source of Energy

Several developing countries are located in that part of the earth where intensive sunshine is available throughout the year. Hence, they have a great potential for solar energy [For example, India has a solar energy potential of 5000 Trillion kWh per annum (Nair, 2012)]. Other renewable energy sources, such as, wind energy, biomass and hydro energy do also have a high potential in these countries. However the actual utilization of these sources of energy is very low due to various factors, such as, lack of technology, financial aspects, policy issues etc.

After analyzing the global energy scenario and the energy characteristics of the developing countries, it was found out that the energy sector is a complex sector. Hence, for the better understanding of the sector, it becomes important to study the energy sector. As the study is based on Indian oil refineries, it's important to study India's energy sector. Therefore, next chapter is an attempt to analyze the Indian energy sector in depth.

Chapter 2

Indian Energy Sector

Section 2.1: Introduction

“Energy is an important factor which contributes to the economic development of a nation, and is also important for better living conditions of mankind. It is an indisputable fact that the economy of a nation and the mankind depends on energy for their day to day activity” (Fernandez & Pokhriyal, 2011). For the continuous development of any economy at present, or increased Gross Domestic Production [GDP] rates, the long term supply of environmental friendly energy has to be assured.

India is the fifth largest consumer of energy in the world (FICCI, 2011) and as it is a developing country, its energy demand is further going to increase; hence the nation has to speed up the energy sector development to meet this rise. Even though, India has high coal reserves, which is about 7% of the total world coal reserves (BP, 2012) and huge potential on renewable energy sources such as wind, solar and hydro, its hydrocarbon resources are very limited. India has 0.3% of world crude oil reserves and 0.6% of world natural gas reserves (BP, 2012), resulting in high imports of hydrocarbon sources. In 2011, India imported about 33% of natural gas and 75% of crude oil consumed (BP, 2012), and this dependency on hydrocarbon imports is expected to increase (IPC, 2006). In 1991, India imported about 17.85 % of the TPCES which increased to 30% in the year 2005 (IPC, 2006), which is also projected to increase much higher. This increased dependency of the Indian economy on imported commercial energy in the form of crude oil and natural gas has not only raised the oil import bill, which has not only indirectly reduced the foreign exchange resources, but has also raised concerns on the energy security of the nation.

It is noticed in the pattern of energy production in India, that coal and crude oil dominate with a share of 53% and 31% respectively, whereas natural gas and other sources of energy contribute to the rest of the requirement (Raghuraman & Ghosh, 2003). When power generation is considered, coal fired power plants contribute about 70% of the total energy generated and the other sources of energy such as hydro or renewable sources contribute to the rest (Srivastava & Mathur, 2007). The Indian energy market was regulated before the liberalization, privatization and globalization reform policies, introduced by the government of India, after which the market was opened up for the private players and that showcased a new paradigm on energy production.

It was noticed during the study that the industrial sector of India had consumed about 45% of the total energy and is the major consumer of energy (Dutta, 2012). In 2001, the Indian industry underwent a transformation as the economy was opened up for foreign investment and competition (IEA, 2004). The per capita consumption[10] of various energy sources in India is less than 0.5 tons of oil equivalent which is considered among the lowest in the world (BP, 2012).

After the energy sector reforms in India, the sector became complex to understand. It is in light of this that this chapter is an attempt to analyze the Indian energy sector in depth. The focus is to discuss the reserves,

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[10] *It is the ratio of estimated total energy consumption of a year upon estimated mid-year population of that year.*

potential for generation, installed capacity & its utilization, and production & consumption of various energy sources in India[11]. This chapter also discusses various administrative and regulative governmental agencies in the energy sector comprising the central & state nodal agencies, public sector units, technical and research organizations. In this chapter, the evolution of energy conservation in India, various policy initiatives adopted by the government and the reasons for their limited success in terms of industrial energy efficiency are also being discussed.

Section 2.2: Energy Sources

Coal and crude oil dominate India's energy production with a share of 53% and 31% respectively, whereas the rest have been contributed by natural gas and the other sources of energy (Raghuraman & Ghosh, 2003). In case of power generation, 70% of the total energy generated was from coal and the rest 30% was by other sources of energy (Srivastava & Mathur, 2007). Studies have showcased that over a period of 2003 to 2030, the demand for natural gas is going to increase by 534%, whereas the demand for coal and oil is going to increase by 471% and 288% respectively (IPC, 2006).

The energy basket in India includes coal and lignite, crude oil and natural gas, and renewable energy sources. The description about the reserves present in India, potential for the generation, installed capacity and its utilization, production and consumption, and foreign trade of various energy sources are discussed further.

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[11] *Data has been collected from the statistical website "www.indiastat.com".*

Coal and Lignite

Reserve Availability: India has abundant coal and lignite reserves, and as of December 2011, the country has 60,600 Million Tons [MT] of 'proved reserves', which are about 13.3% of the total world reserves with a Reserve/Production [R/P] ratio[12] of 103 years (BP, 2012). 99% of these proved coal and lignite reserves are spread over a few states of India, such as, Andhra Pradesh, Chhattisgarh, Jharkhand, Madhya Pradesh, Maharashtra, Orissa and West Bengal. Since December 2009, the proved coal and lignite reserves in India have increased by 3.4% (BP, 2012) (BP, 2010).

Installed Capacity and its Utilization: The total installed capacity of coal washeries[13] in India as of March 2011 was 109.67 MT per annum with private entities [90.95 MT/annum] having a major share in the industry (MOP, 2012).

Production and Consumption: It was found out that even though the production of coal and lignite by the end of 2011 was about 222.4 million tons of oil equivalents [Mtoe] of coal, and lignite, with a growth rate of 2.25% compared to that of the previous year. During the same year India had consumed about 295.6 Mtoe of coal and lignite which is about 9.16% increase than that of the previous year (BP, 2012). During the decade 2000 to 2011, the Compounded Annual Growth Rate [CAGR] of coal and lignite production was 66.47%, implying that the coal and lignite production had increased from 133.6 Mtoe of coal and lignite in 2000-

[12] *It suggests on how long the source is going to last at the current levels of production and reserve availability in a nation. It is calculated by dividing the 'proved reserves' available by the end of the year with that year production.*

[13] *It's an integral part of coal mining in which the extracted coal is washed to remove the ash content, making the coal ready as a feed stock.*

2001 to 222.4 Mtoe of coal and lignite in 2010-2011 (BP, 2012). The CAGR of coal consumption in India during the decade of 2000 to 2011 was found to be 103.58%, that is the coal and lignite consumption had increased from 145.2 Mtoe of coal and lignite in 2000-2001 to 295.6 Mtoe of coal and lignite in 2010-2011 (BP, 2012). So as to meet the demand and the high quality required[14] by the industries, India has been importing coal and lignite from various countries, such as, Australia and Indonesia. It was noted that in the year 2001, the import dependency on coal and lignite was about 10% and it has been projected to go up-to 70% in the year 2030 (IPC, 2006). The coal and lignite were primarily used for electricity generation followed by steel and cement industries. It has been noted that in earlier days, the Indian railways were the major consumer; but due to the electrification of the railway lines, the consumption of coal and lignite by the Indian railways has been reduced to zero (CSO, 2012). The figure 2.1 given below illustrates the production and consumption of coal in India from 2000 to 2011.

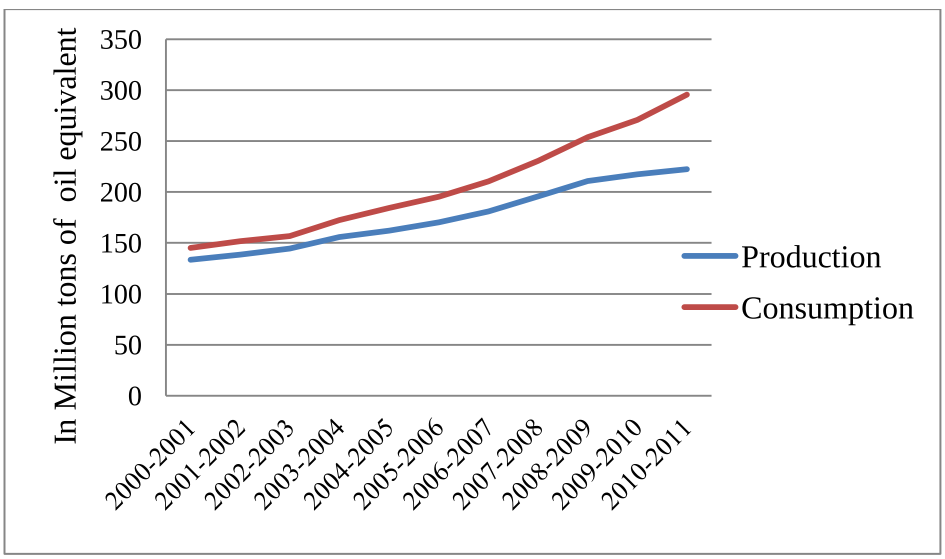

Figure 2.1: Trend Line Chart of Production and Consumption of Coal and Lignite in India since 2000 (BP, 2012)

[14] *It's been noted that the quality of Indian coal has not been to the standards of various industries such as steel industry to name.*

Crude oil and Natural gas

Reserve Availability: By the end of the year 2011, India had 'proved crude oil reserves' of 5.7 billion bls which is about 0.3% of share in world crude reserves. Since 2000, the CAGR of 'proved reserves' of crude oil in India is 3.4% and has a R/P ratio of 18.2 years with a reduction of 2.2% compared to the previous year (BP, 2012). 43% of these crude oil reserves in India is based in the western offshore, 22% based in the Assam basin, and the rest in various other 24 sedimentary basins[15] present in India (CSO, 2012). Figure 2.2 illustrates the trend line chart of crude 'proved reserves' since 2000 in India (BP, 2012).

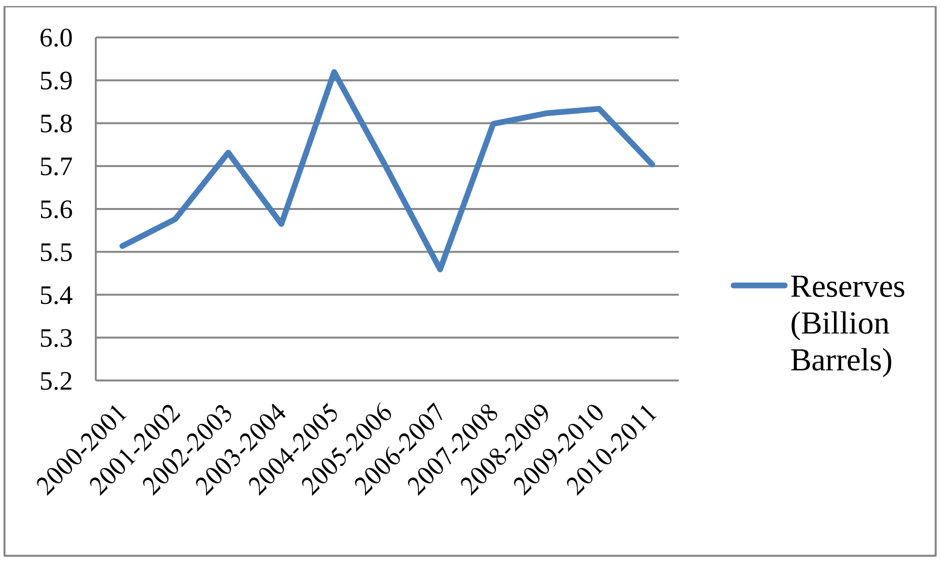

Figure 2.2: Trend Line Chart of Crude Reserves in India since 2000 (BP, 2012)

The natural gas 'proved reserves' available by December 2011 in India was about 1.2 trillion cubic metres [tcm] which is about 0.6% of the total world natural gas reserves. Since 2000, the CAGR of 'proved reserves' of

[15] *India has 26 sedimentary basins on both onshore and offshore with an aerial extend of 3.14 Million sq. km.*

natural gas in India is 3.4% and has grown by 8% compared to the previous year (BP, 2012). 35% of these reserves are basically trapped in the eastern offshore basin, followed by western offshore with about 33% of the reserves, and the rest being trapped in other sedimentary basins of India (CSO, 2012). Figure 2.3 represents, the trend line chart of proved natural gas reserves in India since 2000 (BP, 2012).

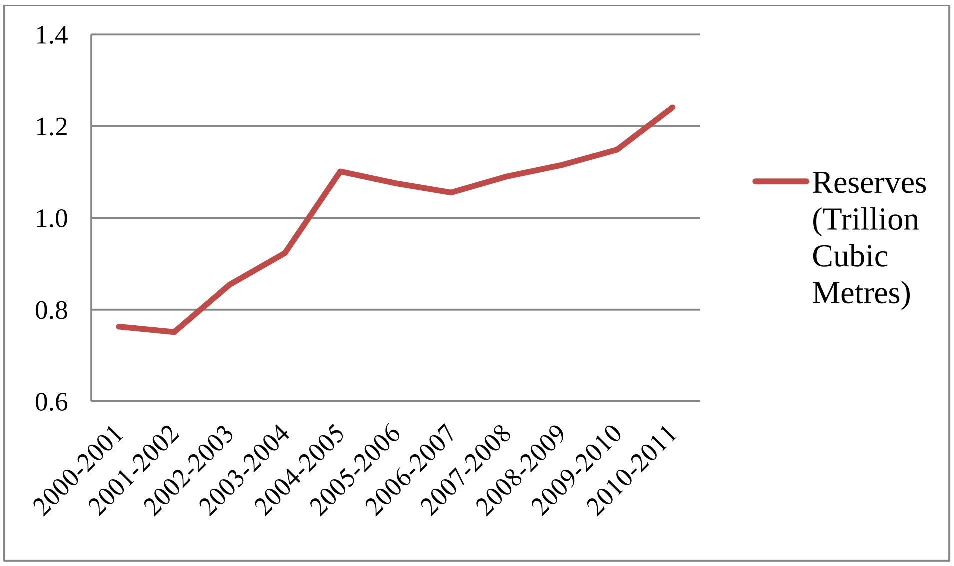

Figure 2.3: Trend Line Chart of Natural Gas Reserves in India since 2000 (BP, 2012)

Installed Capacity and its Utilization: India has 22 refineries as of July 2012 with a refining capacity of 202.38 Million Metric Tons per Annum [MMTPA] (Hindu, 2012) (MoPNG, 2010). Of these 22 refineries, seventeen refineries are of public sector undertaking [PSU], three refineries in the private sector and two refineries as joint ventures [See Appendix A for the list of refineries in India]. During the study period, the output of Indian refining industry has increased by 178% from 63.77 Million Metric Tons [MMT] in 2000-01 to 177.51 MMT in 2009-10. During the study it was noticed that the refineries in India have been utilizing the capacity effectively and efficiently (CSO, 2012). India is not only self-sufficient in refining capacity for its domestic consumption but also exports petroleum products substantially.

Production and Consumption: After coal, crude oil and natural gas are the two major energy sources which are being produced and consumed in India. In December 2011, 858 million barrels per day (mbpd) of crude oil was produced, but the consumption of crude oil has been as high as 3473 mbpd (BP, 2012). During that year the production of crude oil increased by 3.8% compared to the previous year, and the CAGR since 2001 of crude oil production was computed as 18.18%. The case was not much different in consumption patterns also, as in the year 2011; the consumption had increased by 4.2% as compared to the previous year and CAGR of crude oil consumption has been 51.75% since 2001 (BP, 2012). This increasing demand supply gap was met by importing crude oil majorly from the Middle East nations, such as, Saudi Arabia, Iran just to name a few. In the year 2011 India imported about 75% of the total crude oil being refined by Indian refineries (BP, 2012), and this dependency on hydrocarbon imports is expected to increase to 90% by 2030 (IPC, 2006). The figure 2.4 (BP, 2012), shows the trend line chart of production and consumption of crude oil in India since 2000.

The use of natural gas grew over the last few decades and has become the fuel of choice for electricity generation, other industrial and domestic sector energy consumption. The main reasons being that, it is clean and generates lower CO_2 and Nitrogen Oxides [NOx] emissions than other fossil fuels (Shannon LNG, 2006).

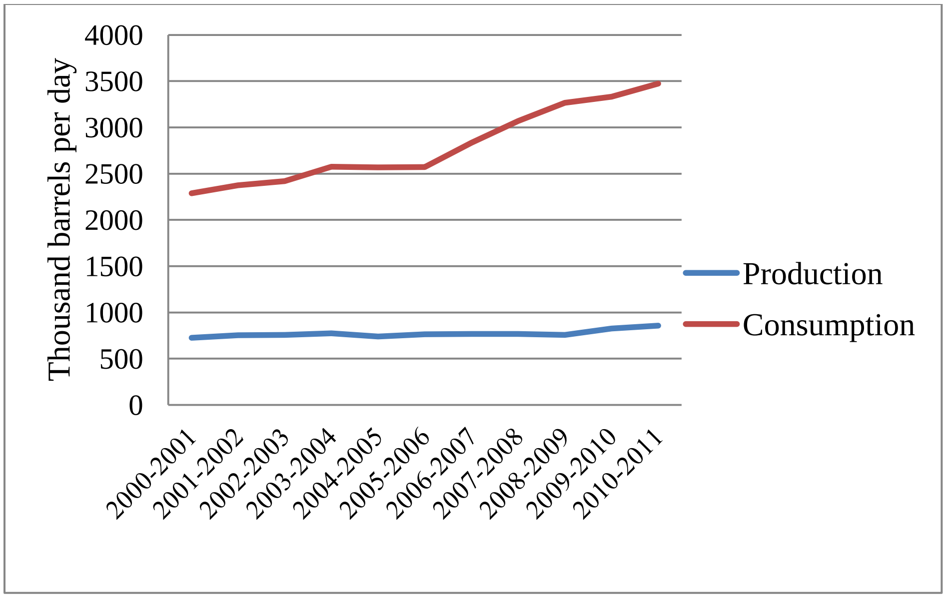

Figure 2.4: Trend Line Chart of Production and Consumption of Crude Oil in India since 2000 (BP, 2012)

In December 2011, about 46.1 billion cubic metres (bcm) of natural gas was produced whereas the consumption was about 61.1 bcm of natural gas (BP, 2012). During that year the production of natural gas in India was reduced by 9.26% compared to the previous year, and the CAGR of natural gas production since 2001 was 74.62%. The case is not much different in consumption patterns as in the year 2011; the consumption of natural gas in India had reduced by 1.22% as compared to the previous year and the CAGR of natural gas consumption since 2001 was computed to be 131.35% (BP, 2012). This increasing demand and supply gap was met by importing natural gas from Qatar, and in 2011 India imported about 33% of natural gas which was consumed by various sectors (BP, 2012) and this dependency on natural gas imports is expected to increase (IPC, 2006). The natural gas is basically used for power generation and as a source of energy in various industries. Figure 2.5 (BP, 2012) illustrates the trend line chart of production and consumption of natural gas in India since 2000.

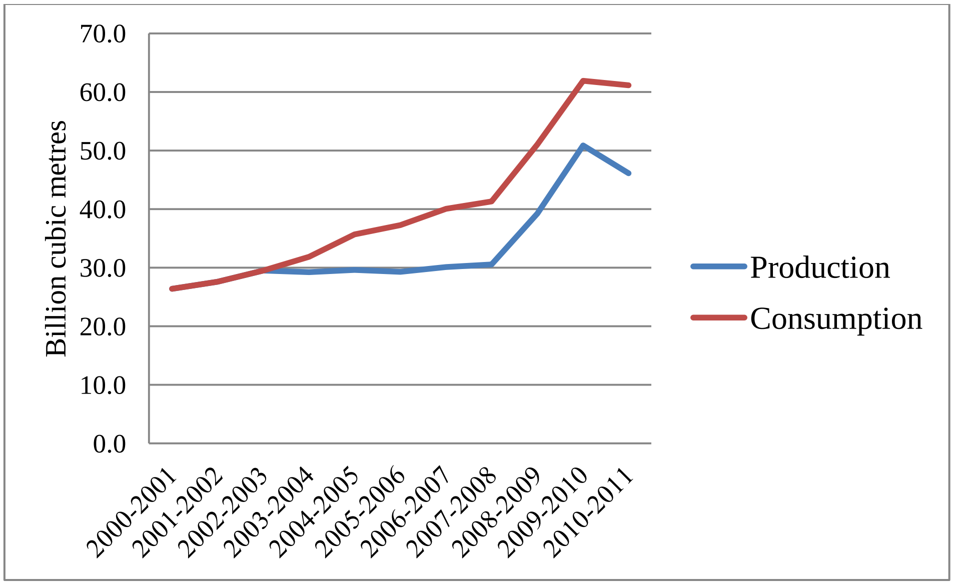

Figure 2.5: Trend Line Chart of Production and Consumption of Natural Gas in India since 2000 (BP, 2012)

Renewable Energy Sources

Potential for Generation: India has huge potential of renewable energy sources such as wind, solar, biomass and hydro for power generation. As of March 2011, it had a total potential of 89760 Mega Watt [MW] of power generation in which 55% was from wind power, 17% from various hydro projects, 26% from biomass and the rest from the other sources of energy (CSO, 2012). The majority of this energy generated from renewable energy sources was contributed by Gujarat, Karnataka and Maharashtra.

Installed Capacity and its Utilization: The installed capacity of grid connected renewable power had increased by 18.75% from 16,817 MW in 2010 to 19,971 MW in 2011 (CSO, 2012). Out of this installed capacity, wind energy contributed about 71% of power to the grid, biomass contributed about 13% of power to the grid and various hydro projects contributed about 15% of power to the grid.

Therefore, the above analysis of energy demand and supply shows significant growth of each energy source. Against the above backdrop, the next section focuses on the understanding of the organizational and institutional efforts being made by the Government of India for managing the vast energy sector in the country.

Section 2.3: Key Decision Makers in Indian Energy Sector

The Indian energy sector is administered, regulated and governed by various governmental agencies and organizations mainly comprising of the central & state nodal agencies, public sector units, technical and research organizations. The Ministry of Petroleum & Natural Gas [MoPNG], the Ministry of Coal [MoC], the Ministry of Power [MoP], and the Ministry of New & Renewable Energy [MNRE] are the various central ministries which are responsible for making decisions and policies pertaining to the energy sector in India. Figure 2.6 above illustrates the administrative and regulative set up of the Indian energy sector.

The roles and responsibilities of various ministries as mentioned above, are responsible in taking decisions and making policies pertaining to the energy sector in India and various statutory and autonomous bodies, which were set up under those ministries are discussed below in an order of priority basis.

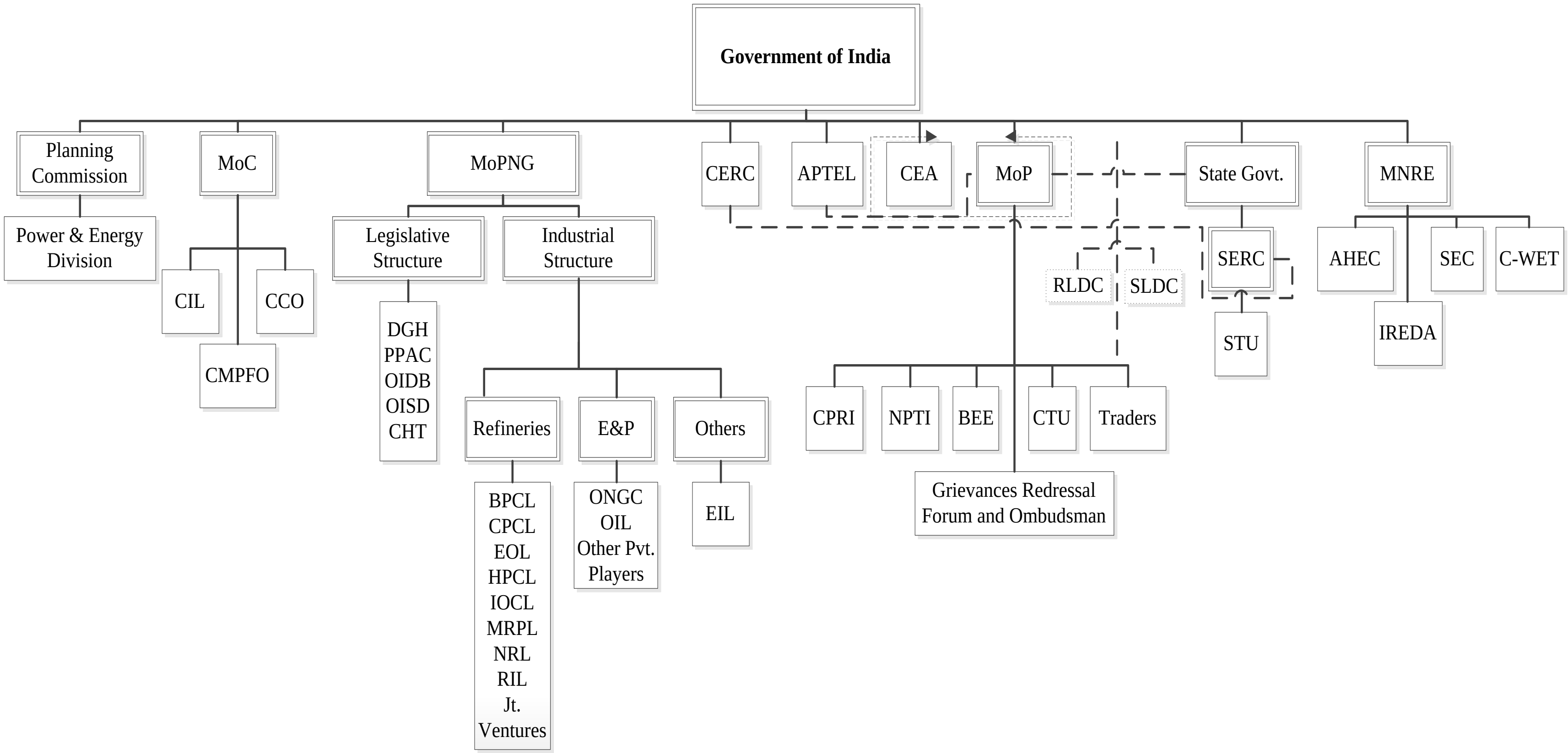

Figure 2.6: key decision makers in India's energy sector (ABC, 2009)

Power & Energy Division, Planning Commission

The power and energy division of the Planning Commission reviews the energy scenario in the country by considering the global energy balance and various concerns pertaining to the environment. So as to ensure continuous availability of energy, the power and energy division proposes various policies considering various energy opportunities available in India. The various roles and responsibilities of this division are as follows (PC, 2009):

- Formulating an integrated energy policy for India, covering all the available energy sources irrespective of whether they are commercially produced or not.
- Formulating policies to ensure continuous supply of energy at reasonable prices to all citizens of India, irrespective of their paying capacity.
- Formulating annual five year plans for the sector and to monitor their implementation in the country.
- Evaluating techno-economic viability of various energy sector investment projects.
- Reviewing the progress of research and development in the energy sector of the country and managing the National Energy Fund for research and development activities.
- Evaluating and monitoring various initiatives of government on electrification[16].

[16] *Some of the key initiatives the power and energy division has to evaluate and monitor are the Rajiv Gandhi Grameen Vidyutikaran Yojana [RGGY], Bharat Nirman, Accelerated Power Development and Restructuring Program [APDRP], Remote Village Electrification and Village Energy Security (PC, 2009).*

- Evaluating strategies for the various emerging energy sources[17].

Ministry of Petroleum & Natural Gas

The MoPNG, has the responsibility of looking after various operations pertaining to all avenues of crude oil & the natural gas business. The ministry focuses on the planning, formulation of various policies, administering and enacting various legislations[18], and decision making on various projects and investments, pertaining to Exploration and Production [E&P] of crude oil and natural gas, refining, marketing and pricing of these produced oil and gas, import, export and conservation of petroleum products and Liquefied Natural Gas [LNG] (MoPNG, 2009). This ministry also assists various industries coming under them to plan, and develop various projects.

There are various administrative and regulative governmental agencies under the jurisdiction of this ministry to regulate the industry and a society which acts as a facilitator for the oil industry, and these are as follows:

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[17] *Some of the emerging energy sources comprise of in-situ coal gasification, coal bed methane, coal liquefaction, carbon capture and sequestration, LNG import (PC, 2009).*

[18] *Various legislations the ministry has to administer and act upon are Petroleum Act 1934, The Oil Field Act 1948, The Petroleum Pipeline Act 1962, Kerosene Order 1970, Paraffin Wax Order 1972, Light Diesel Oil Order 1973, The ESSO Act 1974, The Oil Industry Act 1974, The Oil Industry Rules 1975, Furnace Oil Order 1975, Lubricating Oils & Greases Regulation Order 1987, Liquefied Petroleum Gas Order 1993, Motor Spirit and High Speed Diesel Order 1990. (MoPNG, 2009).*

- Directorate General of Hydrocarbons
- Petroleum Planning and Analysis Cell
- Oil Industry Development Board
- Oil Industry Safety Directorate
- Centre of High Technology
- Petroleum Federation of India

The above agencies are further explained below in succeeding paragraphs:

Directorate General of Hydrocarbons

Directorate General of Hydrocarbons [DGH] was instituted in 1993 under the MoPNG through a resolution. DGH promotes various blocks of oil and natural gas, coming under various sedimentary basins in India and ensures a balance with regard to the environment, safety, technological and economic aspects of the upstream industry during the development of the asset (DGH, 2003). DGH acts as a regulator and a facilitator for companies which are doing business in the E&P activities in India. DGH is responsible for implementing New Exploration Licensing Policy[19] [NELP] and various matters concerned with the same, which are as follows (DGH, 2004):

- Promoting investments in E&P Sector.

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[19] *NELP is a policy adopted in the year 1997-98 by the government of India to promote exploration and production activities in India. This policy on its various rounds have advertised the under offer where any national or international oil company can bid (DGH, 2008). The implementation of this policy has been a success as the development of assets was speeded up and discoveries were made compared to the pre-NELP era.*

- Monitoring E&P activities of companies who have been awarded blocks in India at various life cycle stages of awarded blocks.
- Evaluating and reviewing the development plans of commercially exploitable reserves in terms of technical feasibility and economic perspective.
- Monitoring the various blocks awarded to the companies, and the performance of those companies in that block.
- To advise the government on awarding the blocks through NELP and MoPNG on various technical aspects of E&P.
- Managing the data availability of various reserves in India.
- Various responsibilities have been given by the Government from time to time.

Petroleum Planning and Analysis Cell

Petroleum Planning and Analysis Cell [PPAC] was established in April 2002 as the oil co-ordination committee was abolished after the dismantling of Administered Pricing Mechanism [APM]. PPAC's major function is to look into the past and present patterns of petroleum statistics, such as, domestic and international crude prices, production and consumption of petroleum, import and export of petroleum etc. Also to analyze, so as to forecast the future requirement to deal with any emergencies and unforeseen situations (PPAC, 2004)

Oil Industry Development Board

After the first oil shock of 1973, the government of India had legislated the Oil Industry [Development] Act 1974. This act was enacted to establish a board for the development of the oil industry, resulting in the formation of Oil Industry Development Board [OIDB]. To achieve self-reliance in energy, an Oil Industry Development Fund [OIDF] was instituted by this board to provide financial assistance to various organizations that are in the business of oil and gas. OIDF gets its money for providing support to the organizations by levying cess and excise duties on oil and natural gas (OIDB, 2003).

Oil Industry Safety Directorate

Oil Industry Safety Directorate [OISD] is a technical directorate under MoPNG. Various sectors in the oil industry, such as, upstream, midstream and downstream come under the jurisdiction of OISD, where they formulate and implement various policies to boost safe operations in the industry. OISD consists of technical experts from various domains of the oil industry under deputation. OISD ensures that the industry is doing their operations in a safer and compliant manner by reviewing disaster control procedures and the company's preparedness, by conducting regular safety audits, giving suggestions for improvement and closely monitoring the implementation of these suggestions. They carry out inquiries in case of any mishap and provide support to the committees set up by the government to look into the issue. The major activities of OISD are as follows (OISD, 2012):

- *Standardization:* Develops standards and codes that are suitable for Indian conditions.
- *External safety audits:* Regular monitoring to check the compliance.
- *Offshore safety regulations:* Acting authority to enhance offshore safety.

- *Safety awards:* Awards are given to best performing organizations in terms of safety in all avenues of industry.
- *Dissemination of information:* relevant information is disseminated to various organizations in the industry.
- Accident reporting and investigation.

Centre of High Technology

Centre of High Technology [CHT] is a technology cell instituted by MoPNG in 1987 to look into the technology upgradations in Indian refineries. CHT was formed to ensure that the refineries are competent in technical advancements and to ensure that on certain strategic avenues these refineries are self-reliant to achieve excellence. The expenditures incurred by CHT are borne by OIDB through various funds, as the major objective of CHT is the development of technology in the oil industry (CHT, 2004).

Petroleum Federation of India

Petroleum Federation of India [PFI] is a society which acts as a liaison between the oil industry and various governmental agencies. They work to ensure that the Indian oil and gas industry is competitive by optimizing various resources, and also by the efforts put in towards integration of various processes and procedures. This society has about 70 corporate members both national and international who discuss various issues pertaining to the industry through forums, seminars/conference, publications etc. (Petrofed, 2012).

Ministry of Coal

The MoC is responsible for looking after various operations pertaining to all avenues of coal business. The ministry focuses on the planning, formulation of various policies, administering and enacting various legislations[20], and decision making on various projects and investment, pertaining to exploration and development of coal and lignite reserves, and their supply distribution and pricing. The said functions of MoC are exercised through the PSU, namely, Coal India Limited [CIL] and its subsidiary Neyveli Lignite Corporation Limited [NLCL] (MoC, 2009a).

Various administrative / regulatory agencies and organizations under MoC are as follows:

- Coal Mines Provident Fund Organization
- Coal Controller Organization
- Coal India Limited

The details of the above organizations are explained briefly below:

Coal Mines Provident Fund Organization

Coal Mines Provident Fund Organization [CMPF] is an autonomous body that was set up under the Coal Mines Provident Fund and Miscellaneous Provision Act 1948. CMPF monitors, regulates and disburses the fund to

[20] *Various legislations the ministry has to administer and act upon are Administration of Coal Mines (Conservation and Development) Act 1974, Administration of the Coal Mines Provident Fund and Miscellaneous Provision Act 1948, Administration of the Coal Mines Labour Welfare Act 1947, Administration of the Coal Bearing Areas (Acquisition and Development) Act 1957* (MoC, 2009a).

various employees in case of retirement, accident or death. CMPF administers the Coal Mines Provident Fund Scheme 1948, the Coal Mines Family Pension Scheme 1971, which was later revised to Coal Mines Pension Scheme 1998, and the Coal Mines Deposit Linked Insurance Scheme 1976 (MoC, 2009b).

Coal Controller Organization

Coal Controller Organization [CCO] was set up in the year 1916 a view to having the government control on coal reserves so as to meet the demand during the First World War. The main objective of CCO was to regulate the coal business in India, such as, production, distribution and pricing. CCO is the authority for ensuring the quality of coal and provides financial assistance to various coal operators in India for the development of the sector (CCO, 2012).

Coal India Limited

CIL is a government owned company which is the single largest coal producer in the world. CIL was established in 1975 as the government started taking over all the private coal mines. It’s a Maharatna organization who has their presence in 81 mining areas have seven coal producing subsidiaries and a mine planning and consultancy organization. CIL also has a subsidiary called Coal India Africana Limitada [CIAL] which operates in the mines of Mozambique. CIL produces about 81.1% of the total coal production in India and provides feed stock to eighty two coal based fire plants out of eighty six. Of the 52% of India’s coal dependence in the energy mix, 40% has been contributed by CIL from their various mines in India (CIL, 2011).

Ministry of Power

In the year 1992, the Ministry of Energy Sources was rechristened as MoP; which is responsible for the research, development and distribution of electrical energy in India. The ministry focuses on the planning, formulation of various policies, administering and enacting various legislations[21], and decision making on various projects and investment, training, and manpower development pertaining generation of electrical energy in the country. MoP also needs to ensure effective transmission and distribution of electrical energy to all citizens of the country (MoP, 2009).

There are various statutory bodies that come under the ministry and are as follows

- Central Electricity Authority
- Appellate Tribunal for Electricity
- Central Electricity Regulatory Commission
- State Electricity Regulatory Commission
- Central Transmission Utility
- State Transmission Utility
- National Load Dispatch Centre
- Regional Load Dispatch Centre
- State Load Dispatch Centre
- Grievances Redressal Forum and Ombudsman
- Bureau of Energy Efficiency

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[21] *Various legislations the ministry has to administer and act upon are Damodar Valley Corporation Act 1948, Bhakra Beas Management Board as provide in the Punjab Reorganization Act 1966, Energy Conservation Act 2001, Electricity Act 2003 and the legislations pertaining to thermal and hydro power generation, their transmission and distribution* (MoP, 2009).

The above named statutory bodies, under the ministry are explained in brief below:

Central Electricity Authority

Central Electricity Authority [CEA] is a statutory body which was established under an act called Electricity (Supply) Act of 1948, which assists MOP in all technical and economic matters pertaining to generation, transmission, trading, distribution and utilization of electrical energy in the country. CEA is responsible for the technical coordination and supervision of electrical energy generation, transmission, trading, distribution and utilization. CEA is also entrusted with developing a national electricity plan every five years, and has to monitor the plan to ensure that the same is effectively implemented in the country (MoP, 2009) (CEA, 2004).

Appellate Tribunal for Electricity

Appellate Tribunal for Electricity [APTEL] is a statutory body of the ministry that was established in 2004 under the Electricity Act of 2003 to hear the appeals or petitions against the orders awarded by the adjudicating officer or the Central Electricity Regulatory Commission [CERC], or the State Electricity Regulatory Commission [SERC], or by both the commissions. APTEL gives an opportunity to the organization against whom the orders were issued to appeal and APTEL is the final authority to take a decision, and thereafter give the verdict in all matters relating to the generation, transmission, trading, distribution and utilization of electrical energy in the country (MoP, 2009).

Central Electricity Regulatory Commission

CERC is a statutory body under the ministry, which is responsible for regulating the tariffs of electrical energy in the country, and also to grant licenses for inter-state transmission, distribution and trading of electrical energy in the country. CERC also advises the ministry in formulating the National Electricity Policy and Tariff Policy (MoP, 2009). CERC functions under Section 76 of the Electricity Act 2003 which was constituted on 24^{t} July 1998 under Electricity Regulatory Commissions Act 1998 (CERC, 2009).

State Electricity Regulatory Commission

SERC is a statutory body under the ministry which is responsible for regulating the tariffs of electrical energy within the state and also to grant licenses for intra-state transmission, distribution and trading of electrical energy within the state (MoP, 2009).

Central Transmission Utility

Central Transmission Utility [CTU], which is also known as Power Grid Corporation of India Limited [PGCIL], is the statutory body under the ministry which is responsible for undertaking the transmission of energy through inter-state transmission system and discharge all functions of planning and co-ordination relating to the inter-state transmission system with the State Transmission Utility [STU], Central and State governments and the generating company (PGCIL, 2011) (MoP, 2009).

State Transmission Utility

STU is the statutory body under the ministry which is responsible for undertaking the transmission of energy through intra-state transmission system and discharge all functions of planning and co-ordination relating to intra-state transmission system with the CTU, Central and State governments and the generating company (MoP, 2009). The Maharashtra State Transmission Utility [MSTU], the Punjab State Transmission Corporation Limited [PSTCL] etc., are a few STU's to name.

National Load Dispatch Centre

The National Load Dispatch Centre [NLDC] was established under the Electricity Act 2003 which is responsible to ensure the optimum scheduling and dispatch of electricity to the regional load dispatch centres. The other roles and responsibilities have to be decided and prescribed by the government (MoP, 2009).

Regional Load Dispatch Centre

The Regional Load Dispatch Centre [RLDC] is a statutory body which was established to ensure the dispatch of electricity regionally in an effective, economical and integrated approach (MoP, 2009).

State Load Dispatch Centre

The State Load Dispatch Centre [SLDC] is a statutory body which was established to ensure the dispatch of electricity in the state in an effective, economical and integrated approach (MoP, 2009).

Grievances Redressal Forum and Ombudsman

Grievances Redressal Forum and Ombudsman is a statutory authority appointed by the state commission to address the grievances of the customers.

Bureau of Energy Efficiency

BEE was established in 2002 under the provisions of EC Act 2001; BEE was established for spearheading the energy efficiency initiatives in Indian economy through regulatory and promotional instruments. The major objective of BEE is to promote energy efficiency and its conservation in India and the better implementation of the Energy Conservation Act [EC Act] in the country (BEE, 2010) (MoP, 2009).

Some of the programs which have been initiated by BEE are as follows (BEE, 2010) (MoP, 2009):

- Indian Industry Program for Energy Conservation
- Standards and Labeling Program
- Demand Side Management
- Energy Conservation Building Codes
- Professional Certification and Accreditation
- School Education Program
- Energy Conservation Awards
- Energy Efficiency in Buildings and Establishments

The above mentioned programs are briefly discussed in the later part of this chapter under the section, 'initiatives taken by the government for energy efficiency and its conservation'.

Other than the various statutory bodies, as discussed above, there are various autonomous bodies under the ministry and they are as follows and are explained briefly below:

- Central Power Research Institute
- National Power Training Institute

Central Power Research Institute

Central Power Research Institute [CPRI] was established by the Government of India in 1960 and became an autonomous body under the ministry in 1978. CPRI acts as a national laboratory for electric power engineering research, and also, acts as a testing and certification authority for electrical equipments and components to ensure the reliability of the product. CPRI also undertakes sponsored research work from industries, e.g., development of technology for fire retardant low smoke power cables[22] (MoP, 2009) (CPRI, 2009).

National Power Training Institute

National Power Training Institute [NPTI] was set up by the ministry for the training and development of power sector personnel in India. NPTI conducts technical trainings in power generation and other related areas (MoP, 2009).

[22] *It was joint Research and development program CPRI and Farcom cables with the funding from DSIR.*

Ministry of New and Renewable Energy

The price hike, supply deficiency and its impact on the balance of payment, due to the first oil shock in 1973, promoted the Government of India to look for various options to secure energy to meet the demand; be it for that moment or for meeting the futuristic demand. This led to the establishment of the Commission for Additional Sources of Energy [CASE] in 1981 to formulate and implement policies to develop new and renewable energy in India. During its initial days, the said commission was under the Department of Science and Technology [DST], which in 1992 was made as a ministry known as Ministry of Non-Conventional Energy Sources [MNES]. In 2006, MNES was rechristened as Ministry of New and Renewable Energy [MNRE] (MNRE, 2011).

The major role of MNRE is to formulate strategies to develop various new and renewable energy sources cost-effective for achieving the energy security, and also to ensure that these sources are deployed effectively keeping the goal of energy security and its independence. It also assists the industry in research and development, manufacture and deployment of various new and renewable energy systems (MNRE, 2010).

There are various administrative / regulative governmental agencies and various autonomous bodies which come under MNRE and they are as follows:

- Solar Energy Centre
- Centre for Wind Energy Technology
- Indian Renewable Energy Development Agency
- Alternate Hydro Energy Centre

The above agencies are further explained below in brief:

Solar Energy Centre

Solar Energy Centre [SEC] is an autonomous agency under MNRE whose major function is to develop technologies pertaining to solar energy. Since its establishment in 1982, SEC has collaborated with various research institutions on various aspects pertaining to effective resource utilization and the development of various solar technologies. The SEC has various facilities for technology evaluation and its validation, testing and standardization, and to analyze the performance reliability of various solar technologies being implemented (MNRE, 2012a). The major function of the SEC is to act as a liaison between the government and the stakeholders for developing, promoting and utilizing the solar energy in India (SEC, 2010).

Centre for Wind Energy Technology

Centre for Wind Energy Technology [C-WET] is an autonomous agency under MNRE whose major function is to develop technologies pertaining to wind energy (MNRE, 2012b). C-WET was set up in 1998 under MNRE to conduct research and development activities in the complete spectrum of wind energy as an energy source. C-WET has a unit dedicated only for research and development, another unit for testing and certification and another for assessing the wind energy potential in various parts of the country (C-WET, 2006).

Indian Renewable Energy Development Agency

Indian Renewable Energy Development Agency [IREDA] is a public limited company formed in 1987 as a public financial institution under Companies' Act 1956 and registered as a non-banking financial institution with the Reserve Bank of India [RBI]. The major objective of IREDA is to provide financial assistance through term loans for new and renewable energy projects, and also for energy efficiency and conservation projects (MNRE, 2012c) (IREDA, 2008).

Alternate Hydro Energy Centre

Alternate Hydro Energy Centre [AHEC] is an agency formed in the Indian Institute of Technology [IIT], Roorkee with the funding of MNRE to promote the generation of power through small hydro projects in concurrence with other renewable energy sources. AHEC covers all techno-managerial aspects of small hydro projects, such as, Engineering Procuring, Commissioning [EPC] and Monitoring of these commissioned projects for their clients, be it government, public institution or private institutions (MNRE, 2012d).

After discussions on the organizational and the institutional efforts made the Government of India to manage the energy sector of the country, it was found that the energy sector is facing complex issues and challenges to meet the energy gap in the country. The next section, 'issues and challenges in the Indian energy sector' therefore is focused on understanding issues and challenges faced by the energy sector in India.

Section 2.4: Issues & Challenges in Indian Energy Sector

The Indian energy sector has various issues and challenges to be addressed so as to ensure continuous growth of the economy. These issues can be pertaining to a certain energy source, be it the import dependency on oil or it could be pertaining to the entire energy sector.

When the energy sector is studied at a macro level, the availability and access of energy becomes one of the major challenges that has to be addressed. Studies have shown that half of the countries' population doesn't have access to any form of commercial energy (IPC, 2011). Hence, this is one of the major challenges that has to be addressed. Another major challenge, that the Indian energy sector has to address, is to improve the supply of commercial energy in a cost effective manner, be it electricity or fossil fuels. It's to be noted that due to the inadequate supply of natural gas, some of the natural gas fired power plants are kept still (IPC, 2011).

The energy security of India is another challenge in the energy sector that has to be addressed. The continuous supply of commercial energy at competitive prices to all the citizens in the future will become possible if this challenge is addressed, otherwise the increasing energy demand supply gap will shoot up the energy prices higher as well as energy sector's dependence on imports.

The issues and challenges pertaining to various sectors of energy vertical are explained further:

Oil and Natural Gas Sector

Various studies (PwC, 2012) (IPC, 2011) (Ernst & Young, 2010) have quoted the issues and challenges faced by the oil and gas sector in India and they are as follows:

- The high import dependence on oil is one of the major challenges that have to be addressed.
- Maximizing the supply of oil and natural gas to ensure that energy security is also a challenge that needs to be addressed.
- More and more investment needs to be made in the infrastructural development, be it a pipeline or a port.
- Another challenge that needs to be addressed is the effective delivery of subsidies.
- The shortage of human skills in the oil & gas sector, combined with lack of better technology, is also a major challenge that has to be addressed.

Coal Sector

The coal sector in India has various challenges which have to be addressed and various studies (Agarwal, 2012) (PwC, 2012) (IPC, 2011) (RBN, 2011) (AES, 2009) (IDFC, 2007) (Bose, 2003) have quoted the same, and these are as under:

- The growth in demand for coal is expected to increase by 9% but the domestic production growth is only 6%. If the coal producing companies do not make any strategy on how to meet the demand, it will have its effect on the economy and the power sector.

- The infrastructure development is another challenge that needs to be looked into. If more coal is produced, infrastructure has to be available to transfer that produced coal.
- Price discovery mechanism of coal is again a challenge that needs to be addressed. A regulator is required for the coal sector to look into the pricing of coal, allotting the coal blocks etc.
- Rapid increase in production needs better technology for exploration of the coal assets, and better drilling technology is required for the production. Technology transfer is also a challenge that needs to be taken care of.
- The market challenges, such as, quality of the coal being used, competition in the coal market from both international and national players, and low acceptability of coal due to high ash content are some issues that need to be discussed.
- The coal sectors also face various issues pertaining to policies, such as, allotment of coal mines, acquiring clearances from the forest and environmental department.
- Land acquisition and rehabilitation of the people, who have been affected by the mining of coal, is also an issue that has to be addressed.

Power Sector

There are various issues and challenges that have to be addressed in the power sector which various studies have quoted (PwC, 2012) (IPC, 2011) (ERSAF, 2009) (PARFORE, 2009), and these are as follows:

- The aggregate technical and commercial losses are as high as 40% in India, which makes the PSU's financially weak preventing them further investing in the sector.
- Making the power sector more efficient and effective, as there still exists the shortage of power in various parts of the country and electricity is still not accessible for more than half of the population of the country.
- The project delay is also a challenge that has to be addressed
- Another main challenge is to step up investment in the distribution infrastructure.
- Continuous availability of feed stock for power generation is also a major challenge that has to be handled.
- Securing the land as well as various clearances for a power project is still a challenge.
- The poor policy initiatives have affected the power industry as they were not able to achieve capacity additions.

New and Renewable Energy Sector

The new and renewable energy sector has also various issues and challenges which have to be addressed (IPC, 2011) (Singh, 2010), and they are as follows:

- At the present growth rate of renewable energy in India, in 2030-31, renewable energy will only have a share of 5% in India's energy mix.
- High capital requirement along with high energy costs.
- The lack of institutional support.
- The lack of awareness among the economically backward people.

In the foregoing sections, the organizational efforts have been studied from energy supply and demand perspective, and on enhancing energy supply in the country. On the other hand, the succeeding section discusses about the demand side management of energy.

Section 2.5: Initiatives taken by the Government for Energy Efficiency and its Conservation

The serious efforts in terms of setting up various institutional efforts and policies on energy efficiency and their conservation started off late. The emphasis on Energy Efficiency started in 1970s, after the first oil shock where the supply of primary energy was scarce.

In 1970, the Government of India set up the Fuel Policy Committee [FPC] to prepare an outline of the energy policy of the country and to look into the scope of energy efficiency in the country (GOI, 1974). The committee submitted their report in 1974 which emphasized on substituting oil with coal, on electricity generation and on energy conservation in general but the major thrust of the study was on the supply side of energy than on demand side management (Ramachandra, 2009).

The response of the Indian government to the enormous hike in oil import bill during the first oil shock was by setting up the Petroleum Conservation Action Group [PCAG] in 1976. The PCAG was later restructured and named as Petroleum Conservation Research Association [PCRA] in 1978, with the objective of formulating strategies to promote measures for accelerating the conservation of petroleum products, to create awareness about the benefits of petroleum conservation, to promote research, development and deployment efforts aimed at petroleum conservation, to establish synergistic institutional linkages at the national and international levels, and to function as a think tank for the government of India for proposing policies and strategies on petroleum conservation. In this regard, PCRA is the one initial effort of the Government of India for the purpose of conservation of energy in India (PCRA, 2010) (PCRA-AR, 2010).

In 1977, the government constituted an expert group the Working Group on Energy Policy [WGEP] to outline a national energy policy (GOI, 1979). The committee submitted their report in 1979 and suggested numerous corrective measures to manage the demand of energy.

Realizing the potential of energy efficiency and its conservation, an Inter-Ministerial Working Group was constituted in 1981. The report was submitted by the committee in 1984, which provided the vision for instituting energy efficiency in the country (MSDA, 2012), and it proposed an apex body to initiate, coordinate and monitor the progress and implementation of energy conservation measures in India (Dey, 2009) (IMWGEC, 1983).

Even though the FPC and WGEP emphasized on the need of an integrated energy planning, no formal institution was formed (Ramachandra, 2009). It was in this context that the Advisory Board on Energy [ABE] was formed in 1983 with the objective of empowering the government to take measures for the purpose of energy conservation. Along with various recommendations on the technical, financial and institutional aspects of energy, ABE was instrumental in the formation of Nodal Energy Conservation Organization [NECO] which was replaced by Energy Management Centre [EMC] in 1989. The major objectives of these agencies were to coordinate energy audits in both the commercial and industrial sectors (Ramachandra, 2009) (Nandi & Basu, 2006).

The eco labeling program, known as Eco-Mark, was initiated in 1991 by the Government of India and is tied up with the Bureau of Indian Standards [BIS] product quality standards (CUTS, 2005) and it provides clauses for energy conservation in the production processes of industries.

Even though various policy initiatives / institutional efforts were taken by the government of India, the actual implementation was sluggish (GOI, 2005). It was also noticed that one third of the total energy is used for domestic cooking, but the success in disseminating information on improving domestic cooking processes were limited (Parikh, Smith, & Laxmi, 1999) (Reddy, 1999). The numerous regulatory requirements and the cost involved in coming up with Eco-Mark products resulted in its failure (CUTS, 2005). The possible reasons for the limited success of these measures were identified by Dipankar Dey (Dey, 2009) namely frivolity, technical barriers, erroneous policies pertaining to pricing and subsidy, easy and cheap access to energy, limited competitive pressure, etc.

Due to the limited success of the above policy / institutional efforts the government of India enacted the EC Act 2001 which identified numerous energy intensive industries as designated consumers. This act provides a legal framework, institutional arrangement and a regulatory mechanism at the central and state level to embark upon energy efficiency drive in the country. The EC Act 2001 strives to facilitate and enforce the efficient use of energy and its conservation in India, and various promotional provisions in support of EC Act have been initiated which are as follows:

Designated Consumers: EC Act 2001 has identified numerous energy intensive industries as designated consumers which have to comply with the norms and regulations mentioned in the act. These consumers have to implement techno-economic viable energy efficiency measures, and need to report the same to the government or the nodal agencies. The Indian refining industry is also one among the designated consumers.

Bureau of Energy Efficiency [BEE]: Under the provisions of EC Act 2001, BEE was established in 2002 for spearheading the energy efficiency initiatives in Indian economy through regulatory and promotional instruments. The major objective of BEE is to promote energy efficiency and its conservation in India, and better implementation of EC Act in the country (BEE, 2010).

Indian Industry Program for Energy Conservation [IIPEC]: In this, various task groups were formed for some of the energy intensive industries which are being headed by the stakeholders of those industries. In this initiative the members declare their voluntary targets, benchmarking and sharing their best practices in their organization (Energy Manager Training, 2010).

Standards and Labeling Program: This program ensures that in the market only energy efficient equipments and appliances are available to the consumers, resulting in a huge potential to reduce the energy being consumed in the households (Energy Manager Training, 2010).

Demand Side Management [DSM]: Another initiative being adopted was the implementation of measures to reduce the energy consumption and the related costs at the consumers' end. This refers to all those activities that involve the intervention by the utility in the market to alter the consumers' load profile (GoI, 2010).

Energy Conservation Building Codes [ECBC]: These codes are applicable to all the new commercial buildings which are being constructed after the adoption of ECBC to design and build them considering energy efficiency from the initial stages of itself (ECO-III, 2010).

Professional Certification and Accreditation: As per EC Act the designated consumers have to appoint energy managers with recommended qualifications and need to conduct energy audits by an accredited energy auditor. Any engineer can become an energy manager / auditor by passing of certification examination conducted by BEE (Energy Manager Training, 2010).

School Education Program: This initiative basically focuses on awareness creation among the school students through their course curriculum. This initiative undertakes practical oriented programs and awareness sessions for students to be more conscious about the effective use of energy resources.

Energy Conservation Awards: By this initiative the industrial units were recognized for the effort undertaken by them to reduce the energy consumption in their respective units. Even though the national energy conservation awards were introduced in 1991 by the MoP, it was well accepted only after 2002.

Energy Efficiency in Buildings and Establishments: The BEE has undertaken energy audits in the government buildings to set up an example for private buildings to pursue similar efforts (Dey, 2009).

National Mission on Enhanced Energy Efficiency [NMEEE]: NMEEE is an Indian Government initiative proposed to address national problems of inefficient energy use.NMEEE spelt out the following four new initiatives to enhance energy efficiency, and they are:

- A market based mechanism to enhance cost effectiveness of improvements in energy efficiency in energy-intensive large industries and facilities, through certification of energy savings that could be traded [Perform Achieve and Trade]
- Accelerating the shift to energy efficient appliances in designated sectors through innovative measures to make the products more affordable [Market Transformation for Energy Efficiency]
- Creation of mechanisms that would help finance demand side management programmes in all sectors by capturing future energy savings [Energy Efficiency Financing Platform]
- Developing fiscal instruments to promote energy efficiency [Framework for Energy Efficient Economic Development]

By implementing NMEEE effectively will unlock energy efficiency opportunities, estimated to be about INR 74,000 Crores and by 2014 - 2015, it has a potential to save 23 Mtoe of fuel and avoid electricity capacity addition of 19,000 MW assuming the economic growth rate to remain between eight to nine percent (Bhargava, 2011). Although NMEEE has been implemented, but as of now only nine industries have been specified as designated consumers in which oil refining industry is not included [oil refineries are among the designated consumers as per EC Act 2001].

These various promotional provisions in support of EC Act 2001, are considered to be a success as the impact they had in terms of energy conserved, energy cost savings etc. were positive.

Chapter 3

The Indian Refining Industry

Since independence, India has seen a tremendous growth in the petroleum refining industry. From a single refinery, with a refining capacity of 0.25 MMTPA, the refining industry has grown to twenty two refineries with the capacity of 202.38 MMTPA. The refining capacity of Indian refineries as on June 2012 was 202.38 MMTPA (Hindu, 2012) (MoPNG, 2010) with an excess of petroleum products production over the domestic demand, except for Liquefied Petroleum Gas [LPG]. These surplus petroleum products are then exported.

India has twenty two refineries [As of June 2012], of which seventeen refineries are of PSU, three refineries in the private sector and two refineries as joint ventures of Bharat Petroleum Corporation Limited [BPCL] & Oman Oil Company and Hindustan Petroleum Corporation Limited [HPCL] & Mittal Energy [See Appendix A for the list of refineries]. Out of these seventeen public sector undertakings eight refineries are owned by Indian Oil Corporation Limited [IOCL], two each by BPCL, HPCL, Chennai Petroleum Corporation Limited [CPCL], one refinery each by Mangalore Refinery & Petrochemicals Ltd. [MRPL], and Tatipaka Refinery both are now a subsidiary of Oil and Natural Gas Corporation [ONGC], and Numaligarh Refinery Limited [NRL]. In the private sector two refineries are owned and run by Reliance Industries Limited [RIL] and the third one is owned by Essar Oil Limited [EOL] (MoPNG, 2010).

During the decade 1947-57, three refineries were commissioned by Burmah Shell[23], Stanvac[24] and Caltex[25], the first two in Mumbai and the last one in Visakhapatnam. These refineries had a refining capacity of 4.8 MMTPA and the major purpose was to refine the imported crude.

During 1957 - 1967, IOCL commissioned three refineries with the cooperation between Romania and Soviet Union at Guwahati in Assam, Barauni in Bihar and at Koyali in Gujarat. The addition of these three refineries during the decade raised the refining capacity in India to 12.7 MMTPA. These refineries were commissioned to process the crudes from Assam and Gujarat assets[26]. During the decade a refinery in Cochin was also commissioned as a private refinery.

During 1967 - 1977, two refineries were set up, one in Chennai and another one in Haldia, taking the refining capacity of India to 22.9 MMTPA. The next three decades saw a tremendous growth in the Indian refining sector with the commissioning of 11 refineries both in the public and private sectors, and other refineries increased their refining capacity which reached 187.38 MMTPA. After 2007, two more refineries were commissioned in India. The joint ventures of BPCL & Oman Oil Company and HPCL & Mittal Energy refineries, that were commissioned after 2007, have increased the refining capacity to 202.38 MMTPA. Since 2000, the refining capacity of Indian refining industry has increased by

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[23] *In the year 1976, Government of India took over the Burma – Shell Oil Storage and Distribution Company of India Limited and formed Bharat Petroleum Corporation Limited. This refinery formed by Burma – Shell is now known as BPCL Mumbai refinery.*

[24] *In the year 1974, Stanvac has merged to HPCL and now this refinery is known as HPCL Mumbai refinery.*

[25] *In the year 1978, Caltex Oil Refining (India) Ltd has merged into HPCL and now this refinery is known as HPCL Visakhapatnam Refinery.*

[26] *The oil and gas reserves is also known as an asset.*

96%. Considering the projects under implementation, the refining capacity will be increased by another 9 MMTPA[27].

The process of deregulation in India has rejuvenated the Indian refining scenario, resulting in the commissioning of private refineries in the country. As of June 2012, 34% of the refining capacity in India is constituted by private players, such as, RIL and MRPL in which about 85% of that 34% was added after the deregulation. This deregulation has made the Indian refining industry more vibrant and efficient as these private refineries came up with the best technology and a Nelson index[28] scale of more than 11, which is considered to be the best in the world. The major refining companies in India are as follows:

- Bharat Petroleum Corporation Limited
- Chennai Petroleum Corporation Limited
- Hindustan Petroleum Corporation Limited
- Indian Oil Corporation Limited
- Mangalore Refinery & Petrochemicals Ltd.
- Numaligarh Refinery Limited
- Reliance Industries Limited

These companies are further explained below:

Bharat Petroleum Corporation Limited

BPCL is an Indian public sector company having its own presence globally, and is the 225th biggest corporation in the world for the year

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[27] *As IOCL Paradip refinery will be commissioned in September 2003.*

[28] *Nelson complexity index is a measure to check the complexity of a refinery (RIL, 2009a).*

2012 (ET, 2012) with an annual turnover of INR 2233 billion (BPCL, 2012).

Burmah Oil Company, incorporated in the year 1886 in Scotland, was earlier known as Rangoon Oil Company, which was commissioned in the year 1871 so as to refine the crude from the wells in erstwhile Burma. The Burma – Shell Oil Storage and Distribution Company of India Limited was formed in the year 1928 with an alliance between the Burmah Oil Company and the Asiatic Petroleum Company of India to import and market the kerosene in India. In the year 1976, Government of India took over the Burma – Shell Oil Storage and Distribution Company of India Limited and formed Bharat Refineries Limited which in the year 1977 was rechristened as BPCL (BPCL, 2011).

BPCL has two refineries, one in Mumbai in Maharashtra [12 MMTPA] and another in Cochin in Kerala [9.5 MMTPA]. BPCL is also a partner in a joint venture refinery with Oman Oil Company in Bina in Madhya Pradesh [6 MMTPA] which takes BPCL's total refining capacity to 27.5 MMTPA which is about 13.5% of the total refining capacity in India (Hindu, 2012) (MoPNG, 2010).

BPCL produces a wide array of products spanning from petrochemicals and solvents to aircraft fuel and specialty lubricants which are being marketed through their widespread Petrol Stations, Kerosene Dealers, LPG Distributors, Lube Shoppes, etc., and also through business-to-business dealings with various industries and airline companies, both national and international. BPCL is the first public sector company to implement Enterprise Resource Planning [ERP] solutions through System Application program [SAP] and is the largest SAP project in India.

BPCL has diversified its business from refining business to upstream sector business through its subsidiary Bharat Petro Resources Limited [BPRL], which has acquired oil & gas reserves in India, Brazil and Indonesia. They have even signed an Memorandum of Understanding [MoU] with L G Chem to diverge into the petrochemical business (BPCL, 2012).

Chennai Petroleum Corporation Limited

Madras Refineries Limited [MRL], later rechristened as CPCL was commissioned in the year 1965 as a joint venture between the Government of India [74%], American Oil Company [AMOCO] [13%] and National Iranian Oil Company [NIOC] [13%]. The refinery was set up with a refining capacity of 2.5 MMTPA and didn’t face any time or cost overrun as the refinery was set up in 2 years and 3 months with INR 430 Million (CPCL, 2012).

In 1985, AMOCO disinvested itself from MRL, leaving the Government of India with 84.62% of shares and NIOC with 15.38%. In 1992, the Government of India disinvested 16.92%, thus bringing their shares to 67.7%. In 2001, IOCL acquired the shares from the government currently holds 51.88% whereas NIOC has continued with its shares holding (CPCL, 2012). The crude throughput in the year 2010 – 2011 was 10.55 MMT with a turnover of INR 453.8 billion (CPCL, 2012).

CPCL owns two refineries, one in Manali in Tamil Nadu [1 MMTPA] and another in Nagapattanam in Tamil Nadu [9.5 MMTPA], which take CPCL’s total refining capacity to 10.5 MMTPA, which is about 5.1% of the total refining capacity in India (Hindu, 2012) (MoPNG, 2010).

CPCL mainly produces LPG, Motor Spirit [MS], Superior Kerosene Oil [SKO], ATF, High Speed Diesel [HSD], Naphtha, Bitumen, Lube Base Stocks [LBS], Paraffin Wax, Fuel Oil, Hexane and Petrochemical feed stocks.

The wax plant at CPCL, which has a capacity of 0.03 MMTPA, produces paraffin wax, which is used as a raw material for the manufacturing of candle wax, waterproof formulations and match wax. The propylene plant at CPCL with the same capacity supplies the petroleum feed-stock to the nearby industries.

Hindustan Petroleum Corporation Limited

HPCL, a Navaratna Public Sector Company in India is the 267th biggest corporation in the world for the year 2012 (ET, 2012) and was ranked in the 1054th position during 2010-11 in the prestigious list of Forbes 2000 with a turnover of United States [US] dollars [$] 36.9 billion (HPCL, 2011). HPCL was formed by the merger of erstwhile Esso Standard and Lube India Limited in the year 1974 and in the year 1978 Caltex Oil Refining (India) Limited and in 1979 the Kosan Gas Company were merged to the company HPCL (HPCL, 2008a).

The refining output of the company has also grown since 1984, from 4.47 MMTPA in the year 1984-85 to 23.8 in the year 2012-13, which is about 432% increase from the initial refining capacity. HPCL accounts for about 11.7% of the total refining capacity in the country and about 20% of the market share (HPCL, 2012) (Hindu, 2012) (MoPNG, 2010) (HPCL, 2008a).

HPCL has two fully owned and operated refineries, one in Mumbai in Maharashtra [6.5 MMTPA] another in Visakhapatnam in Andhra Pradesh [8.3 MMTPA]. HPCL is also a partner in a joint venture refinery with Mittal Energy Investments Private Limited in Bhatinda in Punjab [9 MMTPA]. HPCL also has a 16.95% stake in MRPL [11.82 MMTPA] (Hindu, 2012) (MoPNG, 2010).

HPCL has the largest lube refinery in the country which accounts for 40% of the national capacity of lube oil production (HPCL, 2012). HPCL produces about 300+ grades of lubes and greases along with other petroleum products such as Petrol, diesel, LPG, auto LPG, Aviation Turbine Fuel [ATF], lubricants, bulk fuel and specialties, kerosene, etc.

Indian Oil Corporation Limited

IOCL is the largest Indian public sector corporation in India in terms of revenue generation and the world's 83rd largest public corporation (IOCL, 2012). IOCL, earlier known as Indian Oil Company Limited, started its operation in 1959, and in 1964 became IOCL after its merger with the Indian Refineries Limited. IOCL has about 46% share in the petroleum products market, 27% share in refining capacity and 68% downstream sector pipeline's capacity in India as of 2011 (IOCL, 2011) (MoPNG, 2010).

IOCL has refineries in 10 locations mainly Panipat in Haryana [15 MMTPA], Koyali in Gujarat [13.7 MMTPA], Mathura in Uttar Pradesh [8 MMTPA], Haldia in West Bengal [7.5 MMTPA], Barauni in Bihar [6 MMTPA], Bongaigaon in Assam [2.35 MMTPA], Guwahati in Assam [1 MMTPA] and Digboi in Assam [0.65 MMTPA] with a total refining capacity of 54.2 MMTPA (Hindu, 2012) (MoPNG, 2010). Another refinery will be commissioned in Paradip in September 2013 with a refinery capacity of 9 MMTPA. The President of India has about 78.92% [1.9162 billion shares] shares of the company (IOCL, 2011). During the financial year 2010-11, the government exchequer received Indian Rupees [INR] 274 billion from IOCL as excise duty and taxes. The company in that year made a Profit Before Tax [PBT] of INR 90.96 Billion (IOCL, 2011).

IOCL through their 19,463 fuel retail outlet stations and Auto LPG Dispensing Stations [ALDS] sells various products such as petrol, diesel, LPG, auto LPG, ATF, lubricants, naphtha, bitumen, paraffin, kerosene, etc.

Mangalore Refinery & Petrochemicals Ltd.

MRPL is a refinery having the mini-ratna status given by the government of India in 2007. MRPL was set up in the year 1988 as a joint venture company between HPCL and AV Birla group with an initial refining capacity of 3 MMTPA. In 2003, ONGC acquired the majority of shares making MRPL a subsidiary of ONGC thereby becoming a PSU. In 2007, ONGC had about 71.62% of shares, HPCL had about 16.95% of shares and the rest of the shares with various public and financial institutions (MRPL, 2011).

This refinery has the capability of refining any crude, be it light or heavy, sweet or sour, which is having API gravity[29] in between 24-26 API so as to maximize the production of middle distillates (MRPL, 2011). MRPL is the only refinery in India which has two Crude Catalytic Reformers [CCR]

[29] *It is a scale developed by American petroleum Institute [API] to measure the density of various petroleum liquids.*

to produce unleaded petrol of high octane and two hydrocrackers producing premium diesel.

Presently MRPL has a refining capacity of 11.82 MMTPA, which is about 5.84% of the total refining capacity in India. Since its inception, MRPL has increased its refining capacity by 294% (MRPL, 2011) (MoPNG, 2010).

The main products from MRPL are petroleum, petrochemicals and natural gas, feedstock, LPG, ATF, automotive fuel, furnace oil, Low Sulphur High Sulphur Diesel [LSHSD], Bitumen, naphtha, etc.

Numaligarh Refinery Limited

NRL is a PSU with mini-ratna status due to its contributions to the socio-economic development of the state combined with a track record of continuous growth (NRL, 2011). NRL was incorporated in 1993 with BPCL having 32% of stake, Indo Burma Petroleum Limited [IBP] having 19%, Government of Assam having 10% and the rest of the shares with the public. It was set up in Assam basically for the faster economic development of the north eastern region of India (NRL, 2011).

In 2000, NRL started commercial operation and in 2001 it became a subsidiary of BPCL. In 2006, the shareholding structure changed with BPCL having 61.65% of stake in the company, government of Assam having 12.35% and Oil India Limited [OIL] having 26% of stake in the company (NRL, 2011).

NRL has 3 MMTPA refining capacity, which is about 1.4% share of India's refining capacity (Hindu, 2012) (MoPNG, 2010). NRL has a range of products such as LPG, Naphtha, MS, ATF, SKO, HSD, Raw Petroleum Coke [RPC], Calcined Petroleum Coke [CPC] & Sulphur which is being sold directly to the industrial consumers or through their retail outlets called 'Energy Stations' (NRL, 2011).

NRL has installed a Naphtha Splitter Unit to supply 160 TMT per annum of petrochemical grade Naphtha to the Assam Gas Cracker as feed stock (NRL, 2011).

Reliance Industries Limited

RIL is a private sector refinery in India and is the largest private refinery in the world (IE, 2008). RIL refinery has a complexity index of 11.3 [As defined by Nelson Index] and can refine any quality of crude to produce various grades of fuel which benefit the company from the lower input costs. RIL refinery has a capacity of 60 MMT and had a refining share of 26.8% of refining during 2009 – 2010. The RIL Jamnagar refinery is integrated with a downstream petrochemical unit as well and has its own jetty in Kandla port to import the raw material through which it imports about 70% of their total requirement (Halar, 2006).

During 2004-2005, this refinery utilized nearly 100% of its capacity with minimal downtime which outperforms the average utilization rate of refineries in Asia Pacific, European Union and North America (RIL, 2008a). The refining complex has about 50 refining processes which together process the crude oil to provide various products.

Chapter 4
Literature Review

Section 4.1: Introduction

Before the industrial revolution took place, mankind depended upon the various renewable energy sources, such as, wind, solar, water, animal and human labour to name a few for their various day-to-day activities. As the industrial revolution started taking place, the energy consumption began to increase. This increased energy consumption is an important factor for the development of any economy. During the industrial revolution, the increased energy requirement was met by using fossil fuels which were used for both industrial and domestic activities. The benefits of the fossil fueled civilization have been dramatic as (Smil, 1994) mentions:

> "No gain has been more fundamental than the substantial rise in global food production. No change has moulded modern societies more than the process of industrialization, and no new developments have contributed more to the emergence of global civilization than the evolution of mass transportation and telecommunications"

This fossil fuel consumption has resulted in emissions of various hazardous materials[30] into the environment, resulting in water and air pollution. But, the role of fossil fuel in the global climate change has

[30] *The various hazardous materials being emitted into the atmosphere are carbon di oxide, Methane, chlorofluorocarbons and nitrous oxides.*

raised the concern. This fossil fuel consumption and its emissions have led the fuel to be a major contributor to the greenhouse gas emissions which have changed the atmospheric composition (UNDP, 2000). In 2001, fossil fuels contributed about 81% of the world energy use and emitted 23.7 Giga Tons [GT] of CO_2 into the atmosphere (IEA, 2004), and the concentration of CO_2 in the atmosphere increased by 31 +/_ 4% compared to the pre-industrial period (Prentice, et al., 2001). It was also found that during the 20th century the average global surface temperature increased by 0.6 ^{0}C (IPCC, 2007) (IPCC, 2001). This increase in the CO_2 in the atmosphere, and the average global surface temperature has resulted in changes in the climate, such as, cloud cover, precipitation, wind patterns and the duration of seasons (BEE, 2002b), and also has resulted in the changes in sea level, snow cover and ice extension.

Furthur emissions from the fossil fuels can result (BEE, 2002b) in the following consequences as mentioned below

- Severe storms and flooding
- Food shortages
- Dwindling fresh water supply
- Loss of biodiversity
- Increased diseases and
- Acid rain

Hence, these emissions have to be brought down from the current levels and the strategies adopted (Prentice, et al., 2001) (UNDP, 2000) for the same are as follows:

- Use energy efficiently.
- Increase the use of renewable energy sources.

- Design, develop and deploy technologies that produce near zero greenhouse gases.

According to various studies (Metz, B., Davidson, O.; Bosch, P.; Dave, R.; Meyer, L. (Eds.), 2007) (Vuuren & Vries, 2000), most of these reductions during the years 2005 to 2030 will be due to the implementation of energy efficiency measures, and from 2030 the reduction in the emissions will be due to decreased use of fossil fuels as the renewable sources of energy and will thus replace the fossil fuels.

Section 4.2: Energy Efficiency

Energy efficiency is an attractive option to reduce the emissions of the fossil fuels and assuring the equal level of economic activity with less quantity of fuel. The concept of energy efficiency is much discussed in the world as it has commercial, industrial competitiveness and energy security benefits. Even though energy efficiency plays a vital role in various countries' policies, little or no attention has been given to define the term ‘energy efficiency’ (Patterson, 1996). Some of the definitions for energy efficiency in various writings are as follows:

> “Energy efficiency is the ratio between output of performance, service, goods and energy, and an input of energy, or it is to obtain an unchanged output value at a reduced energy consumption level, or it is to obtain an increased output value with unchanged energy consumption, or it is the amount of energy consumption per unit of product/output, or it is the amount of energy consumed per unit of feed-stock, or it is the energy consumption per unit of product (excluding feed-stocks)”

(McKenna, 2009) (European Commission, 2006) (Patterson, 1996) (Fawkes & Jacques, 1987).

(UNIDO, 2007) defines energy efficiency as:

> "Energy efficiency is understood to mean the utilization of energy in the most cost effective manner to carry out a manufacturing process or provide a service, whereby energy waste is minimized and the overall consumption of primary energy resources is reduced. In other words, energy efficient practices or systems will seek to use less energy while conducting any energy-dependent activity: at the same time, the corresponding (negative) environmental impacts of energy consumption are minimized".

Another definition given by (Irrek & Thomas, 2008) is:

> "It is the ratio between the benefit gained and the energy used".

The World Energy Council [WEC] defines energy efficiency as:

> "Energy Efficiency is the reduction in the energy used for a given energy service of a level or activity. These reductions in energy consumption can change with better organization and management or improved economic efficiency in the sector rather than being just a result of technical change" (WEC, 2004)

From Ibid. definitions it's been understood that various researchers have defined the term energy efficiency depending upon the context of that literature or area of study. In industrial sense, the energy efficiency can be defined as, "it is the amount of energy consumption per unit of product/output" (McKenna, 2009) and this definition is being widely used.

Measuring Energy Efficiency

Industrial energy efficiency being defined by (Patterson, 1996) is "Using less energy for producing the same amount of services or useful output" can only be measured using various energy efficiency indicators.

The term indicator is defined by (Godin, 2002)[31] as:

> "An indicator is a statistic of direct normative interests which facilitates concise, comprehensive and balanced judgments about the condition of major aspects of society. It is in all cases a direct measure of welfare and is subject to the interpretation that, if it changes in the 'right' direction, while other things have got better, or people better off"

And the term energy efficiency indicator is defined by (Martin, Worrell, Schipper, & Blok, 1994) as:

> "Energy intensity indicators measure the quantity of energy required to perform a particular activity, such as the production of output"

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[31] *This is the definition of Indicator defined by US Department of Health, Education and welfare in 1970 and was quoted by (Godin, 2002) in his study in 2002.*

The energy efficiency can be analyzed based upon macro-economic perspective[32] or sub-sectoral analysis[33]. Depending upon the availability of the data, these energy efficiency indicators can perform various functions, such as, analyzing the effectiveness of energy efficiency measures being implemented, monitoring various processes, inter and intra economy comparisons, appraisal of new technologies, energy demand analysis, etc.

Calculating energy efficiency indicators

Various literatures suggest a number of methods to measure the energy efficiency indicators which are as follows:

According to (Ramírez, 2005) the industrial energy efficiency can be measured in two different approaches using the indicators. These are:

- Based on physical terms
- Based on economic terms

If the output is being recorded in physical units, then the parameter is known as physical energy intensity or energy intensity factor and if the said output is measured in economic terms then it is known as economic energy intensity or energy intensity. In various literatures, energy efficiency is often measured in terms of economic energy intensity in which energy consumption per unit of output or energy consumption per unit of GDP is used as an indicator.

To measure energy efficiency in the industry (Patterson, 1996), has identified a number of indicators which could be categorized as:

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[32] *Calculated in terms of monetary values.*
[33] *Calculated in terms of physical units.*

- Thermodynamic: Purely, based on the efficiency of a process in the industry.
- Output Based
    - Physical thermodynamic: In other terms physical energy intensity or energy intensity factor.
    - Economic thermodynamic: In other terms economic energy intensity or energy intensity.
- Economic: Purely based on terms of market values.

Various studies (Ramírez, 2005) (Farla, 2000) (Freeman, Niefer, & Roop, 1997) (Patterson, 1996) have identified that these indicators have both advantages and disadvantages of their own. (Ramírez, 2005) has questioned whether the economic energy intensity indicators can be used to measure the changes in technical efficiency or vice versa, and suggests that the selection of indicator strongly affects the outcome of the analysis of the effectiveness of energy efficiency measures. Hence, the decision on which indicator is to be used for the analysis basically depends upon the availability of the data. The energy efficiency indicator pyramid (Farla, 2000) (Phylipsen, Blok, & Worrel, April 1998) helps in identifying which indicator needs to be used depending upon the requirement. It’s been noted that the economic based indicators are widely used to analyze the effectiveness of energy efficiency measures being used (McKenna, 2009).

Section 4.2: Methods of Energy Efficiency Improvements

Due to its commercial and industrial competitiveness benefits, various industries are implementing various energy efficiency measures. Before implementing any energy efficiency measure, the industries have to identify their current energy consumption trend and have a baseline to understand which measure has to be implemented. There are various methods for energy efficiency improvements which could be broadly classified into:

- Social or behavioural measures
- Technological measures
- Policy related measures

Social or behavioural measures include changing the usual practices being followed in the industry without changing any of the resources. For these measures in some cases the investment is not required and in other cases the investment required is negligible (Dwivedi & Diwan, 2008) (Vaishampayan, 1995). Whereas in technological measures there is a requirement of investment/capital, as in these measures either a modification/upgrade is done on the process/equipment or a new process/equipment is being installed. These measures could be either developed by the research and development wing of the organization, or it could be bought. Industries implement technological measures, as the new technologies tend to efficiently use the energy (Worrell, Laitner, Ruth, & Finman, 2003) (von Weizsäcker, Lovins, & Lovins, 1997). These technological measures has been further classified by (Langley, 1984) as:

- Installation of new process/equipment
- Replacement of existing process/equipment
- Upgrading of existing process/equipment

The third category, which improves energy efficiency is policy related that is due to the change in legislation, resulting in social/behavioural change measures or implementation of technical measures.

These three identified methods of energy efficiency improvement measures are explained below in depth.

Social or Behavioural Approach

Various studies (Wedge, 2003) (Dahle & Neumayer, 2001) (Bertoldi, Ricci, & Almeida, 2001) suggest that the behavioural approach measures are an effective way for improving energy efficiency. The behavioural approach measure is an effective way for improving energy efficiency. This behavioural measure requires a change in the usual practices the industry/organization was following or changes in the human attitude without affecting the economic welfare which could be achieved by motivation and by raising awareness. It's been suggested that these measures have to be implemented before any other measure is implemented as the capital required for this is low (Wedge, 2003) (Dahle & Neumayer, 2001) (Bertoldi, Ricci, & Almeida, 2001).

In these measures the people may be persuaded to change their lifestyle for reducing the energy consumption, such as, switching off air conditioners or lights when not in use, driving the car in optimum speed, car pools etc. The scope of conservation of energy exists right from the stage of extraction to the point where it changes in work - heat, light or motive power. The scope of structural[34] and social/behavioural measures are more than the technological measures [35], indicating the role of economists in this field (Dwivedi & Diwan, 2008) (Vaishampayan, 1995).

[34] *It includes the installation of new process/equipment.*
[35] *In this only replacement of existing process/equipment or upgrading of existing process or equipment is considered.*

Technological Measures

Another way to improve the energy efficiency in an industry is by implementing the technical measures which could be by installation of new process/equipment, replacing the existing process/equipment or upgrading the existing process/equipment. Various studies (IEA, 2007) (Shipley & Elliot, 2006) (European Commission, 2006) (Enviros Consulting, 2006) (Future Energy Solutions & The Carbon Consortium , 2005) (McKane, Perry, Aixian, Tienan, & Williams, 2005) (Ross & Tincher, 2004) (de Keulenaer, et al., 2004) (Klostermann & Tukker, 1998) (Kreith, 1997) (von Weizsäcker, Lovins, & Lovins, 1997) (Langley, 1984) showcase that there is a considerable potential in energy saving by implementing various technical measures in Combustion systems, Steam systems, Motor systems, Heat recovery and transport systems, Cogeneration & combined heat and power systems, process modifications etc.

When technical measures are implemented, the energy consumption being consumed has been reduced but has an investment; hence it is being suggested that this approach is a simple case of substitution of one factor by another [36] (Dwivedi & Diwan, 2008) (Vaishampayan, 1995). Economically, therefore, the energy saving investment is not justified, unless the cost of energy saved is more than the cost of additional capital investment.

The scope for technical approach to improve energy efficiency is tremendous as the leak detection and its plugging alone saves huge amounts of energy[37].

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[36] *It is because both the energy and capital are factors of production.*
[37] *Been discussed further in detail in Section 4.5.*

Policy Related Measures

The third option available to improve the energy efficiency is by policy formulation. This has the potential to reduce the energy consumption by legal compliance. In India, the government has taken serious efforts in terms of setting up various institutional efforts and policies on energy efficiency and its conservation; let it be setting up of FPC in the year 1970 or establishing PCRA in the year 1976 or the enactment of Energy Conservation Act 2001 in 2001.

Even though various policy initiatives / institutional efforts were taken by the government of India during the period 1970 to 2000 (MSDA, 2012) (PCRA-AR, 2010) (PCRA, 2010) (Dey, 2009) (Ramachandra, 2009) (Nandi & Basu, 2006) (CUTS, 2005) (IMWGEC, 1983) (GOI, 1979) (GOI, 1974), the actual implementation of them was sluggish (GOI, 2005). The possible reasons for the limited success of these measures were identified by Dipankar Dey (Dey, 2009) these are frivolity, technical barriers, erroneous policies pertaining to pricing and subsidy, easy and cheap access to energy, limited competitive pressure etc.

Due to the limited success of these policies / institutional efforts the government of India enacted the EC Act 2001, which has identified numerous energy intensive industries as designated consumers. This act provides a legal framework, institutional arrangement and a regulatory mechanism at the central and state level to embark upon energy efficiency drive in the country. The EC Act 2001 strives to facilitate and enforce the efficient use of energy and its conservation in India and various promotional provisions in support of EC Act have been initiated (BEE, 2010) (Energy Manager Training, 2010) (GoI, 2010) (ECO-III, 2010) (Dey, 2009). These various promotional provisions in support of EC Act

2001 and the act itself, are considered to be a success, as the impact they had in terms of energy conserved, energy cost savings, etc., were positive. The factors of success of these measures were identified as the legal compliance of the designated consumers, better implementation of various initiatives, awareness about the policy measures, etc. Hence, the effective implementation of the policy measures could also result in improving energy efficiency.

Section 4.3: Barriers to and Driving Forces for the Implementation of Energy Efficiency Measures

Energy is important for better living conditions of mankind and for their production activities. Due to the scarcity of various conventional sources of energy, today the world is facing a problem of energy crisis. The energy crisis with the increase in the rate of consumption of energy due to development of growing economies has made energy efficiency and its conservation more important. Though, energy efficiency is the need of the hour, studies suggests that energy efficiency measures are not always implemented, implying the existence of an energy efficiency gap (Rohdin, Thollander, & Solding, 2006b) (Dias, Mattos, & Balestiere, 2004) (DeCanio S. , 1998) (Weber, 1997) (Velthuijsen, 1995) (Jaffe & Stavins, 1994b) (DeCanio S. , 1993). This energy efficiency gap is in turn explained by the existence of barriers in various industries and household (Palm, 2009) (Schleich & Gruber, 2008) (Thollander & Ottossom, 2008) (Rohdin & Thollander, 2006a) (Rohdin, Thollander, & Solding, 2006b) (Ramirez, Patel, & Blok, 2005) (Dias, Mattos, & Balestiere, 2004) (de Groot, Verhoef, & Nijkamp, 2001) (Sorrell, et al., 2000) (DeCanio S. , 1998) (Weber, 1997) (Velthuijsen, 1995) (Sanstad & Howarth, 1994) (Jaffe & Stavins, 1994a) (Jaffe & Stavins, 1994b) (Jaffe & Stavins, 1994b) (Howarth & Andersson, 1993) (Stern, 1992) (Hirst & Brown, 1990)

(Blumstein, Krieg, Schipper, & York, 1980). These barriers differ from sector to sector and region to region (Sorrell, et al., 2000) (SPRU , 2000), indicating a need for regional and sector specific studies. However, certain studies have identified that the energy efficiency can be better implemented because of certain factors (Thollander & Ottossom, 2008) (Rohdin & Thollander, 2006a) (Rohdin, Thollander, & Solding, 2006b).

Section 4.4: Industrial Energy Consumption

The demand for energy is growing in the world due to industrialization and is expected to increase by 53 percent in 2035 (IEA, 2004). The five most energy intensive industrial sectors, such as, iron and steel, petroleum refining, cement production, pulp and paper and chemicals constitute about 45 percent of total industrial energy consumed (UNESCAP, 2001). Hence, the industrial sector are one of the major contributors to the greenhouse gas emissions, which is likely to increase by 50 + percent by 2030 (UNEP, 2006).

Among the industries, the manufacturing industry itself consumes about 75 percent of the world's yearly coal consumption, 44 percent of the world's natural gas consumption, 20 percent of global oil consumption and also uses 42 percent of all electricity produced (IEA, 2004) . The industrial / manufacturing sector is one of the major consumers of energy, in which oil refining industry, being a capital and lucrative industry, has its own position. Studies to understand the effectiveness of energy efficiency measures being implemented in the industries were conducted on steel, fertilizers, cement, sugar industries (Dwivedi & Diwan, 2008) (Vaishampayan, 1995) but no study was conducted on the refining industry.

The petroleum refining industry is considered to be one among the largest consumers of all forms of energy, and its consumption varies from refinery to refinery depending on the type of crude being processed, the quantity of impurities present, the complexity of the refinery, etc. Out of the whole, among refinery operations only a few processes are the major energy consumers. These processes include the distillation processes, hydrotreating, cracking, reforming etc. Various studies have quoted the advantages of increased energy efficiency, such as, reduction in atmospheric pollution, boosting up of industrial competitiveness, generation of employment and better business opportunities, enhancing the productivity, increasing the security of supply and contribution to poverty alleviation along with other aspects (IAC, 2007) (Levine, Metz, Davidson, Bosch, & Dave, 2007) (Jakob M. , 2006) (Jochem, 2000) (Leaman & Bordass, 1999) (Laponche, Jamet, Colombier, & Attali, 1997). Studies have shown that the utilities, fired heaters, process optimization, heat exchangers, motor and motor applications have a potential of saving energy if energy efficiency measures are implemented at 30%, 20%, 15%, 15% and 10% respectively (Dorgan, Way, Bryan, Huff, & Stewart, 2003)

The petroleum refining industry globally consumes about four percent of total primary energy consumption, and is one of the largest energy consuming sectors. Most of the petroleum refining capacity can be found in OECD countries, Eastern Europe and former Soviet Union, wherein the share of the developing countries is growing (Phylipsen, Blok, & Worrel, April 1998). The case is not so different in India either. The petroleum refining industry in India is a major energy user which consumes 7.5 percent of total primary energy consumed by the industrial sector (PCRA, 2009).

The petroleum refining industry provides inputs to various economic sectors in the world, and they spend about 58 percent of their operating costs on energy, which makes it as an important opportunity for cost reduction (Stutzmann, Seillier, & Petela, 2005). Hence, implementation of energy efficiency measures has its own importance in refineries.

Due to the fierce global competitive environment, the Indian refineries have to reduce the costs associated with production without affecting the quantity and quality of the products. Effective investments in the energy efficient technologies, and their practices ensure the output of the same quality and quantity without reducing the production costs. These technologies are very important, as they not only decrease the energy cost but also increase the production yield.

Over the last few years the refinery fuel uses and their losses have increased as the refinery throughput has enhanced and new units have been brought on line (Sathaye, Price, Can, & Fridley, 2005). Studies have proved the existence of considerable potential for energy efficiency improvement in the refining industry (Worrell & Galitsky, 2005).

In the next section 4.5, various studies, which proved the existence of considerable potential for energy efficiency improvement in the refining industry is studied and summarized.

Section 4.5: Review of Energy Efficiency Measures in Refineries

This section assesses various energy efficient measures implemented in the refineries worldwide and discusses their economic effectiveness. This paper considers various technological measures, that are available globally and describes the specific energy savings of these technologies. It also reviews various literatures, comprising of research articles, reports, brochures, case studies, etc., to identify, and evaluate the economic effectiveness of various energy efficiency measures that could be implemented in five processes and various other units associated with it in refineries.

This section focuses on various technologies/measures that could reduce the energy consumption which can be implemented in the following processes, such as, steam generation and distribution, heat exchangers, process heaters, distillation units, hydrogen management and recovery units. This study also focuses on the recovery of the energy that has been wasted / emitted during the process operations and to reuse the same for better energy savings.

Steam Generation & Distribution

Steam is one of the forms of energy being used by a refinery, and it is very expensive to produce and distribute. Hence, the steam has to be carefully considered and evaluated. In a typical refinery the steam is being generated through cogeneration units, boilers or through waste heat recovery, and it is being widely used in distillation units, steam cracking units and also in the process heating. The following table shows numerous energy efficiency measures being implemented in the steam generation and distribution process of the refinery and its economic advantages.

Table 4.1: Techno-economic Analysis of Energy Efficiency Measures taken in Steam Generation and Distribution Process

Measure	Characteristics	Economic Impact
Boilers		
Preparation of Boiler Feed Water [BFW] (U.S. DOE-OIT, 2001)	In this measure the Reverse Osmosis [RO] with membranes is used to purify the incoming water [this water is being used as BFW] before it is pre-heated to various temperatures.	Energy consumption was reduced with an annual savings of $200,000 and enabling the refinery to recover the investment [$350,000] in less than two years. It has also reduced the maintenance and disposal costs and the chemical use. [Implemented in Flying J's North Salt Lake refinery in Utah, USA].
Improved process control (IAC, 1999)	In this the optimum flame temperature of flue gases is maintained along with the monitoring of carbon monoxide, oxygen & smokes. This measure also detects small leaks in the system.	Reduced the energy consumption and emissions and has a payback period of seven months.

Reduction in Flue gas[38] quantities (U.S. DOE-OIT, 1998)	In this measure the wastage of flue gases is prevented by identifying and repairing the leaks.	Energy consumption was reduced with an annual savings upto 2-5%.
Reduction of excess air usage (U.S. DOE-OIT, 1998) (Ganapathy, 1994)	In this the boilers are properly maintained, thereby, reducing the excess usage of air.	Energy was saved upto eight percent of the total energy consumed for heating up the boilers.
Better Insulation (Caffall, 1995)	In this measure the boilers are insulated with a new and better insulator [Ceramic Fiber].	Annual energy savings of 6 - 26 percent depending on the processes was noticed.
Maintenance (U.S. DOE-OIT, 2001)	The boiler and its various components are maintained properly.	Energy was saved upto ten percent of the total energy consumed per annum.
Steam Recovery from blowdown (IAC, 1999)	The low grade steam that has been produced by the reduction in pressure is being used in space heating and feed water pre-heating	Energy can be saved upto 1.3 percent of the total boiler fuel used per annum and the refinery can recover the investment within 1 - 3 years.
		57 Peta Joules [PJ]/annum [54 trillion British Thermal Unit [btu] / annum] of energy saved and have recovered the

[38] *Flue gas is the exhaust gas that is being exited from a boiler through a pipe or channel.*

Reduction of Standby Losses (CADDET, 1997b)	An automatic control system is attached to the standby boiler to achieve full capacity utilization.	investment [$270,000] in one year and six months [Implemented in Kemira Oy ammonia Plant in Netherlands].
Steam Distribution		
Improve insulation (IAC, 1999) (U.S. DOE-OIT, 1998)	The heat distribution system in the refinery is insulated with a better insulator.	3 - 13 percent of the total fuel used in the generation of heat on all systems was saved with a payback period of a year and a month.
Improve Steam traps (Alesson, 1995)	Modern thermostatic elements are being used to improve the steam traps.	Reduced the energy usage and improved the reliability of the system. The economic benefits are unknown.
Maintenance of Steam Traps (Brueske, Smith, & Brasier, 2002) (IAC, 1999) (U.S. DOE-OIT, 1998) (Bloss, Bockwinkel, & Rivers, 1997) (Jones, 1997)	The steam traps are regularly monitored and maintained.	Energy was saved up to ten percent with a payback period of six months. Reduced energy consumption with an annual savings of $147,000 per annum [Implemented in Flying J's North Salt Lake refinery in Utah, USA].

Automatic monitoring of Steam traps (Jones, 1997) (Johnston, 1995)	Automatic monitoring systems are installed to identify the leaks and also to monitor the proper functioning of the system.	An additional saving of five percent along with the savings of maintenance of steam traps is being noticed.
Repairing the leaks on time (IAC, 1999) (U.S. DOE-OIT, 1998)		An additional savings up to three percent was noticed with a payback period of five months.
Flash Steam [39] Recovery (Bronhold, 2000) (Johnston, 1995)	The flash steam that has been produced when the steam trap purges condensates which can be used for space heating and also for water pre-heating.	Recovered 100 percent of the flash steam and have saved 2.8 percent of the total energy consumed [Implemented in Vulcan Chemicals in Geismar, Louisiana, USA].
Return condensate [40] (Van de Ruit, 2000) (IAC, 1999) (U.S. DOE-OIT, 1998)	The hot condensate is reused in the boilers.	Saved energy upto ten percent with a payback period of one year & a month and also reduced the costs incurred on chemicals.

The implementation of these measures in a refinery has not only reduced the energy consumption but also reduced the emissions, maintenance and

[39] *Flash steam is a vapor which is being generated from a hot condensate which holds more heat than it can seize at lower pressure.*
[40] *Liquid formed by the condensation of steam or gas.*

disposal cost usage of the chemicals and also has increased the annual savings.

Heat Exchangers and Process Integration[41]

In a petroleum refinery, energy is consumed in the heating and cooling processes. Hence, a better design and use of the heat exchangers optimally reduces the energy consumed by various processes. The use of process integration or pinch technology of this multiple heating and cooling demand also increases the efficient use of energy. Various studies have quoted that these measures can reduce the energy consumption in a refinery (Smith, 1995) (Shenoy, 1994).

Table 4.2: Techno-Economic Analysis of Energy Efficiency Measures taken in Heat Exchangers

Measure	Characteristics	Economic Impact
Heat Transfer		
Heat Transfer-Fouling (U.S. DOE-OIT, 2002a) (Barletta, 1998)	Various heat exchangers and reactors are redesigned by understanding the principles of fouling[42]. Various methods that have been implemented to reduce the fouling mainly focus on the regular maintenance of	Energy saved was about 0.7 percent of the total energy consumed with a payback period of eight months and thirteen days [Implemented in Various European refineries].

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[41] *It is an integrated approach adopted to design the processes in a fashion so as to exploit the interaction between various processes to achieve an optimum usage of resources and thereby reduce the costs.*

[42] *It is the Accretion of various deposits in an exchangers.*

	the heat exchangers and also on process & temperature control	Reduced energy consumed with energy savings of $14 Million/annum and enabling the refinery to recover the investment [$9.8Million] in eight months. [Implemented in Shell's Refinery in Martinez, USA].
Process Integration		
		Resulted in energy saving of 20-30 percent per annum. Although the economic potential for these savings is found only 10-15 percent per annum [Implemented in Amoco refinery, Italy and BP refinery, Netherlands].
		An annual energy savings of $3.9 million, $0.9 million, $3.6 million at their various plants in Decatur, Anniston,

Total site pinch analysis [43] (Dunn & Bush, 2001) (Linnhoff, 2000)	In this measure various processes with heating and cooling demands are integrated together into the analysis.	Pensacole respectively [Implemented in Chemical Producer Solutia].
Hot rundown (U.S. DOE-OIT, 2002a)	In this measure the heat in the intermediate process is retained so as to reduce the energy need for cooling in one unit and the energy required for reheating in an another unit	Reduced energy consumption with an annual energy savings of $ 4.3 million. [Implemented in Shells refinery in Martinez, California, USA].
Crude Distillation Unit [44] [CDU] (Querzoli, Hoadley, & Dyron, 2002) (Petrick & Pellegrino, 1999) (Lee, Morabito, & Wood, 1989) (Sunden, 1988) (Clayton, 1986)	Various processes in the CDU are integrated.	Reduced the fuel consumption between 10-19 percent with a payback period of less than two years.
		35-40 percent of the heating demand has been reduced with a payback period of one year and seven months. [Implemented in BP refinery in Kwinana, Australia].
		Reduced the energy consumption by 27 percent with a payback period of nineteen months

[43] *It is also known as heat integration. In this, the processes are designed in such a fashion so as to minimize the consumption of energy and to maximize the recovery of heat.*

[44] *It is the first processing unit in a refinery which refines the incoming crude into various fractions depending upon their boiling range.*

		[Implemented in a refinery in Romania].
Fluid Catalytic Cracking [45] [FCC] (Venkatesan & Iordanova, 2003) (Al-Riyami, Klemes, & Perry, 2001)	Various processes in the FCC are integrated.	Reduced the energy consumption resulting in an annual savings of $210,000 and have recovered in two years [Implemented in a refinery in UK].
FCC Process flow changes (Petrick & Pellegrino, 1999)	FCC was optimized by modifying the equipment so as to increase the product yield.	Increased the product yield of gasoline from 3 - 7 percent per bbl of crude oil.
Coker [46] (Zhang, 2001)	Coker is optimized to integrate the heat flow	Reduced the energy consumption and have saved $100,000 per annum [Implemented in Nanjing refinery, Jinling Petrochemical Corp. in China].

The implementation of these measures has reduced the total energy consumed by a refinery, thereby, resulting in an annual savings. These measures have also increased the product quality.

[45] *In this process the heavier fractions are converted into more valuable lighter products.*

[46] *In this process the residual oil from the Vacuum Distillation Column or Atmospheric Distillation Column is converted to low molecular weight products.*

Process Heaters

In a petroleum refinery, the majority of the energy being consumed is being used by the boilers and furnaces. Studies have shown that the theoretical efficiency of a furnace, after considering its thermal efficiency followed by the losses, is only 90 percent (Petrick & Pellegrino, 1999). Hence, it makes an attractive area for further energy efficiency improvements.

Table 4.3: Techno-economic Analysis of Energy Efficiency Measures taken in Process Heaters.

Measure	Characteristics	Economic Impact
Regular Maintenance (Petrick & Pellegrino, 1999)	Various burners, draft controls and heat exchangers are regularly maintained	Improved the energy efficiency of furnaces by 10 percent.
		Reduced the energy consumption by 3 - 6 percent and NOx emissions by 10 - 25 percent. This measure has resulted in cost savings of $ 340,000 per annum [Implemented in Valero's Houston Refinery, Texas, USA]
		The regular maintenance of the system has resulted in an annual savings of $ 290,000 and have recovered the investment in two months [Implemented in Asphalt Refinery of Paramount Petroleum Corporation in

Draft Control (Valero, 2003) (U.S DOE-OIT, 2003a) (Brueske, Smith, & Brasier, 2002) (U.S. DOE-OIT, 2002a).	In this measure control systems are insulated so as to reduce the excess combustion of the air in the furnace. Even the regular maintenance of the draft control is carried out.	Paramount, Califormia, USA].
		Resulted in an annual savings of $12 million [Implemented in Shell Refinery, Martinez, California, USA].
		Resulted in an annual savings of $100,000 [Implemented in Flying J's North Salt Lake Refinery in Utah, USA].
Air Pre-Heating [APH] (Garg, 1998)	It is the most popular way to revamp the fired heaters. In this when the exit flue gas temperature is dropped by 35 degree Fahrenheit the thermal efficiency increases by 01 percent.	Total energy savings range from 8 - 18 percent.
Vacuum Distillation Unit[47] [VDU] (Venkatesan & Iordanova, 2003)	Combustion air heater and a Forced Draft [48] [FD] fan is installed thereby reducing the temperature of the flue gas.	This measure has saved $109,000/annum and in two years and three months, the investment has been recovered. [Implemented in a refinery in UK].
New Burners (Seebold, Waibel, & Webster, 2001)	New low NOx burners are installed which has the technology to reduce the Nox emissions.	Reduced the NOx emissions by 90 percent and has eliminated the need for Selective Catalytic Reduction [SCR] resulting in an $11.5 million in the first year considering both capital and annual operating costs of SCR's [Implemented in Chevron

[47] *VDU further distills the oil left at the bottom of the crude distillation unit.*
[48] *It supplies the air under a certain pressure to the fuel burning equipment.*

		Texaco refinery in Richmond, California, USA].

The implementation of these measures has not only reduced the consumption of energy resulting in annual savings but also reduced the emissions from the refinery.

Distillation

Distillation is the process where the energy consumption is enormous. The separation of products in a refinery takes place during the distillation process depending on their boiling points.

Table 4.4: Techno-economic Analysis of Energy Efficiency Measures taken in Distillation Columns

Measure	Characteristics	Economic Impact
Reducing reboiler duty (Petrick & Pellegrino, 1999)	Re-boiler duty is being reduced by lowering the overhead condenser temperature with the use of chilled water. [It's not commercially applied].	This measure has a potential to save 12.8 GJ/hr of fuel with a payback period of 1 - 2 years [A study was conducted on 100,000 bls/day CDU in bu-sing Chilled water].
Progressive Crude Distillation [49] [PCD] (Technip, 2000)	The pre-heater and the distillation columns are redesigned to work at low pressure.	Resulted in annual energy savings up to 35 percent [Implemented in a refinery in Leuna, Germany]

[49] *It is an alternative to crude distillation columns to save the energy consumed*

Diving Wall Distillation [50] [DWD] (Schultz, Stewart, Harris, Rosenblum, Shakur, & O'Brien, 2002)	Two conventional distillation columns are integrated in one column to increase the heat transfer.	Resulted in an annual energy savings upto 30 percent and has lower capital costs compared to conventional columns [Implemented in BP Refinery in Veba Oel, Germany and SASOL refinery in South Africa].

The implementation of these measures has showcased the energy savings resulting in the annual savings.

Hydrogen Management & Recovery

Among many operations within refineries, hydro-processing capacity and the associated hydrogen network has limited refinery throughput and operating margins in many refineries. Along with the increased H_2 consumption for deeper hydro-treating, additional hydrogen is needed for processing heavier and higher Sulphur crude slates. Hydrogen consumption in the oil refining industry grew at a compound annual growth rate of four percent from 2000 to 2003 and had increased to up to 10 percent through to 2010 (Xebec, 2012) (Edmunds, 2012). The effective utilization of the hydrogen gas in refineries is paramount to improving the overall energy efficiency of the refinery operations.

[50] *It is an alternative to distillation columns which saves both the capital and energy costs*

Table 4.5: Techno-economic Analysis of Energy Efficiency Measures taken in Hydrogen Management and Recovery

Measure	Characteristics	Economic Impact
Hydrogen Integration (U.S. DOE-OIT, 2002a)	The hydrogen network is integrated and optimized to identify the best match for hydrogen between various hydrogen sources based on the quality of the streams and also to select the best and effective technology to purify Hydrogen.	Resulted in an annual savings of $4.5 million [Implemented in BP Refinery in Carson, California, USA].
Hydrogen Recovery (Zagoria & Huycke., 2003) (Shaver, Poffenbarger, & Groteworld., 1991) (Glazer, Schott, & Stapf, 1988)	Various technologies such as cryogenic distillation and membranes, pressure and thermal swing absorption etc. are used.	Improved the efficiency of the system and reduced the costs of hydrogen recovery which resulted in 50 percent cost savings of the costs of producing hydrogen [Implemented in Conoco Phillips refinery at Ponca City, Oklahoma, USA].
Hydrogen Production (Worrell & Blok., 1994) (Abrardo & Khuruna., 1995)	An adiabatic pre - reformer is being used to utilize the excess steam available at the plant to reform the hydrocarbon feed with an active nickel catalyst.	Reduced the energy consumption with an annual an annual energy savings of 4 percent and increased the product yield. This measure has recovered the investment in less than three years [Implemented in Kemira Oy ammonia Plant in Rozenberg, Netherlands].

Implementation of this measure has not only reduced the energy being consumed by the refinery with annual saving, but has also increased the product yield.

Energy Recovery

Another measure in increasing the energy efficiency, and thereby, reducing the energy consumption, is by recovering the energy that has been emitted after the processes or by the energy transmission losses.

Table 4.6: Techno-economic Analysis of Energy Efficiency Measures taken in Energy Recovery

Measure	Characteristics	Economic Impact
Flare Gas Recovery (Ezersky, 2002) (Fisher & Brennan., 2002) (U.S. DOE-OIT, 2002a)	Various recovery systems such as recovery compressors etc. are installed to achieve the objective of flare gas recovery. These recovered gases are then collected and stored for future use.	Increased the energy efficiency of the replacing fuel and reduced the pollutant emissions. The initial investment required for the project is not available, as this is a part of an overall energy efficiency project of the refinery. This overall project had $52 Million annual savings and the investment was recovered in two years. [Implemented in Chevron Texaco Refinery, Pascagoula, USA and Lion Oil Company in El Dorado, Arkanason, USA].
		Upgraded the turbo expanders resulting in an additional saving of 22 MW of Power [Implemented in Valero's

		Houston Refinery].
	Power recovery turbine or turbo expanders are used to recover energy in refineries. These equipments recovered the power from the pressure in the flue gas as various operations in refineries which run at elevated pressures. These measures are implemented in various processes such as FCC, Hydrocrackers etc.	A new efficient turbo expander was installed resulting in an additional savings of 19 PJ [18 trillion btu] of power per annum [Implemented in Petro Canada's Edmonton Refinery].
Power Recovery (Valero, 2003) (CADDET, 2003)		The power recovery turbine which was installed have produced about 7.3 Million KWh of power per annum and have recovered the investment [$1.2 Million] in two years and six months [Implemented in Total's Vlissingen Refinery].

The implementation of these measures not only reduced the energy consumption and increased the annual savings, but also reduced the emissions. Thereby, increasing the organization's energy image in the public on their environmental policies and its implementation.

Total Site Energy Monitoring and Management

Total site energy monitoring and its management plays an important role in reducing the energy consumed by the refining industry. In a refinery usually only one process is monitored; but, in this case, information from various separate but related processes are collected and monitored. Thereby the exchange of various energy streams between the processes increase. The processes that are being monitored in this, includes the FDU, CDU, boilers, co-generation units etc.

Table 4.7: Techno-economic Analysis of Energy Efficiency Measures taken at Total Site Energy Monitoring and its Management

Measure	Characteristics	Economic Impact
Monitoring & Control Systems (Martin, et al., 2000) (CADDET, 2000) (Caffall, 1995)	Optimized various operations carried out in the refinery which have reduced the time consumed to complete its desired task and increased the quality of the product.	Reduced energy consumption which resulted in an energy savings of eight percent and have recovered the investment in less than 2 years [Implemented in various industries in UK].
Refinery wide optimization (Aspen Technology, 2010) (Valero, 2003) (Timmons, Jackson, & White, 2000) (U.S. DOE-OIT, 2000)	Optimizes and integrates various intermediates in the refining processes along with the use of electricity, fuel, steam and hydrogen to an energy monitoring system.	Energy consumption is expected to reduce by 2 - 8 percent with an annual savings of $7 - $27 Million [Implemented in 12 Valero refineries in USA].
	Various control equipments are implemented for CDU unit optimization. In this the predictive control and optimization of linear programming of CDU for online quality control has also been included.	Reduced the energy consumption resulting in an energy savings of $0.05-$0.12 per barrel with a payback period of less than three months and an increased throughput by 6 - 7percent under ideal conditions. [Implemented in Petrogals Sines refinery (Portugal)].
	Fractional Distillation	Energy consumption was reduced resulting in an energy saving of $0.02-$0.4per barrel with a payback period of 6 - 18 months [Implemented in

	Unit [FDU] units are optimized by implementing various control equipments	CITGO refinery in Corpus Christi, Texas, USA and ENI refinery in Sannarrazzo, Italy]
	Multi-variable predictive control system [MPCS] software was implemented which integrated various data that had been collected from the pinch analysis, Chemical reactor analysis, the energy that has been consumed by the processes and the emissions of the refinery.	The output production was increased by one percent with the reduced consumption of electricity, steam, cooling water and chemicals by 4.4 percent, 2.2 percent, 4.9 percent and 5 - 6 percent respectively. The economic benefits are not available. [Implemented in Motivas Convent refinery in Louisiana, USA].

The implementation of this measure has optimized various operations in the refinery, and it not only has reduced the consumption of energy in the refinery but has also reduced the downtime, maintenance costs, processing time.

Motors

Motors are being generally used in the petroleum refining and are one of the major consumers of energy. Fans, pumps, compressors, etc., use the motors, and have a wide range of opportunity to save the energy.

Table 4.8: Techno-economic Analysis of Energy Efficiency Measures taken in Motors

Measure	Characteristics	Economic Impact
Correct sizing of Motors (Xenergy, 1998)	The over-sizing of the motors consumes more energy for its operations, hence in this measure the motors have to be sized as per the requirement.	Resulted in an energy savings of 1.2 percent of the total energy consumed by the motors.
Adjustable Speed Drives [ASD] / Variable Speed Drives [VSD] (Martin, et al., 2000)	Various control units are installed which adjusts the speed of the motors as per the requirement of load.	This measure has a payback period of a year & a month and the other economic parameters are not available.

Even though no much study has been conducted on the implementation of energy efficiency measures in refineries. Various studies conducted in other industries make it as an attractive opportunity to save the energy (CDA, 2001) (Xenergy, 1998) (LBNL, 1998)

Pumps

In a refinery, pump alone consume 59 percent of the total energy consumed with a savings potential of 20 percent (Xenergy, 1998). Studies have revealed that pumps are the best in reducing the energy consumed by implementing the energy efficiency measures (Hodgson & Walters, 2002).

The various measures that have been implemented in refineries are as follows:

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Table 4.9: Techno-economic Analysis of Energy Efficiency Measures taken in Pumps

Measure	Characteristics	Economic Impact
Operation and Maintenance of Pumps (Xenergy, 1998) (U.S. DOE-OIT, 2002b)	Ensured that the pumps and its various components are maintained properly and is operating at its peak performance.	Pumping electricity was saved in between 2 - 7 percent per annum and has increased the pump efficiency which in turn reduced the pump wear out and its related costs with a payback period of less than a year.
Correct Sizing of pumps (U.S. DOE-OIT, 1999)	The over sizing of the pumps consume more energy for their operations, hence in this measure the pumps has to be sized as per the requirement	Implementing this measure has reduced the energy consumption by 4.3 million KWh per annum [$215,000] with a payback period of 1.4 years for the investment of $300,000 [Implemented in Chevron Refinery in Richmond, California, USA].
Trimming the Impellers (HIE, 2001)	The impeller [diameter] was reduced so as to prevent the excessive flow resulting in pumps not developing much head.	Reduced the energy consumption by 26 percent with a payback of less than a month for the investment of $390. It also reduced the maintenance costs, excessive vibration and noise. [Implemented in Chemical Processing Industry in USA].

Remote control systems in pumps (CEC-OIT, 2002)	The remote control systems for pumps automatically shut off when the pumps are not required.	Reduced the energy consumption by 400,000 kWh with an annual energy savings of $32,000 and have recovered the investment in eleven months. It also increased the equipments [pumping systems] life and reduced the maintenance cost. [Cisco Systems in California, USA].
ASD (Martin, et al., 2000)	Various control units are installed which adjusts the speed of the pumps as per the requirement of load.	Reduced the energy consumption by 12 GWh per annum with the cost savings of $700,000 per annum [Implemented in Chevron Refinery in Richmond, California, USA].
Avoid throttling valves (Brueske, Smith, & Brasier, 2002) (Tutterow, 1999)	Throttling valves are avoided as this indicates that the pumps are oversized.	Resulted in an annual energy savings of $39,000 [Implemented in Flying J's North Salt Lake City refinery in Utah, USA].

The implementation of these measures not only reduced the energy consumption resulting in annual saving, but also reduced the maintenance costs, noise and increased the life of the pumps.

Compressors and Compressed Air

It is the most expensive form of energy being used in the refinery when considering its poor quality and higher operating costs. Hence, in a refinery so as to reduce the cost incurred for compressed air, the better opportunity is to use the minimum quantity of the energy for a shorter period of time with continuous monitoring.

Table 4.10: Techno-economic Analysis of Energy Efficiency Measures taken in Compressors

Measure	Characteristics	Economic Impact
Monitoring and maintenance (LBNL, 1998) (CADDET, 1997b)	The compressors are regularly monitored and maintained.	Increased the compressor efficiency and reduced the air leakage thereby leading to low operating temperatures which reduced the additional costs.
Leak detection and its repair (U.S. DOE-OIT, 2003b)	Leaks in the pipes and equipments are detected and repaired. In certain cases these compressed air systems are replaced too.	Resulted in energy savings of $20,700/annum and have recovered the investment [$23,000] in a year and a month. [Implemented in Mobil Distribution Facility in Vernon, California, USA].
ASD (Radgen & Blaustein, 2001)	Various control units are installed which adjusts the speed of the rotary compressor systems.	Reduced the compressed air energy consumption by 15 percent per annum.

The implementation of these measures has not only reduced the energy consumed, but has also increased the efficiency of the compressors being used by the refineries.

Comparative picture of energy efficiency measures

The above studies have shown that the utilities, fired heaters, process optimization, heat exchangers, motor and motor applications have a potential of saving energy if energy efficiency measures are implemented at 30 percent, 20 percent, 15 percent, 15 percent and 10 percent respectively (Dorgan, Way, Bryan, Huff, & Stewart, 2003). Out of which, the investments made in heat exchangers and fired heaters are less compared to other opportunities.

The above studies have showcased that the investments required for energy efficiency measures in a refinery are less but will change from refinery to refinery depending on the capacity and complexity. By implementing these measures the refineries has a potential in savings, ranging from a few dollars to millions of dollars per annum depending on the refinery's present efficiency, size and its complexity. These measures will also result in the co-benefits such as the reduction in emissions, maintenance costs, down time, processing time, etc.

The researcher has noticed that the above studies were based on individual energy efficiency measures and no integrated study was found for the energy efficiency measures implemented in a single refinery. Even these studies haven't mentioned the impact of behavioral measures being implemented, in terms of, cost and energy conserved. Hence, studies have to be conducted to understand the overall effectiveness of energy efficiency measures implemented in a single refinery as well as their impact on the industry.

Studies have pointed to the fact that the efficient use of energy could be the largest and most profitable way to reduce the costs (Jakob &

Madiener, 2004) (Jochem, 2000). The prior studies and literature prove that there is a huge techno-economic opportunity for the cost effective energy efficiency investments in the industrial sectors (Schipper, Meyers, Howarth, & Steiner, 1993) (Levine, Gadgil, Meyers, Sathanye, Stafurik, & Wilbanks, 1992) (Philips, 1991) (Levine & Meyers, 1991). The above studies have shown that the utilities, fired heaters, process optimization, heat exchangers, motor and motor applications have a potential of saving energy if energy efficiency measures are implemented at 30 percent, 20 percent, 15 percent, 15 percent and 10 percent respectively (Dorgan, Way, Bryan, Huff, & Stewart, 2003).

It was noticed from the above studies that the implementation of these measures have not only reduced the energy consumed by a refinery resulting in an annual saving, but also increased the efficiency of the processes with better product yield, and has also increased the production.

It was also noticed that investing in these measures can be much more attractive with the change in attitude and behavior of the employees, it's also noticed that the employees of the organization should be aware of the energy use and energy efficiency improvement objectives (Caffall, 1995). These studies have showcased that on the given available resources and technology there do exist quite a number of opportunities in the petroleum refining industry to reduce not only the energy consumed, but also to reduce the air pollutant emissions, maintenance costs, down time, processing time. As a result there is an increased in the annual energy cost savings with plant/process life while enhancing or maintaining the productivity.

Chapter 5

Research Design

Section 5.1: Introduction

Energy is important for better living conditions of mankind and for their development. It's an indisputable fact that it's the link to the challenges of sustainable development. (IAC, 2007) (IEA, 2004) (Johansson & Goldemberg, 2002). In 1992, the United Nations Conference on Environment and Development [UNCED], it came up with a framework for sustainable development, but the important role of energy in the perspective of sustainable energy was clearly addressed in 2002 during the World Summit for Sustainable Development [WSSD] (Bradbrook, Lyster, Ottinger, & Xi, 2005) (Goldemberg & Johansson, 2004). Considering, the importance of production and use of energy for the achievement of the human needs, significant connections were made between energy and water [environmental impact of hydropower], between energy and biodiversity [impact of climate change due to emission from energy], between energy and human health [impact of pollution due to inefficient energy technologies] which resulted in confirming several aspects of the plan of implementation on energy as an instrument in supporting the sustainable development beyond the energy policy arena (Goldemberg & Johansson, 2004). With the focus on implementation, the WSSD argues that the energy is important for the sustainability of economic, social and technological systems (UNDP; UNDESA; UNIDO; FAO; UNICEF, 2002).

Even though the energy plays a major role for mankind, the energy production and consumption patterns remain unstable (Bradbrook, Lyster, Ottinger, & Xi, 2005) (IEA, 2004) (Johansson & Goldemberg, 2002). It is to be noted that on daily basis, new scientific evidences are emerging on the ill effects of energy on the environment. Human induced climate change can be considered as the best example (Metz, B., Davidson, O.; Bosch, P.; Dave, R.; Meyer, L. (Eds.), 2007). The health of both the humans and the eco-systems are being threatened by the atmospheric pollution generated by fossil fuels (Johansson & Goldemberg, 2002) (Goldemberg & Johansson, 2004). Studies have shown that approximately two billion people in the world do not have access to any form of modern energy (Goldemberg & Johansson, 2004) (IEA, 2002). Due to rapid urbanization, socio-economic development and the need to attain self-reliance in different sectors of the economy, the energy consumption had increased from 4.16 quadrillion btu in 1980 to 12.8 quads in 2007 in India. Due to non-availability of sufficient domestic energy supply, India has to depend on importing the energy, up from 17.85% of TPCES in 1991, imports accounted for 30% of our TPCES in 2004-05 (IPC, 2006). The dependence of imported fuels makes many countries vulnerable to economic and social disturbances (IEA, 2002).

The energy efficiency has regained its momentum in the context of sustainable development (Metz, B., Davidson, O.; Bosch, P.; Dave, R.; Meyer, L. (Eds.), 2007) (Goldemberg & Johansson, 2004). During the past few years, we have seen a continuous rise in oil prices, increased awareness of energy security, growing energy related environmental problems, etc., which have contributed to the reassessment of society's energy consumption (Metz, B., Davidson, O.; Bosch, P.; Dave, R.; Meyer, L. (Eds.), 2007) (Goldemberg & Johansson, 2004) (Jochem, 2000). It has been proved that the increased energy efficiency benefits both the society and the environment. Various studies have quoted the advantages of increased energy efficiency, such as, reduction in atmospheric pollution, boosting up of industrial competitiveness, generation of employment and better business opportunities, enhancing the productivity, increasing the security of supply and contribute to poverty alleviation along with other aspects (IAC, 2007) (Levine, Metz, Davidson, Bosch, & Dave, 2007) (Jakob M. , 2006) (Jochem, 2000) (Leaman & Bordass, 1999) (Laponche, Jamet, Colombier, & Attali, 1997). Studies have shown that there is a potential of energy saving of 30%, 20%, 15%, 15% and 10% in the utilities, fired heaters, process optimization, heat exchangers, motor and motor applications (Dorgan, Way, Bryan, Huff, & Stewart, 2003). Hence, research on energy efficiency is paramount because of the role it can play in fostering a more sustainable energy future (IAC, 2007) (Levine, Metz, Davidson, Bosch, & Dave, 2007) (Goldemberg & Johansson, 2004) (Jochem, 2000).

Studies have pointed to the fact that the efficient use of energy could be the largest and most profitable way to reduce the costs (Jochem, Jakob et al.: 2004). The prior studies and literature prove that there is a huge techno economic opportunity for the cost effective energy efficiency investments in the industrial sectors (Dwivedi & Diwan, 2008) (Vaishampayan, 1995) (Schipper, Meyers, Howarth, & Steiner, 1993) (Levine, Gadgil, Meyers, Sathanye, Stafurik, & Wilbanks, 1992) (Philips, 1991) (Levine & Meyers, 1991). It is being noted that the major attraction of these studies included steel, fertilizer and cement industries (Dwivedi & Diwan, 2008) (Vaishampayan, 1995). It was also learnt that, studies were being carried out in meat processing and food industry but not in Indian refineries which are a capital and lucrative industry

Despite various advantages of energy efficiency on the social and environmental front, a number of barriers or the market failures have prevented the improvements in energy efficiency (Palm, 2009) (Schleich & Gruber, 2008) (Thollander & Ottossom, 2008) (Rohdin & Thollander, 2006a) (Rohdin, Thollander, & Solding, 2006b) (Ramirez, Patel, & Blok, 2005) (Dias, Mattos, & Balestiere, 2004) (de Groot, Verhoef, & Nijkamp, 2001) (Sorrell, et al., 2000) (DeCanio S. , 1998) (Weber, 1997) (Velthuijsen, 1995) (Sanstad & Howarth, 1994) (Jaffe & Stavins, 1994a) (Jaffe & Stavins, 1994b) (Jaffe & Stavins, 1994b) (Howarth & Andersson, 1993) (Stern, 1992) (Hirst & Brown, 1990) (Blumstein, Krieg, Schipper, & York, 1980). On the other hand various driving forces for energy efficiency have also been identified (Thollander & Ottossom, 2008) (Rohdin & Thollander, 2006a) (Rohdin, Thollander, & Solding, 2006b). Globally the current levels of energy efficiency, in converting the primary energy to useful energy, are estimated at not more than about 35% (Jochem, 2000)[51]. The so called energy efficiency barriers, or gap, is also used to describe the profitable efficient technologies that fail to achieve market success (Jaffe & Stavins, 1994a) (Jaffe & Stavins, 1994b). Some of the barriers that hinder the improvements in energy efficiencies are due to issues pertaining to information, high [implicit] discount rates, bounded rationality, principal agent problems, negative externalities not reflected in energy prices, high transaction costs, uncertainties about technical

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51 A common classification of energy efficiency potentials include: (i) theoretical potential, (ii) technical potential, (iii) techno-economic potential and, (iv) market potential. The theoretical potential refers to the minimum energy input required to keep a given energy service demand satisfied with due consideration to the laws of thermodynamics. Technical potential usually refers to what can be achieved by using the best available technologies at a certain point in time. Consequently, it represents energy savings that can be realized from the most efficient energy technologies regardless of cost considerations. The techno-economic potential refers to the technical potential but with due consideration to costs.

performance, lack of sufficient capital, investment risks, etc. (Palm, 2009) (Schleich & Gruber, 2008) (Thollander & Ottossom, 2008) (Rohdin & Thollander, 2006a) (Rohdin, Thollander, & Solding, 2006b) (Ramirez, Patel, & Blok, 2005) (Dias, Mattos, & Balestiere, 2004) (de Groot, Verhoef, & Nijkamp, 2001) (Sorrell, et al., 2000) (DeCanio S. , 1998) (Weber, 1997) (Velthuijsen, 1995) (Sanstad & Howarth, 1994) (Jaffe & Stavins, 1994a) (Jaffe & Stavins, 1994b) (Jaffe & Stavins, 1994b) (Howarth & Andersson, 1993) (Stern, 1992) (Hirst & Brown, 1990) (Blumstein, Krieg, Schipper, & York, 1980). It has to be noted that no such study was conducted on refineries to identify various barriers that hinder the improvements in energy efficiency and driving forces for the implementation of energy efficiency.

Section 5.2: Need for study

The demand for energy in India is expected to grow at an annual rate of six percent over the next 10 years with projected economic growth (IPC, 2006). It’s a significant challenge for India to find enough energy to satisfy this enhanced demand. To overcome a significant amount of this gap, caused by the combination of low levels of domestically available fossil fuels, low level of investment in energy sector and increased global competition, the best option available is to invest on energy efficiency measures (USAID, 2007).

Energy efficiency and its conservation have been the critical elements in the energy policy dialogue, and have taken importance due to the concerns of climate changes and energy security. Energy efficiency can be defined as the energy services provided per unit of energy input.

Studies have pointed to the fact that the efficient use of energy could be the largest and most profitable way to reduce the costs (Jakob & Madiener, 2004) (Jochem, 2000). The prior studies and literature prove that there is a huge techno-economic opportunity for the cost effective energy efficiency investments in the industrial sectors (Dwivedi & Diwan, 2008) (Schipper, Meyers, Howarth, & Steiner, 1993) (Levine, Gadgil, Meyers, Sathanye, Stafurik, & Wilbanks, 1992) (Philips, 1991) (Levine & Meyers, 1991). It is noted that the major attraction of these studies were steel, fertilizer and cement industries. It was also learnt that, studies were being carried out in meat processing and food industry, but not in the Indian refining industry, which is a capital and high cash-intensive industry.

The energy emissions in the oil refineries make energy efficiency an attractive opportunity to reduce emissions and operating costs. The governmental policies on energy efficiency have made Indian refineries a designated consumer, resulting in energy efficiency measures to improve competitiveness through increased energy efficiency and reduced environmental impact.

Studies have shown that the utilities, fired heaters, process optimization, heat exchangers, motor and motor applications have a potential of saving energy if energy efficiency measures are implemented at 30%, 20%, 15%, 15% and 10% respectively (Dorgan, Way, Bryan, Huff, & Stewart, 2003).

The researcher has searched various databases on the search criteria 'economic evaluation/impact of energy efficiency measures in Indian refineries'. It is to be noted that the researcher was not able to get any literature on the above said, but enough literature is available for technological/process improvements in the industry in energy efficiency in refineries, however no specific studies have been carried out for a specific refinery.

Business Problem

The refining industry today is facing huge losses due to the under recovery, and the best way reduce their losses is by reducing the cost. The major cost centers of the refinery are human resource costs, raw material costs and the energy costs, but the only option that is available with the refinery is to reduce the energy costs by demand side management. The energy conservation is the best opportunity available in demand side management. No study has been conducted to check the effectiveness of the measures implemented by these refineries. Hence, study has to be conducted to analyze the effectiveness of energy efficiency measures in Indian refineries.

Research Problem

Studies have to be conducted to find the energy efficiency measures that have been implemented in Indian refineries and how economically effective these measures are. Studies also have to be conducted to identify the barriers and the driving forces for the adoption of energy efficiency measures in Indian refineries.

Section 5.3: Research Objectives

The major objectives of the research are

- To study the energy efficiency measures being adopted by Indian refineries and to evaluate their economic effectiveness[52]
- To identify the barriers and the driving forces for the adoption of energy efficiency measures in Indian refineries

Section 5.4: Research Methodology

To achieve the first objective, the researcher used document analysis methodology. The researcher has identified the players in the Indian refining industry and empirical study was conducted for the study purpose for 10 years [2000 to 2010] [See Appendix A for the list of refineries].

The researcher considered the following parameters, such as, the crude processed and its value, energy consumed and its value, share of various energy sources in the energy mix[53] etc. During the data collection, the researcher has found out that the refineries are using more than one source of energy[54]. Hence, the researcher has standardized the measuring unit of all energies being used to a common measuring unit i.e., Kilo Calories [kcal], so as, to ensure uniformity [See Appendix B for the list of conversions].

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[52] *This study is limited to an overall effectiveness analysis of the measures implemented.*

[53&54] *In a refinery the energy mix usually constitutes Electricity [in kWh], Coal [in MT], Furnace Oil or Liquid fuel [in MT], FCC unit coke [in MT], DHDS Naphtha [in MT]* (BPCL, 2012).

Sources of Data: The researcher has used Centre for Monitoring Indian Economy [CMIE] prowess database to access the data for his study period of 2000 – 2010. To understand the energy efficiency measures being implemented in the Indian refineries, the researcher has studied the energy notes being published by the refineries in their annual reports.

Economic analytical tools being used: In terms of methods for data analysis, the researcher used various quantitative approaches such as energy consumption per unit of crude processed, incremental concept, cumulative concept, cost benefit analysis, cost effectiveness, energy utilization index and energy cost index.

In order to accomplish the second objective, the researcher used surveys with questionnaires. The researcher has identified the barriers to and the driving forces for adoption of energy efficiency measures in Indian refineries with the help of a questionnaire [See Appendix C for the Questionnaire].

Variable Identification: The review of various literatures (Palm, 2009) (Schleich & Gruber, 2008) (Thollander & Ottossom, 2008) (Rohdin & Thollander, 2006a) (Rohdin, Thollander, & Solding, 2006b) (Ramirez, Patel, & Blok, 2005) (Dias, Mattos, & Balestiere, 2004) (de Groot, Verhoef, & Nijkamp, 2001) (Sorrell, et al., 2000) (SPRU , 2000) (DeCanio S. , 1998) (Weber, 1997) (Velthuijsen, 1995) (Sanstad & Howarth, 1994) (Jaffe & Stavins, 1994a) (Jaffe & Stavins, 1994b) (Jaffe & Stavins, 1994b) (Howarth & Andersson, 1993) (Stern, 1992) (Hirst & Brown, 1990) (Blumstein, Krieg, Schipper, & York, 1980) coupled with interviews and group discussions identified 41 parameters that could hinder the implementation of energy efficiency measures in Indian refineries, and 31 parameters that act as driving forces on the implementation of energy efficiency measures in Indian refineries

Designing the Questionnaire: The reliability of the questionnaire was verified [using Chronbach Alpha] based on the responses received from the pilot study of a sample of 30 respondents comprising energy auditors, the employees of various refineries and academicians. This questionnaire was designed on a Likert scale ranging from one to five with five being strongly agree and one being strongly disagree.

Sampling: In this study, the questionnaires were sent to energy managers of all refineries in India, experts in the refining industry [people with a minimum of 20 years experience in middle level management], energy auditors, academicians, representatives from MoPNG [with a total of 6555 in numbers]. Stratified random sampling [strata: proportionate] for a sample size of 377 (Yamane, 1967) is being used.

Data Collection: Through online media the questionnaires were sent to 377 respondents but the response rate was only 51.45% [194 filled questionnaires], which compared to the similar studies is considered to be high (Rohdin, Thollander, & Solding, 2006b) (Velthuijsen, 1995) (Ramirez, Patel, & Blok, 2005). This data was further analyzed using the SPSS 16 software.

Statistical tools used: In order to identify the major barrier and driving forces for energy efficiency implementation, the researcher used factor analysis[55].

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[55] *As the parameters for the study are in large numbers of which some are correlated. These data have to be reduced to a manageable level for achieving the second objective. Hence, the researcher has used factor analysi.s*

Section 5.5: Limitations of the study

The limitations of the study are:

- The study could only focus on the technical measures because of non-availability of data on behavioral and structural measures in the annual reports.
- Due to the non-availability of continuous data, the researcher hasn't considered MRPL for the study purpose.
- Due to unavailability of continuous data, the researcher could not carry out the cost benefit analysis of energy efficiency measures of all Indian refining companies except IOCL.

Section 5.6: Further Scope of study

The further scope of this study is as follows

- Further study can be done to identify the ancillary revenue being generated by the implementation of these measures, and also the impact of them on various environmental factors.
- The economic and financial effectiveness of load management, fuel substitution and load building can be studied in terms of demand side management.
- The economic and financial effectiveness of structural and behavioral measures implemented in a refinery can also be studied further.
- The impact of each barrier to the energy efficiency implementation in Indian refineries can be studied further

Chapter 6

Analysis & Findings

The petroleum refining industry is considered to be one among the largest consumers of all forms of energy, and its consumption varies from refinery to refinery depending on the type of crude being processed, the quantity of impurities present, the complexity of the refinery etc. Out of the whole refinery operations only a few processes are the major energy consumers related. These processes include the distillation processes, hydro-treating, cracking, reforming etc. Over the last few years, the refinery fuel use and their losses have increased, as the refinery output has expanded, and new units have been brought on line (Sathaye, Price, Can, & Fridley, 2005). Studies have proved the existence of considerable potential for energy efficiency improvement in the refining industry (Worrell & Galitsky, 2005).

The study of refineries is for the decade from 2000 to 2010 and it covers eight companies in each year. For the study purpose, the researcher has studied seven companies, i.e., IOCL, RIL, BPCL, HPCL, MRPL, CPCL and NRL[56].

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[56] *Due to the inconsistent data availability of Essar Oil Limited, Researcher has not considered Essar oil for the study purpose.*

Section 6.1: The Energy Efficiency Measures being adopted by Indian Refineries

During the study period of 2000 to 2010, the various refineries in India have implemented various energy efficiency measures. These measures being implemented in these refineries were both in terms of improvement/continuous maintenance in operations as well as the development of new projects. Some of the measures being implemented by these refineries are being mentioned in succeeding paragraphs[57].

Bharat Petroleum Corporation Limited

During the study period of 2000 to 2010, BPCL's continuous efforts were to implement energy efficiency measures, both in terms of improvement/continuous maintenance in operations as well as the development of new projects. During this said period, BPCL has not only implemented various measures, but has also implemented a system using sophisticated instruments and data acquisition instruments which continuously monitor the fuel consumption and hydrocarbon losses in various refineries of BPCL. BPCL has also introduced an Energy Accounting System [EAS] and Management Information System [MIS] for better implementation of energy efficiency in Indian refineries.

The measures being implemented by the BPCL refineries during the study period are as follows:

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[57] *The researcher identified various measures being implemented by the refineries in India by studying the energy notes being appendixes to the respective annual reports of the studied refineries.*

2000 – 2001

BPCL has adopted the following energy efficiency measures during 2000 – 2001 and they are as follows (BPCL, 2001):

- Commissioned a 3rd high efficiency Utility Boiler [UB]
- Provided and sustained operation of sonic soot blowers in the APH of crude/vacuum distillation furnaces
- Installed and sustained operation of six numbers of Fiber Reinforced Plastic [FRP] Blades for fans in air fin coolers of CDU.
- Provided an auto tank gauging system for crude oil tanks.

2001 – 2002

During the year 2001 – 2002, the following measures were implemented by BPCL in their refineries and they are as follows (BPCL, 2002):

- Converted two fixed roof tanks to fixed cum internal floating roof type of light hydrocarbon service
- Installed secondary vapor seals in ten floating roof tanks on light hydrocarbon service.

2002 – 2003

The various measures being implemented by BPCL refineries during the study period of 2002-2003 are as follows (BPCL, 2003):

- Converted one fixed roof tanks to fixed-cum-internal floating roof type of light hydrocarbon service

- Installed secondary vapor seals in seven floating roof tanks on light hydrocarbon service.
- Provided FRP blades for eighteen air fin cooler fans in the Heavy Crude Unit [HCU].

2003 – 2004

During the period of 2003-2004, BPCL refineries have implemented various energy efficiency measures and these are as follows (BPCL, 2004):

- Replaced Leaky APH tubes in the Reformer Feed Unit [RFU] RFU-101 furnace during shutdown, enabling furnace operation on FD mode.
- Provided FRP blades for 11 air fin cooler fans in aromatic / Fluid Catalytic Cracking Unit [FCCU] units.
- Installed secondary vapour seals in three floating roof tanks on light hydrocarbon & crude oil service.
- Replaced 200 gate valves in steam & condensate lines with glandless piston valves to reduce steam leaks.
- Diverted unstabilised naphtha ex Diesel Hydro-Desulphurization [DHDS] to MS rundown instead of slop tanks.

2004 – 2005

The various energy efficiency measures being implemented by BPCL refineries during the year 2004 – 2005 are as follows (BPCL, 2005):

- Commissioned highly energy efficient integrated Crude/Vacuum Unit [CVU].
- Provided 25 FRP blades in lieu of existing aluminum blades in air-fin coolers in the Catalytic Cracking Unit [CCU] and High Vacuum Unit [HVU].
- De-coking of furnaces in the HCU and HVU using modern pigging techniques and cleaning of convection coils.
- Replaced leaking steam traps.
- Procured and used air operated diaphragm pumps for the removal of residual oil from crude oil tanks before handing over for maintenance jobs.

2005 – 2006

During the year 2005 – 2006, BPCL has implemented the following measures in their refineries both in Mumbai and Kochi which are as follows (BPCL, 2006):

- Commissioned new hydrogen, sulphur recovery & hydrocracker units with all modern highly energy efficient equipments.
- Anti-foulant chemicals were injected in pre-heat exchanger trains of the CVU to sustain pre-heat temperatures.
- Cleaned convection coils and decoking of two furnaces in the crude distillation complex using modern pigging techniques.
- Applied special insulating paint for open man-ways in CDU & Feed Preparation Units [FPU].
- Diverted Plant gas ex FPU to FPU Furnace.

- Commissioned High Compressible Pressure [HCP] plant gas system for reducing flaring.
- Undertaken steam insulation and steam leak surveys.
- Replaced insulation for various steam headers.
- Provided still-well sleeve assembly with one of the MS tanks on a trial basis.
- Replaced gland packing with mechanical seal in 2 pumps in the CCU.
- Friction reducing coating was applied Aromatic Recovery Unit [ARU] cooling water pumps for improvement in efficiency.
- De-coking of FPU vacuum heater.
- Installed plant fuel tank 190.
- Conducted insulation survey and replaced the damaged portions with new insulation.
- Replaced mineral wool insulation with more efficient Perlite insulation.
- Conducted surveys on hydrocarbon leak and relief valve passing, and attended to the leaks and repaired the faulty relief valves.
- Replaced leaky steam traps & attended to steam leaks.
- Repaired damaged APH of vacuum heater.
- Repaired air registers, dampers in heaters/boilers.
- Converted single seal arrangement to double seal arrangement in floating roof tanks in a phased manner.

2006 – 2007

Various measures being implemented by BPCL during the year 2006 – 2007 are as follows (BPCL, 2007):

- Installed highly energy efficient integrated CVU.
- Anti-foulant chemicals were injected in all CVU.
- Applied high emissivity ceramic coatings on tubes & refractory of HVU Heater.
- Injected fire side chemical additive in HVU Heater.
- Implemented various recommendations of audit of steam and the condensate recovery system at FCCU and HVU.
- Converted five lightly loaded motors from delta connection to star connection.
- Replaced 115 old tube lights by efficient T-5 tube lights.
- Provided 83 energy saving Compact Fluorescent Lamps [CFL] for emergency lighting.
- Compressors of Air Conditioning [AC] system of administration building were cleaned
- Applied special insulating paint for open manuals in CVU and CCU.
- Reduced the generation of slops by tighter operational control.
- Reduced the Hydrogen loss to flare from Make-Up Gas compressor [MGC] section of the hydrocracker unit by the resetting of set point of control valve.
- Installed rotary disc skimmer for oil recovery.
- Provided still well sleeve assembly for three MS & naphtha tanks to reduce evaporation losses.
- Water washed & cleaned of vacuum unit aph.
- Regular steam insulation & steam leak surveys and repairs were conducted.

- Applied friction reducing coating in cooling water pumps in the ARU, which resulted in an improvement of 12% in pump efficiency.
- Condensate recovery from Vaccum Residue [VR]/plant fuel tank farm.
- Improved the efficiency of Steam Turbo Generator [STG] by increasing Low Pressure [LP] steam extraction from STG

2007 – 2008

During the year 2007 – 2008, BPCL have implemented the following measures in their refineries both in Mumbai and Kochi, which are as follows (BPCL, 2008):

- Effective capacity utilization in modern highly energy efficient Integrated CVU.
- Anti-foulant chemical was injected in all CVU.
- Fireside chemical additives were injected in HVU Heater.
- The high emissivity ceramic coating was applied in process tubes and refractory walls of crude reformer unit Inter 1 & 2 furnaces
- Reduced the generation of slops by tighter operational control.
- Reduced the Hydrogen loss to flare from MGC section of the hydrocracker unit by resetting of set point of control valve.
- Remote Gas Calibrator [RGC] seal gas drain pot vent was modified from flare to RGC suction in hydrocracker resulting in a reduction of 2 tons/day of hydrogen to flare.

- Provided still well sleeve assembly for 15 MS & naphtha tanks to reduce evaporation losses.
- Regular steam insulation & steam leak surveys and repairs were conducted.
- Reduced condensation in STG by increasing LP steam extraction.
- Optimized Gas Turbines [GTB] / STG operation based on marginal cost advantage.
- Reduced amine re-boiler steam consumption in DHDS - amine regeneration unit by maintaining higher amine concentration.
- Optimized power consumption in UB drives and auxiliaries.
- Optimized the de-aerator systems for boilers.
- Stopped the highest energy consuming UB 3 and boiler feed water pump turbine UB1.
- Steam optimization was achieved in Main Air Blower [MAB] compressor using advanced control.
- Reduced purge gas flaring in hydrogen unit.
- Maximized the crude circulating refluxes for increasing crude pre-heat.
- Improved heat recovery in High Vacuum Gas Oil [HVGO] heater.
- Optimized the pre-heat temperature in FCCU.
- Operating the recycle gas compressor in LP extraction mode.

2008 – 2009

BPCL has adopted the following energy efficiency measures during 2000 – 2001 and are as follows (BPCL, 2009):

- Effective capacity utilization in modern highly energy efficient Integrated CVU.
- Anti-foulant chemical was injected in all CVU.
- Fireside chemical additives were injected in HVU Heater.
- High emissivity ceramic coating were applied to process heater tubes and refractory walls of the new CVU furnaces [F 101 & 102] during the March 2009 shutdown, to improve furnace efficiency.
- Insulated bare hot tubes of the Net Hepatic Glucose Uptake [NHGU] furnace with special type insulation.
- Air fin coolers in the new Crude Unit complex and C3-C4 Unit were cleaned using foam / chemicals to improve performance.
- "Chemical decontamination" technique was adopted for the first time in the refinery during the turn-around. This helped to improve heat exchanger cleaning and better hydrocarbon freeing for carrying out plant turn-around jobs.
- Replaced two modules of APH in the CDU 1 B2 furnace for improved heat recovery.
- Installed Step-less control in MGC of the hydrocracker unit to reduce power consumption.
- Processed hydrogen rich CRU off gas in the hydrocracker unit, Pressure Swing Adsorption [PSA] system and new

hydrogen unit to reduce overall naphtha consumption for hydrogen generation.

- A comprehensive survey on "Instrument air supply system" was carried out to identify and rectify instrument air leaks.
- To improve efficiency "dry ice blast" cleaning of the convection section of heaters was conducted.
- Stopped one fuel oil turbine at boiler house – for saving in steam consumption.
- Used energy saving CFL lamps.
- Energy saving device/ toroidal core transformers for energy saving in lighting circuits was used.
- Converted motors from delta to star motor windings for power saving.
- Installed capacitor banks to maximize the power factor.
- Replaced GTB 2 rotor and accessories for fuel saving and eliminated hot gas path inspection.
- Replaced high efficiency boiler-2 FD fan with variable frequency drive.
- Reduced hydrocarbon slops by tighter operational control.
- Converted metallic blades to FRP blades for 25 air fin fans.
- Optimized the excess air in UB 10 & UB 7 Steam generators through an automatic air fuel ratio based combustion control scheme.
- Replaced naphtha stabilizer reboiler with a steam reboiler.
- Replaced mineral wool insulation by perlite.
- Provided LP steam air heater ahead of cast APH in the Crude heater to mitigate cold end corrosion and reduce the downtime of APH.
- Removed overhead column compressor in the CDU-1 by routing overhead gas directly to heaters after amine wash.

- Swapped MP steam with LP steam for product strippers in FCCU & CDU1.
- Waste heats were recovered through steam generation in Biturox unit.

2009 – 2010

During the year 2009 – 2010, BPCL implemented the following measures in their refineries both in Mumbai and Kochi, which are as follows (BPCL, 2010):

- The high emissivity ceramic coating was applied to process heater tubes and refractory walls of the new CVU furnaces (F 101 & 102) to achieve better heat absorption in the radiant section and fuel saving.
- Special type insulation was installed on bare hot tubes of the NHGU furnace.
- To improve performance of air fin coolers in the new Crude Unit complex was cleaned using Foam / chemical.
- “Chemical decontamination” technique was adopted for the first time in the refinery during the turnaround. This helps in improved heat exchanger cleaning and better decontamination for carrying out plant jobs.
- Replaced APH in CDU 2 furnace for improved heat recovery.
- Installed Step-less control in the MGC of the Hydrocracker Unit to reduce power consumption.
- Modified Lube Oil Base [LOB] plant to warm up feed pump – fuel saving by reducing furnace load.

- Processed the hydrogen rich CRU off gas in the hydrocracker unit, PSA system and the new hydrogen unit to reduce overall naphtha consumption for hydrogen generation.
- To improve efficiency "dry ice blast" cleaning of the convection section of heaters were conducted.
- Stopped Naphtha fuel pumps in Captive Power Plant [CPP] –LNG replacing Naphtha fuel in GTB.
- HVU heater process tubes were cleaned using chemicals to improve heat absorption.
- Impellers of VDU pump were trimmed for power saving.
- Used energy saving CFL lamps.
- Energy saving device/toroidal core transformers were used for energy saving in lighting circuits.
- Capacitor banks were installed to maximize power factor
- Effective capacity utilization in modern highly energy efficient integrated CVU.
- Anti-foulant chemicals were injected in all CVU's.
- Fireside chemical additives were injected in HVU Heater.
- Slops were reduced by tighter operational control.
- Commissioned High Pressure [HP] to Medium Pressure [MP] steam turbine for cooling water pump in DHDS.
- LP steam was extracted from a recycle gas compressor in DHDS.
- Di-ethanolamine [DEA] flow was optimized in fuel gas Amine Absorption Unit.
- Automatic combustion control was installed for DHDS charge heater.
- FRP blades were provided for air-fin fans in crude unit.
- One feed water pump of boiler UB8/9 was stopped.

The impact of implementation of these measures in BPCL refineries both in the industry as well as in the Indian refining industry as a whole have been discussed in Section 6.2 below.

Chennai Petroleum Corporation Limited

After analyzing the annual reports of CPCL, since 2000 to 2007, no data on the measures implemented by the refinery is mentioned in the energy notes in the annual report of that year, which could be either because no measures were implemented in the refinery or because they could have overlooked the matter, and missed mentioning the same (CPCL, 2007) (CPCL, 2006) (CPCL, 2005) (CPCL, 2004) (CPCL, 2003) (CPCL, 2002) (CPCL, 2001). Various energy efficiency measures being implemented by the refinery during the period 2007 to 2010 are as follows:

2007 - 2008

During the year 2007-08, CPCL had only implemented various energy efficiency measures in terms of improvement/continuous maintenance in their operations. These are as follows (CPCL, 2008):

- Changed the double pump operations of boiler feed water service to single pump operation
- Cogen boilers consumed the surplus fuel gas generated from Visbreaking Unit [VBU].
- The de-aerator pressure in GTB & Heat Recovery Steam Generators [HRSG] was reduced.
- Steam to feed ratio was optimized to 4.7 from 5.0 in hydrocracker unit

2008 - 2009

During the year 2008-09, CPCL has only implemented various energy efficiency measures in terms of improvement/continuous maintenance in their operations which are as follows (CPCL, 2009):

- Boilers utilized the surplus fuel gas of Refinery III.
- Increased the reliability of the refinery by single pump operations.
- Reduced the stack temperature by increasing the heat recovery of economizer in UB IV.
- Shutdown of low efficiency UB 3.
- Installed a magnetic resonator in GTB-2 for reducing furnace oil consumption.
- Inter-connection of fuel gas in refinery iii and refinery i & ii for optimum utilization.

2009 - 2010

During the year 2009-10, CPCL implemented various energy efficiency measures, both in terms of improvement/continuous maintenance in their operations as well as the development of new projects which are as under (CPCL, 2010):

- Installed a step less controller in Once-Through Hydrocracker Unit [OHCU] & MGC compressor to reduce load on the compressor motors
- Conversion of LPG firing to Fuel gas firing in Pt 78 Sulphur Recovery Unit [SRU] incinerator.

- Optimization of Fuel gas consumption by inter-connection of Ref III and Ref I and II fuel gas headers.
- Modification of Out Board Steam Generator [OBSG] in Pt. 206 for reduction of stack temperature and increasing steam generation.
- Conversion of DEA to Methyl Di-ethanolamine [MDEA] in Pt. 209
- Optimization of crude II pre-heat and reduction of excess oxygen in heaters

The impact of implementation of these measures in CPCL refineries, both in the industry as well as in the Indian refining industry as a whole, has been discussed in Section 6.2 below.

Hindustan Petroleum Corporation Limited

During the study period of 2000 to 2010, HPCL's continuous efforts were to implement energy efficiency measures, both in terms of improvement/continuous maintenance in operations as well as the development of new projects. No data on the measures implemented by the refinery during the year 2001 - 2002 is mentioned in the energy notes in the annual report of that year, which could be either because no measure had been implemented in the refinery or because they might have overlooked the matter, and missed mentioning the same. Various energy efficiency measures were introduced in the refineries of HPCL. The same are mentioned below:

2000 – 2001

The various measures implemented by HPCL refineries during the period of 2000 – 2001 are as follows (HPCL, 2001):

- The steam network efficiency study was conducted during March-June, 2000. Various recommendations of the study have been successfully implemented.
- The refinery had maximized captive electricity generation after commissioning of Gas Turbine Generator [GTG] GTG-V, thereby shifting maintenance, startup and shutdown load to own CPP. The maximization of electricity generation from CPP resulted in an additional steam generation from the waste heat, thus reducing steam generation from conventional boilers.
- Modifications were done in lubes refinery where Vacuum Pipe Still Tower Trays [VPSTT] have helped in bringing about more efficient fractionation at lower furnace heat duty.
- Sonic Soot Blower was installed in the FR Boiler House which uses the kinetic energy of sound waves to clean boiler tubes.
- Two Glass Reinforced Plastic [GRP] blade fans in the FR cooling tower replaced with energy efficient FRP blade fans.
- Use of Fuel Efficiency Monitors [FEM] and Online Oxygen Analyzers [OOA] have helped in improving furnace and boiler efficiencies

- Use of advanced hydrocarbon loss monitoring instruments for estimation of gas losses through relief valves and for estimation of fugitive losses.
- Under Operations Maintenance & Storage [OM&S] automation project, a special planning software package was commissioned to minimize hydrocarbon loss. Also commissioning of tank gauging system is in progress to minimize hydrocarbon loss.
- A floating drum skimmer for oil recovery was purchased and commissioned.
- New Flare System with Closed Circuit Television [CCTV] had been provided for constant monitoring of Flare to reduce hydrocarbon losses.
- Four flare gas meters were installed at new flare stack and battery limits of new process units to monitor flare gas flow.
- Periodic steam leak surveys were conducted and measures were taken to arrest the leaks.
- Several operational measures were undertaken to reduce the energy consumption. monitoring and regular checking of furnace and boiler efficiencies, using portable FEM, steam balances, flaring losses, APH and soot blower service factors, fuel consumption for power generation, etc., were undertaken and necessary corrective actions taken for reducing the energy consumption.

2002 – 2003

Various energy efficiency measures, implemented by HPCL during the year 2002 – 2003, are as follows (HPCL, 2003):

- A periodic performance survey of steam traps was conducted, using sophisticated ‘trapman’ for taking immediate corrective measures, which resulted in reduction of steam loss.
- Periodic monitoring of furnace and boiler efficiencies with the help of FEM and OOA.
- Replaced thermodynamic steam traps with balance pressure steam traps in tracer lines.
- A fugitive emission survey was conducted in the refinery by Gas Measuring Instrument [GMI], gas-surveyor & corrective action for reduction in hydrocarbon loss.
- Safety valves / control valves survey was conducted by V-pack to control hydrocarbon loss.
- GTG load was optimized by running 4 GTGs instead of 5 GTGs to reduce fuel consumption.
- Steam load in the boilers was optimized to reduce fuel consumption.
- Quarterly steam leak survey and timely corrective action for reduction of steam leaks were conducted.
- A preliminary study was carried out on Condensate recovery in Fuels Refinery.
- Hydrocarbon loss monitoring instruments VPAC[58]- 5131 tested for estimation of gas losses through relief valves and GMI Gas surveyor, for estimation of fugitive losses for their proper functioning. Pressure safety valves survey carried out in FCCU-I, FCCU-II, DHDS, Propelene Recovery Unit [PRU] and CDUs

[58] *It is a patented instrument which is used to estimate the through-valve gas leakage.*

- UB in FCCU-I was commissioned to reduce fuel consumption
- Planning software package commissioned under OM&S automation project. Commissioned tank gauging system to minimize apparent hydrocarbon loss and to improve accountability
- New flare system with CCTV provided for reducing hydrocarbon loss and to control flaring
- Four flare meters installed at new flare stack and battery limits of new process units for continuous monitoring in order to reduce hydrocarbon loss
- Regular monitoring of furnace & boiler efficiencies, steam balance, flare loss, APH and soot blower service factors and fuel consumption for power generation
- Project for oil recovery from sludge was initiated
- Compressed air system audit carried out to identify areas of energy conservation in the system.

2003 – 2004

During the year 2003 – 2004, HPCL implemented the following measures (HPCL, 2004):

- GTG loads and steam load in UB were optimized
- Steam leak survey and timely corrective actions were taken
- Periodic monitoring of furnace and boiler efficiencies with the help of fuel efficiency monitors, and online oxygen analyzers were conducted.

- A periodic performance survey was conducted at steam traps, using sophisticated 'trapman' for taking immediate corrective measures
- A fugitive emission survey was conducted by GMI, gas-surveyor & correction action
- Efficiency survey of the furnace / boiler was conducted by the CHT nominated team
- A refinery hydrocarbon loss study was carried out and recommendations are being reviewed and implemented.
- Motivational/mass awareness activities were conducted
- Regular monitoring of furnace & boiler efficiencies, steam balance, flare losses, APH and soot blower service factors, fuel consumption for power generation etc. were carried out.
- Periodic steam leak surveys were conducted and necessary measures taken to arrest the leaks.

2004 – 2005

Various measures implemented by the HPCL refineries during the year 2004 – 2005, are as follows (HPCL, 2005):

- Optimized GTG load and reduced specific energy consumption from 0.373 to 0.365 [Kg of fuel per unit power generation in CPP].
- Installed secondary seals in 18 numbers of floating roof storage tanks to reduce tank emission losses.
- Replaced FR-CDU / VDU / FRE-CDU rotary APH with stationery APH to improve the furnace efficiency by about 4%.

- Converted FRE and LR -VDU natural draft furnaces to balance draft furnaces for efficiency improvement by 9 %.
- Recovered LR units' condensate [24 Tons/hr] for usage in CPP as boiler feed water.
- Optimized FR/FRE unit's crude pre-heat exchangers network to improve the pre-heat temperature by 20 Degree Celcius.
- Firing of FR vacuum column off gas [low calorific value] in heaters.
- Ceramic coating was done in SEU-II furnace and hydrogen reformer to improve the thermal efficiency
- Carried out comprehensive refinery's compressed air survey by engaging an external agency. The performance of all refinery compressors was studied in detail and survey identified 3000 Nm^3/h air leaks in the compressed air system. Identified air leaks arrested and spared one compressor operation.
- The steam leaks joint survey was carried out by CHT nominated team

2005 – 2006

During the year 2005 – 2006, HPCL introduced various energy efficiency measures and they are as follows (HPCL, 2006):

- Replaced CDU & VDU rotary APH with stationery APH which improved the furnace efficiency.
- Modified / replaced steam traps of dehydrator & SEU-III fuel oil system.

- Applied the state of the art ceramic coating in the radiation section of SEU-II & Hydrogen Generation Unit [HGU] reformer, which improved furnace efficiency.
- Routed DHDS sweet gas to fuel gas header and reduced flare loss.
- Implemented partly zero steam leak module for minimizing the steam leak through steam traps and achieved steam saving
- Proposals developed to install secondary seals in 18 nos. of floating roof storage tanks to reduce tank emission losses.
- Schemes developed to convert FRE & LR –VDU natural draft furnace to balance draft.
- A proposal developed to generate approximately 6 tons/hr low pressure flash steam from light ends unit condensate.
- Planned to rout CDU-I & II vacuum column off gas to respective CDU furnaces.
- Commissioned CDU-I condensate recovery system
- Carried out comprehensive refinery's air leak survey by engaging an external agency.
- It planned to route CDU-I and II hot-well off gas to respective furnaces
- Initiatives undertaken to reduce CPP specific Fuel consumption from 0.39 units to 0.38 units
- A proposal developed to recover CDU-II and FCC-II condensate
- A furnace efficiency joint survey was carried out by CHT nominated team
- Implemented condensate recovery from steam traps in CDU-I and achieved estimated recovery of 2 Tons / hr.

2006 – 2007

During the year 2006 – 2007, HPCL implemented the following energy efficiency measures (HPCL, 2007):

- Improved heaters / boilers efficiency from 86.5% to 87.2% by periodic surveys, cleaning & decoking of the tubes.
- Improved condensate recovery by replacing steam traps with efficient steam traps and cleaning of Naphtha stabilizer re-boiler.
- Repaired / replaced primary & secondary seals of six floating roof storage tanks to reduce emission losses.
- Improved CDU / VDU heater's efficiency by on-line chemical cleaning.
- Techno-economic study of GTGs is being conducted by National Thermal Power Corporation [NTPC] to evaluate and reduce energy consumption and power generation cost.
- Carried out the study of LNG firing in heaters / boilers based upon economic consideration / environmental norms and proposal is being developed accordingly.
- A steam leak survey was carried out by CHT nominated team
- Proposal developed to replace FRE-CDU rotary APH with stationery APH to improve the furnace efficiency and pre-heat augmentation.
- Schemes developed to convert FRE & LR–VDU natural draft furnace to energy efficient balance draft furnace.
- A proposal developed to generate low pressure flash steam from light ends unit condensate.

- Initiatives undertaken to optimize FR / FRE crude exchangers pre-heat to improve the crude pre-heat temperature.
- Planned to route CDU-I & II vacuum column off gas to respective CDU furnaces.
- Conducted comprehensive energy audit / hydrogen loss survey during the year and recommendations were implemented.
- Reduced steam leaks by installing 21 steam traps on Copper tracing lines.
- Conducted training program on Energy conservation along with the National Productivity Council [NPC], Chennai to create the awareness.
- Improved CDU / VDU heater efficiency by on-line furnace tube chemical cleaning.
- A steam leak survey was carried out by CHT nominated team
- Initiated steam purity study for improving turbine steam quality.

2007 – 2008

During the year 2007 – 2008, HPCL implemented the following energy efficiency measures which are as follows (HPCL, 2008b):

- Carried out on-line chemical cleaning of FRE-CDU/VDU and LR-VDU heaters by M/s GTC technology
- Installations of secondary seals on two numbers floating roof naphtha / MS tanks to reduce the tank emission.

- Carried out a compressed air leak survey and implemented the recommendation
- Developed in-house economical schemes for firing the gas in the furnaces / boilers. Signed the Gas Transmission Agreement [GTA] with Gas Authority of India Limited [GAIL] to use the gas network.
- Implemented generation of low pressure flash steam from high pressure condensate in Light ends Units.
- Provided Pressure Relief Devices [PRDS] system in the Light End Unit to optimize the steam consumption in de-pentaniser and de-haxaniser and two number de-super-heaters for naphtha stabilizers.
- Installed de-super heater to reduce the steam temperature of MP steam header by quenching the boiler feed water at Lube units which will produce the additional steam.
- Proposal developed to increase SEU-I furnace [F-202] by installing two additional exchangers.
- Improved Diesel Unifying Unit [DUU] furnace pre-heat by installing the additional heat exchanger in raw diesel pre-heat circuit
- Carried out frequent steam leak surveys
- Carried out air leak survey and reduced air leaks considerably.
- Routed hot well off gas to atmospheric furnace in CDU-II
- Carried out in-situ chemical processing of high oily crude sludge of tank to recover oil.
- Carried out on-line chemical cleaning of atmospheric & vacuum furnaces

- Conducted a training program on energy conservation along with NPC to create the awareness among employees and their families.
- Carried out a joint oil conservation survey for “furnace / boiler insulation effectiveness” & “furnace / boiler efficiency”.

2008 – 2009

During the year 2008 – 2009, the following energy efficiency measures were implemented in various refineries of HPCL (HPCL, 2009):

- Extended ceramic coating to FR / FRE & LR -VDU furnaces.
- Reduced specific energy consumption by generating more power from CPP.
- Reduced tank emission by installing secondary seals on one floating roof naphtha tank.
- Developed & commissioned in-house light ends unit condensate recovery system for generation of LP steam.
- Carried out a compressed air leak survey and reduced the air leak by repairs.
- Reduced average steam leak by attending to the steam leaks in a planned manner.
- Signed GTA with GAIL to use the gas network for using the Gas in the process units.
- Routed CDU-I hot well off gas to Atmospheric Furnace
- Continued online chemical cleaning of CDU / VDU Furnaces to sustain optimum crude throughput as well as fuel saving.

- Maximized hot feed to FCCU-II
- Carried out hydrokinetic decoking of CDU-I furnaces instead of steam-air de-coking, which saved steam / fuel considerably.

2009 – 2010

HPCL refineries implemented various energy efficiency measures during the period of 2009 – 2010 and they are as follows (HPCL, 2010):

- Started receiving Re-liquefied Natural Gas [RLNG] through GAIL receiving station/ pipeline as a result of which all GTGs and other furnaces were switched to gas. This has helped in reduction of emission levels and saving of internal fuel cost of Refinery.
- Achieved 100% gas firing in GTG's.
- Carried out online chemical cleaning of furnaces to bring down the Bridge Wall Temperature [BWT], stack temperature and to improve furnace efficiency.
- Improved DHDS furnace pre-heat temperature by installing the additional exchanger in raw diesel pre-heat circuit.
- Commissioned Propane Gas Recovery [PGR] system in lube refinery, first stage [wax recovery circuit] by in house modification.
- Carried out leak detection survey for fugitive emission benchmarking in refinery process units. Leaks were identified and attended.
- Carried out periodic steam leak/steam trap survey during the year by engaging external agency using an ultrasonic

detector and visual methods. These identified leaks were arrested.

- Carried out a compressed air leak survey by appointing external agency by using ultrasonic detector. These identified leaks were arrested.
- Carried out online furnace cleaning by using solid spray, resulting in reduced stack temperatures and increased heater efficiencies.
- Commissioned new boiler FD fan turbine to motor auto cut in facility for continuous running of turbine in place of motor, thereby avoiding venting of turbine steam.
- Commissioned d-emulsifier injection facility to the crude receipt line to reduce sediment to crude feeding units.
- Commissioned Anti-foulant chemical injection facilities to the SR pre-heat exchanger in CDU-3 to reduce fouling of exchangers.
- Identified fouled pre-heat exchangers by the heat 4N software and cleaning was carried out for sustaining pre-heat temperature in CDUs.
- Commissioned automatic blow down facility for steam drum in hydrogen unit resulting in energy saving due to controlled blow down.

The impact of implementation of these measures in HPCL refineries both in the industry as well as in the Indian refining industry as a whole have been discussed in Section 6.2 below.

Indian Oil Corporation Limited

During the study period of 2000 to 2010, IOCL's continuous efforts were to implement energy efficiency measures, both in terms of improvement/continuous maintenance in operations as well as the development of new projects. Various energy efficiency measures were introduced in the refineries of IOCL. which are mentioned below in annual basis.

2000 – 2001

The various measures being implemented by IOCL during the study period of 2000 – 2001 are as follows (IOCL, 2001):

- Delayed coker unit revamp and furnace replacement was done at Guwahati refinery.
- Modifications were done in CDU, APH and pre-heat train at Guwahati refinery.
- Yield and energy optimization and installation of waste heat boiler in coker – A, was done at Barauni refinery.
- Installed heat recovery facility at coker A at Barauni refinery.
- Energy optimization was done in Atmospheric Unit [AU] number three at Barauni refinery.
- Installed GTB with HRSG at Barauni Refinery.
- Pre-heat improvement was done in AU-3 at Gujarat refinery.
- Pre-heat improvement was done in FCC at Mathura refinery.
- Debottlenecking of FCC was done at Mathura refinery.

- Re-insulation of MP steam header was done at Mathura refinery.
- Installed GTB with HRSG at Panipat refinery.

2001 – 2002

During the study period of 2001 – 2002, the following measures were implemented in the IOCL refineries (IOCL, 2002):

- Pre-heat improvement was done in FPU-2 at Gujarat refinery.

2002 – 2003

IOCL implemented the following energy efficiency measures during the study period of 2002 – 2003 (IOCL, 2003):

- Installed a GTB with HRSG each in Barauni Refinery & Haldia Refinery

2003 – 2004

Various energy efficiency measures being implemented by the IOCL refineries during the study period of 2003 – 2004 are as follows (IOCL, 2004):

- Installed a GTB with HRSG each in Barauni refinery & Haldia refinery.

2004 – 2005

IOCL implemented various energy efficiency measures during the year 2003 – 2004 and they are as follows (IOCL, 2005)

- Yield and energy optimization revamp of CDU was done at Mathura refinery.
- New 2X50 TPH boiler was installed at Guwahati refinery.
- Hydrogen was recovered from low pressure off gases of OHCU at Panipat refinery.

2005 – 2006

Various energy efficiency measures implemented by IOCL during the study period of 2005 – 2006 are as follows (IOCL, 2006):

- 12 MW steam turbine was installed at Guwahati Refinery.
- Hydrogen was recovered from off gases of Catalytic Reforming Unit [CRU] at Barauni Refinery.
- Pre-heat improvement was done in CDU at Haldia refinery.

2006 – 2007

During the year 2006 – 2007, IOCL implemented various energy efficiency measures and they are as follows (IOCL, 2007):

- Installed 12 energy efficient CRU at Guwahati refinery.
- The low level heat was recovered from tempered water system in VDU at Haldia refinery.
- Installed flare gas recovery system at Mathura refinery.

2007 – 2008

IOCL implemented various energy efficiency measures in their refineries during the year 2007 – 2008 and they are as follows (IOCL, 2008):

- Yield and pre-heat improvement was done in AU-2 of Barauni refinery.
- Installed hydrogen recovery unit to recover hydrogen from CRU off gas at Koyali refinery.
- Installed APH in VBU furnace at Mathura refinery.
- Stepless controls for MGC in OHCU were installed at Mathura refinery.

2008 – 2009

During the year 2008 – 2009, IOCL implemented various energy efficiency measures which are as follows (IOCL, 2009):

- Installed flare gas recovery system at Guwahati refinery.
- Installed stepless control in MGC of HDT unit each in Guwahati and Mathura refinery.
- Yield and energy improvement was done in AU 1 at Barauni refinery.
- Commissioned GTB-II along with HRSG at Haldia Refinery.
- Installed flare gas recovery system at Haldia refinery
- Installed foggy cooler for GT at Mathura refinery.
- Pre-heat improvement was done in AU through heat exchanger train optimization at Digboi refinery.

2009 – 2010

IOCL implemented various energy efficiency measures during the year 2009 – 2010 and they are as follows (IOCL, 2010):

- Installed flare gas recovery system at Barauni refinery.
- Installed stepless control in MGC of DHDT & CRU units at Barauni refinery.
- Installed hydrogen recovery units to recover hydrogen from Cold Low Pressure Separator [CLPS] off-gas of HCU at Gujarat refinery.
- Installed a second heat exchanger to recover additional heat from VDU-II tempered water for pre-heating De-mineralized [DM] water for GT-2 at Haldia refinery.
- Replaced fouled APH in HGU-1 at Mathura refinery.
- Pre-heat improvement was done in CDU at Mathura refinery.
- Revamping of the bitumen unit with butrox technology was done in Mathura refinery.
- Installed additional heat exchangers in two trains to optimize energy in bitumen blowing unit at Mathura refinery.
- Replaced gas AC compressor with Vapour Absorption Machines [VAM] in various building at Panipat refinery.
- Installed Flare gas recovery system at Bongaigaon refinery.
- Installed a Helitower in CRU.

The impact of implementation of these measures in IOCL refineries, both in the industry as well as in the Indian refining industry as a whole have been discussed in Section 6.2 below.

Mangalore Refinery & Petrochemicals Limited

During the study period of 2000 to 2010, MRPL's continuous efforts were to implement energy efficiency measures, both in terms of improvement/continuous maintenance in operations as well as the development of new projects. MRPL had also reduced their energy costs by the fuel substitution, where the share of electricity had gone down and the share of furnace oil had increased[59]. The measures implemented by MRPL is discussed below on a yearly basis.

2000 – 2001

The various energy efficiency measures implemented by MRPL during the years 2000 – 2001 are as follows (MRPL, 2001):

- Installed heat recovery units, resulting in the recovery of heat from HCU 1 hot kerosene product to DM water [CPP de-aerator make-up].
- Routed crude column overhead gases to crude heater in column, to increase operational flexibility.
- Optimized grid transformer operation by keeping only one transformer either phase 1 or phase 2 in line.
- Routed excess hydrogen to fuel gas – resulted in the utilization of hydrogen to the tune of 1000 Nm^3/hr.
- Installed new heat exchangers for diesel/Vacuum Gas Oil [VGO] and recycle splitter feed/recycle in combination with routing of hot VGO feed, to save 4000 tons/yr of fuel.

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[59] *Discussed further in Section 6.2*

- Cascaded blowdown from phase 2 cooling tower to phase 1 cooling towers and taking blowdown from cooling tower as makeup to another
- Video camera installed to continously monitor the flare
- Periodical monitoring of crude unit pre-heat exchanger train performance was conducted by conducting a temperature survey and rigorous exchanger simulation was done.
- Routed hot VGO from VDU to HCU and hot Naphtha from Naphtha Splitter Unit [NSU] to Naphtha Hydrotreating Unit [NHT].

2001 – 2002

During the period of 2001 – 2002, MRPL implemented the following energy efficiency measures (MRPL, 2002):

- Installed heat recovery units resulting in the recovery of heat from hydrocracker 2, hot kerosene product to DM water.
- Periodical monitoring of crude unit pre-heat exchanger train performance by conducting a temperature survey and rigorous exchanger simulations was done.
- Reduced cooling water losses by means of cascade blowdown.
- Interconnected phase 1 and phase 2 MP steam header to prevent venting due to imbalance.
- Controlled excess hydrogen in the hydrocracker unit through a smaller control valve – reduced flaring to near zero.

- Periodically steam trap performance was monitored and rectified, if any as required.
- Identified and attended to the leakage in the vacuum column chimney trays in phase 1 and phase 2 VDU.

2002 – 2003

MRPL implemented the following energy efficiency measures during the year 2002 – 2003 and they are as follows (MRPL, 2003):

- Heavy flushing oil pump in phase 1 crude unit was stopped with minor modification
- Variable speed drives were installed on two Low Temperature [LT] drives in Hydrocracker unit 2.
- Used a special material for APH tubes in power plant 2 – lasts longer with lower flue gas temperature.
- Regular monitoring and maintenance of excess air in furnaces and functioning of steam traps was conducted.

2003 – 2004

During the year 2003 – 2004, MRPL implemented various energy efficiency measures in their refinery and are as follows (MRPL, 2004):

- Advanced Process control was installed in CDU 1, for yield and energy consumption improvement.
- Steam optimization of ejectors in vacuum system of CDU 2 was done.

- De-aerators were interconnected to save the condensate and the power.
- New energy saving transformer was installed in the plant area, street lighting of CDU/VBU/merox units.

2004 – 2005

MRPL implemented the below mentioned energy efficiency measures during the year 2004 – 2005 (MRPL, 2005):

- Advanced Process control was installed in CDU 1 for yield and energy consumption improvement.
- Installed a system for receiving hot feed to the gas oil hydrodesulphurization unit and thereby utilizing the heat to generate steam.
- Rainwater was harvested, saving in pumping costs.
- Routed the excess low pressure separator off-gas from the hydrocracker unit to Hydrogen plant feed.
- An optimized vacuum column operation was installed to reduce the steam supply to ejectors

2005 – 2006

During the year 2005 – 2006, MRPL implemented many energy efficiency measures and they are as follows (MRPL, 2006):

- Variable frequency drives were installed and commissioned for 119 LV and 3 MV drives.
- PSA Adsorbents were changed in Hydrogen 2 and CRU-2 units to improve hydrogen recovery.

- Heat recovery units were installed resulting in the recovery of heat from splitter bottoms for feed pre-heating at hydrocracker 1 unit and from product diesel for feed pre-heating at hydrocracker 2 unit.

2006 – 2007

MRPL implemented various energy efficiency measures in the year 2006 – 2007 which are as follows (MRPL, 2007):

- Steam lines were better insulated.
- Optimized the refinery sour water stripper operation thereby reducing steam consumption.
- Double seals were provided for five existing floating roof tanks and six new floating roof tanks – reducing fugitive emissions.

2007 – 2008

During the year 2007 – 2008, MRPL implemented various energy efficiency measures and they are as follows (MRPL, 2008):

- Commissioned Condensate Recovery Scheme [CRS] in CPP for recovering hot condensate.
- An advanced process control system was implemented in phase 2 CDU.
- On-line cleaning of Furnace tube external surface was carried out by chemical spraying in the vacuum heater of phase 2 CDU.

- Double seals were provided for ten more existing floating roof tanks & Gauge pole sock were provided for two floating roof tanks, thereby reducing fugitive emissions.
- 25 Solar powered traffic signals & lighting installed in the company & township.
- Continued Anti-foulant injection in CDU-1, to minimize heat exchanger fouling rate, thus improving heat recovery over the period.

2008 – 2009

MRPL implemented various energy efficiency measures during the year 2008 – 2009, which are as follows (MRPL, 2009):

- Modification of hot well slop oil to Light Gas Oil [LGO] stripper was carried out in CDU.
- In VBU 2, all steam generators' tube bundles were cleaned, to maximize medium pressure steam production
- An advanced process control system was implemented in CDU – 2.
- Provided automatic water draining facility for one crude storage tank.

2009 – 2010

During the year 2009 – 2010, MRPL implemented various energy efficiency measures and they are as follows (MRPL, 2010):

- On-line chemical cleaning activity was carried-out in CDU and VBU furnaces.

- Routed the hydrocracker unit's LP separator off-gases to CCR-2 unit PSA system, for additional Hydrogen recovery.
- Routed CCR unit net gas to the isomerisation unit, for minimizing fresh hydrogen requirement.
- Modified hydrocracker unit-1 kerosene product air cooler for sponge absorber service, for improving LPG recovery.

The impact of implementation of these measures in MRPL refinery, both in the industry as well as in the Indian refining industry as a whole have been discussed in Section 6.2 below.

Numaligarh Refinery Limited

During the study period, NRL had invested money in implementing various energy efficiency measures in terms of technical and structural changes. No data on the measures being implemented by the refinery during the years 2000 – 2001 and 2002 – 2003, were mentioned in energy notes in their annual reports pertaining to those respective years, which could be either because no measure had been implemented by the refinery or because they might have overlooked matter, and missed mentioning it. To reduce the energy costs, this refinery has undertaken the fuel substitution measures where natural gas has increased its share as a fuel during the study period[60]. The various measures implemented in the rest of the years are mentioned below.

2001 – 2002

The various energy efficiency measures implemented by the refinery during the year 2001 – 2002, are as follows (NRL, 2002):

[60] *Discussed further in Section 6.2*

- Optimized the feed pre-heat temperature in the primary unit.
- Optimized APH in the furnaces.
- Optimized furnace operations.
- Diverged the slop from vacuum suction to HSD pool.
- Utilized the LP gas in primary unit.
- Installed auto sampler in crude oil pipeline.
- Improved the insulation.
- Maximum utilization of the refinery gas.
- Maximization of hot feed to secondary processing units.
- Single GTB operation.

2003 – 2004

During the year 2003 – 2004, NRL implemented various energy efficiency measures which are as follows (NRL, 2004):

- A comprehensive energy audit was carried out during the year, and the recommendations were implemented.
- Reduced the GTG frequency to 49.5 Hz from 50 Hz, resulted in saving of around 666 MT of fuel per year.
- Stopped a FD Fan each in CDU furnace and in HCU furnace, contrary to the normal operating philosophy.
- Diverged the flash drum vapors in CDU from flash zone to Kero zone.
- Optimized HSD pool blending components with unconverted oil of hydrocracker unit.
- Implemented unique spilt seal in the three cooling water pumps in the cooling tower area.

- Stopped steam heating in the crude tanks.
- The exchangers were cleaned and many of the major equipments were overhauled.
- Used slop oil in place of gas oil for quenching purpose in Delayed Coking Unit [DCU].
- Diverged VDU slops oil to the gas oil pool
- Routed filter backwash of hydrocracker unit to VR feed tank instead of slop
- Passing valves and fugitive emission by Acoustic Leak Detector [ALD] and GMI was regularly monitored.
- Flare system was closely monitored and maintained, for maximum fuel gas utilization.
- Water content in crude oil is closely monitored
- Secondary processing units were optimized.
- Adjusted the blade angles of air fin fan coolers for optimum operation.
- Optimum cooling tower operation was done by closely monitoring the cooling tower fan operation

2004 – 2005

As part of energy conservation in the refinery, NRL implemented the following energy efficiency measures during the year 2004 – 2005 (NRL, 2005):

- Implemented advanced process control in CDU/VDU to optimize product recovery and improve product yields.
- Provided special type of telescopic insulation for all the 150 numbers of catalyst tubes at the reformer top to cover the bare hot tube length [550 to 600 degree celcius].

- Installed 12 MW STG for utilizing surplus steam and recovering power from PRDS
- Implemented step less control system in HCU & MUG compressors.
- Implemented a scheme for using VDU hot well waste gas in the CDU furnace.
- Implemented Distributed Control System [DCS] in CPP, which helps in optimization of fuel consumption by allowing close monitoring of the steam parameters, steam venting, etc., through the DCS.
- Improved, and more reliable steam traps have been installed.
- Auto drain traps for moisture separation in air compressor were installed.
- Conducted steam leak survey, and remedial actions have been taken for all the identified leaks.
- Passing valves and fugitive emission by ALD and GMI was regularly monitored.

2005 – 2006

Various energy efficiency measures implemented by NRL during the year 2005 – 2006 are as follows (NRL, 2006):

- Provided special type of telescopic insulation for all the 150 numbers of catalyst tubes at the reformer top to cover the bare hot tube length [550 to 600 degree celcius].
- Implemented 12 MW STG for utilizing surplus waste steam and recovering power from PRDS.

- Combination coke cutting tool in DCU has been implemented.
- Implemented step less control system in HCU, MGCs.
- Modified one of the HRSG with BFW pump to cater the need of BFW requirement of both HRSG as well as UB in CPP.
- Single burner operation of UB has been implemented
- Ultrasonic mass flow meter to measure flare gas flow has been installed.
- Passing valves and fugitive emission by ALD and GMI was regularly monitored.

2006 – 2007

During the year 2006 – 2007, NRL implemented the following energy efficiency measures (NRL, 2007):

- A unique step less control system has been implemented in the MGC of the hydrocracker unit
- Conducted steam leak survey and remedial actions had taken for all the identified leaks.
- Provided special type of telescopic insulation for all the 150 numbers of catalyst tubes at the reformer top to cover the bare hot tube length [550 to 600 degree celcius].
- A dual purpose turbine has been implemented in CPP.
- Passing valves and fugitive emission by ALD and GMI was regularly monitored.

2007 – 2008

NRL implemented various energy efficiency measures during the year 2007 – 2008 and they are as follows (NRL, 2008):

- Cleaned fin fan coolers' finned tubes in hydrocracker unit by application of foam cleaning technique
- Continual use of energy master in air compressor of CPP, for better energy management.
- Continual benefit from the unique step less control system implemented in the MGC of the hydrocracker unit.
- Regular monitoring of all the valves connected to flare system for any passing by ALD was carried out throughout the year, and timely detection and rectification of such passing valves is conducted.
- Fugitive emission survey for detecting and rectifying any minor leak from valve glands, flanges etc. was carried out on a regular basis throughout the year by using GMI.
- During the year new insulation had been provided in the furnace to coke chamber transfer lines as well as over one of the coke chambers resulting the saving of energy by preventing heat loss to the atmosphere.

2008 – 2009

During the year 2008 – 2009, the various energy efficiency measures implemented by NRL are as follows (NRL, 2009):

- Natural gas utilization project for replacement of naphtha as fuel in GTG and replacement of naphtha both as feed &

fuel in hydrogen unit & replacement of fuel oil in refinery furnaces by natural gas.

- Cleaned fin fan coolers' finned tubes in hydrocracker unit by application of foam cleaning technique.
- Continual use of energy master in air compressor of CPP, for better energy management.
- Unique step less control system implemented in the MGC of the hydrocracker unit.
- Regular monitoring of all the valves connected to flare system for any passing by ALD was carried out throughout the year, and timely detection and rectification of such passing valves if required
- Fugitive emission survey for detecting and rectifying any minor leak from valve glands, flanges, etc. was carried out on a regular basis throughout the year by using GMI.

2009 – 2010

Various energy efficiency measures implemented by NRL during the year 2009 – 2010 are as follows (NRL, 2010):

- Implemented 12 MW STG for utilizing surplus waste steam and recovering power from PRDS.
- A natural gas utilization project was implemented, for replacement of naphtha as fuel in GTG, and replacement of naphtha both as feed & fuel in hydrogen unit, and replacement of fuel oil in refinery furnaces by natural gas.
- Improved insulation of calcium silicate.
- Operational procedural changes in DCU for hydrocarbon vapor loss reduction were made and reduced the slop oil

generation during chamber vapor, heating and cooling cycle has been implemented.

- Scheme for utilizing an oxygen rich waste stream from existing nitrogen plants for enhancement of SRU capacity has been implemented.
- Replaced conventional lighting fixture (40W) by more energy efficient fittings of 28W Retrofit T-5 Luminaries.
- A suitable energy conservation scheme has been implemented for heat recovery from HP steam ex-MSP.
- Unique step less control system implemented in the MGC of the hydro cracker unit.
- Regular monitoring of all the valves connected to flare system for any passing by ALD was carried out throughout the year, and timely detection and rectification of such passing valves if required.
- Fugitive emission survey for detecting and rectifying any minor leak from valve glands, flanges etc. was carried out on a regular basis throughout the year by using GMI.

The impact of implementation of these measures in MRPL refinery, both in the company as well as in the Indian refining industry as a whole have been discussed in Section 6.2 below.

Reliance Industries Limited

RIL is one of the private refineries in India which can refine any quality of crude. Improvement in energy efficiency is a continuous process at RIL and conservation of energy is given high priority. Energy audits and benchmarking are done regularly to identify areas of improvement, and steps are taken to implement the measures required for such improvement.

This refinery had undergone fuel substitution to reduce the energy costs[61]. The various energy efficiency measures implemented by the refinery during 2000 – 2012, are mentioned below.

2000 – 2001

The various energy efficiency measures implemented by RIL during the year 2000 – 2001, are as follows (RIL, 2001):

- Heat recovery units were installed, to recover heat from aromatic steam condensate.
- By-pass provision was provided for CPU tank, and feed pump in Cracker plant.
- End capping of purge steam to USX and TLX[62] outlet points in Cracker plant was done.
- Reduced the solvent ratio in aromatic plant from 4.1 to 3.7.
- Additional lean solvent pump of lower capacity was installed, to avoid dual running of higher capacity pumps in aromatic plant.
- Upgraded fractionation feed pumps motor, to avoid dual running during high frequency / load fluctuations in aromatic plant.
- Provided additional MP steam header in aromatic plant and has stopped HP Steam letdown to MP Steam.

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[61] *Discussed further in Section 6.2*

[62] *USX and TLX are basically the furnace tubes that are being used in the refineries/process industries.*

2001 – 2002

During the year 2001 – 2002, RIL implemented various energy efficiency measures and they are as follows (RIL, 2002):

- Implemented advanced process control in aromatic plant.
- Improved the third stage efficiency of compressor in cracker plant.
- Boiler house cooling water was recovered.
- Optimized BFW system.
- Optimized the air system instrument, thereby reducing the air compressors running hours
- Stopped atomizing steam to all gas fired burners and regular soot blowing in all oil fired furnaces, to improve furnace efficiency.
- Reduced excess air for aromatic coker, crude and hydrotreater furnaces.
- Stopped third compressor in the platform of an aromatic plant.
- Debottlenecking of heat exchangers in coker complex was done, to increase MP steam generation.
- Reduced MP steam in light coker gas oil & heavy coker gas oil stripper in coker.
- Anti-foulant was injected in VR exchangers in CDUs of crude, improved fouling factor.
- Power Recovery Turbines [PRT] pressure optimization is done in FCC complex.

__2002 – 2003__

RIL implemented various energy efficiency measures during the year 2002 – 2003 which are as follows (RIL, 2003):

- Insulated phase-1 return condensate header in CPP.
- Installed fogging in 6 GTB.
- Optimized DM water pump for Phase-1 header in CPP.
- Daily flare analysis and monitoring of flare loss from various valves of individual units was conducted by acoustic meter on a continuous basis, to minimize flare loss.
- Daily monitoring of fuel consumption & loss for the refinery is conducted.
- Heater efficiencies of all fired heaters was monitored on a weekly basis.
- Used MP Steam in place of HP Steam in stripper reboiler's in CDU.
- Rerouted VDU ejector off gases to CDU furnaces.
- Installed removable insulation pads for high temperature pumps & strainers, valves, channel end covers and flanges in coker.
- Installed new improved design APH in Hydrogen Manufacturing Unit [HMU] HMU-2.
- Offline & online water washing of gas turbine compressor blades was conducted.

2003 – 2004

During the year 2003 – 2004, RIL implemented various energy efficiency measures which are as follows (RIL, 2004):

- Substituted costlier fuel with cheaper fuel like the use of FCC gas in GTB and HRSGs instead of naphtha.
- Replaced solid metal fan blades with FRP fan blades.
- Installed double sealing arrangement in GTB bypass stack damper.
- Optimized the process operation by the adding catalyst in the slurry mix tank.
- Online water wash of GTB air compressor is done.
- Installed additional de-propaniser column in cracker plant and modified CGC discharge line in cracker plant.

2004 – 2005

RIL implemented the following energy efficiency measures in their refinery during the year 2004 – 2005 (RIL, 2005):

- Transferred excess residual heat from one fluid stream to other fluid streams for heating purposes, like boiler blowdown in CPP.
- Replaced fin fan blades by hollow FRP blades.
- Replaced coker aromatics and PRU plants.
- Installed new parallel fractionator overhead condenser in coker plant.

2005 – 2006

During the year 2005 – 2006, RIL had implemented various energy efficiency measures and are as follows (RIL, 2006):

- An optimizer for steam and power system was implemented at the refinery to adjust controllable parameters continually, to reduce energy consumption.
- CPP and steam generation has been switched over to natural gas from liquid fuels.

2006 - 2007

Various energy efficiency measures implemented in the RIL during the year 2006 – 2007 are as follows (RIL, 2007):

- An energy conservation study for process plants was conducted and this study has unlocked various heat integration opportunities, which are at various stages of detaining and implementation.
- Supplied power from Sub-station-12 to Effluent Treatment Plant [ETP] and isolated Transformer in SS-10
- Replaced cooling tower fan with energy efficient FRP Fans.
- An insulation revamp of heater H-12 was done in cracker plant.
- Plate & frame type heat exchangers were installed in the Amine Treating Units [ATU] - 1 & 2 in the rich amine feed pre-heat section.

- Replaced aluminium blades of fan of cooling towers with FRP blades in Sulphur, Aromatics, CDU, and FCC for reduction of power consumption.

2007 – 2008

During the year 2007 – 2008, RIL refinery implemented various energy efficiency measures and they are as follows (RIL, 2008b):

- Replaced plate & frame exchanger in place of existing rich/ lean amine shell & tube exchanger in ATU of sulphur complex.
- Replaced HP steam with MP steam in stripper reboiler in VGO hydrotreater.
- Replaced Cooling tower induced draft fans with high flow energy efficient fans.

2008 – 2009

RIL refinery implemented various energy efficiency measures during the year 2008 – 2009, which are as follows (RIL, 2009b):

- Routed propylene treater regeneration gases to low LP flare gas recovery compressor, that increased hydrocarbon recovery.
- An acoustic survey a nitrogen tracer technique survey was conducetd as a part of the flare control valves audit.
- Conducted steam leak survey across the complex twice in the year.
- Installed 61 solar water heaters.

2009 – 2010

During the year 2009 – 2010, the following are the energy efficiency measures that were implemented by the RIL refinery (RIL, 2010):

- Reduced the consumption of steam, by decreasing operating pressure of NSU & de-pentaniser column by process side improvements in aromatics plant.
- Diverted isomer separator gas to platformer re-contact loop, which originally was downgraded to unsaturated gas header in aromatics plant to recover hydrogen.
- Provided new tube bundle with additional baffles in inter stage cooler in HMU -2 to reduce the power consumption of the fuel gas compressor.
- Minimized MP steam consumption in naphtha splitter reboiler by recovering more heat from Light Cycle Gas Oil (LCGO) stream in coker plant.
- Reduction in MP steam consumption used as motive steam in ejectors for VDU 1 & 2 by process side improvements.
- Installed low range pressure transmitters on each unit's flare knockout drum, for identification of flare sources in low LP flare.
- Reduced the captive steam generation by decreasing motive steam pressure in all ejector stages in crude-3 & 4 units, decreasing HP steam consumption in PRT 1 & 2 at FCCU and by putting restricted orifices in coke drum steam purge valves at coker plant.
- Reduced the fuel consumption by changing the burner tips for all the furnaces in platformer.

The impact of implementation of these measures in RIL refinery both in the organisation as well as in the Indian refining industry as a whole have been discussed in Section 6.2 below.

From the ibid., it is clearly evident that the energy efficiency measures implemented by the refineries are audit based in most cases, where leakages, replacement of the equipments/processes with more efficient equipments/processes have been implemented. During the content analysis it was found out that the most energy efficient refineries reported energy efficiency measures in an effective manner, and the least energy efficient refinery has given no specific information about energy efficiency measures implemented by them. If we wish to categorize the energy efficiency measures in terms of structural, technical or behavioural, it is clear that the majority of the measures implemented by these refineries are technical and only one refinery was found implementing capacity building along with NPC. As far as structural measures are concerned, both RIL and HPCL had implemented a structural measure each [RIL installed 61 solar water heaters in their refinery during 2008 - 2009 and HPCL signed GTA with GAIL for setting up a gas network during 2008-09].

The refineries implemented these measures as policy compliance and the study would be incomplete if the economic effectiveness of these measures is not studied. Therefore, the next section 6.2 will discuss about evaluation of economic effectiveness of the measures implemented by these refineries.

Section 6.2: Evaluation of Economic Effectiveness of Energy Efficiency Measures Implemented by Indian Refineries

The various parameters that had been considered for the study purpose are crude processed and its value, energy consumed and its value, share of various energy sources in the energy mix, etc. To evaluate the overall economic effectiveness [63] of the above mentioned measures, various quantitative approaches, such as, energy consumption per unit of crude processed, incremental concept, cumulative concept, cost benefit analysis, cost effectiveness, energy utilization index and energy cost index were adopted.

Output Quantity

The table 6.1 below, illustrates the output produced by various refineries and its growth rate in 2009 - 2010 over 2008 - 2009. The table also showcases the CAGR of the output produced by these refineries and the Indian refining industry. During the study period, the output of Indian refining industry have increased by 178% from 63.77 MMT in 2000-01 to 177.51 MMT in 2009 - 2010 and [with a CAGR 10.78%], which was due to the addition/effective utilization of the refining capacity in all the refineries. During the said period, the CAGR of RIL was 40.77% whose refining capacity has increased from 15.62 MMT to 47.74 MMT which was due to the capacity addition in the refinery in 2001 - 2002.

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[63] *This study is limited to evaluate the overall effectiveness of the measures implemented and not on the effectiveness of individual measures.*

Table 6.1: Comparative Study of Various Companies & Industry Output during the Study Period 2000-2010 (in MMT)

Year	BPCL	CPCL	HPCL	IOCL	MRPL	NRL	RIL	Industry
2000-01	8.75	6.09	11.4	31.2	1.97	2.79	1.56	63.77
2001-02	8.74	6.23	11.82	31.77	4.91	4.37	25.59	93.43
2002-03	17.43	6.88	12.37	33.45	6.7	3.57	23.95	104.34
2003-04	17.36	7.09	13.12	35.63	9.35	4.18	24.94	111.67
2004-05	17.9	8.97	13.27	34.32	11.07	3.92	26.06	115.51
2005-06	33.93	10.41	13.2	36.22	11.34	4.1	21.98	131.18
2006-07	39.14	10.45	15.92	40.68	11.71	4.81	28.85	151.57
2007-08	35.31	10.32	15.97	43.94	11.71	4.94	31.32	153.51
2008-09	39.81	10.18	15.13	47.96	11.78	4.34	31.25	160.45
2009-10	40.71	10.12	15.07	47.11	11.68	5.07	47.75	177.51
Growth Rate 2009-10 over 2008-09	2%	-1%	0%	-2%	-1%	17%	53%	11%
CAGR 2000–01 to 2009-10	17%	5%	3%	4%	19%	6%	41%	11%

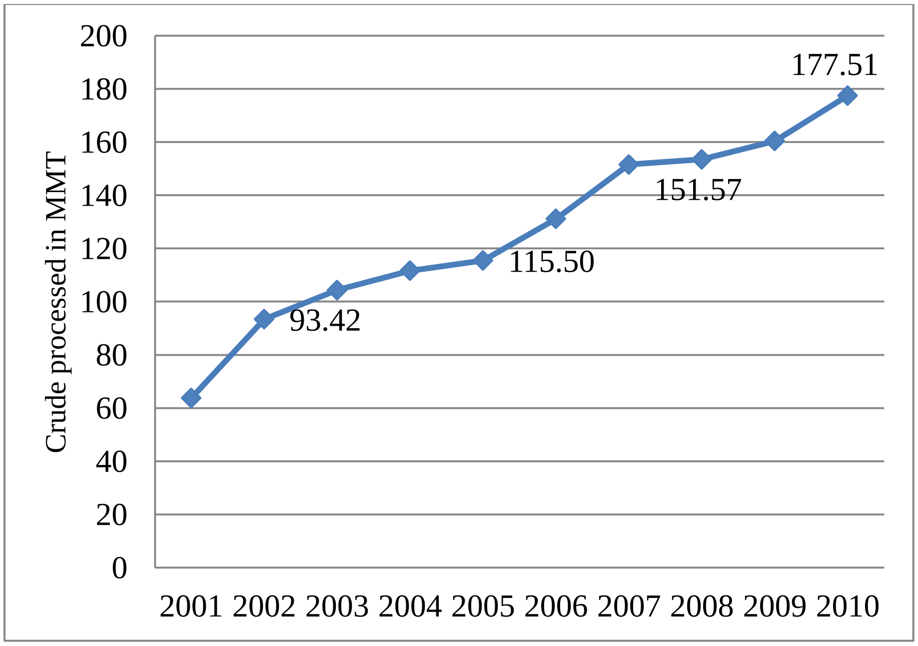

Fig 6.1: Indian Refining Industries Output during the Study Period of 2000-2010

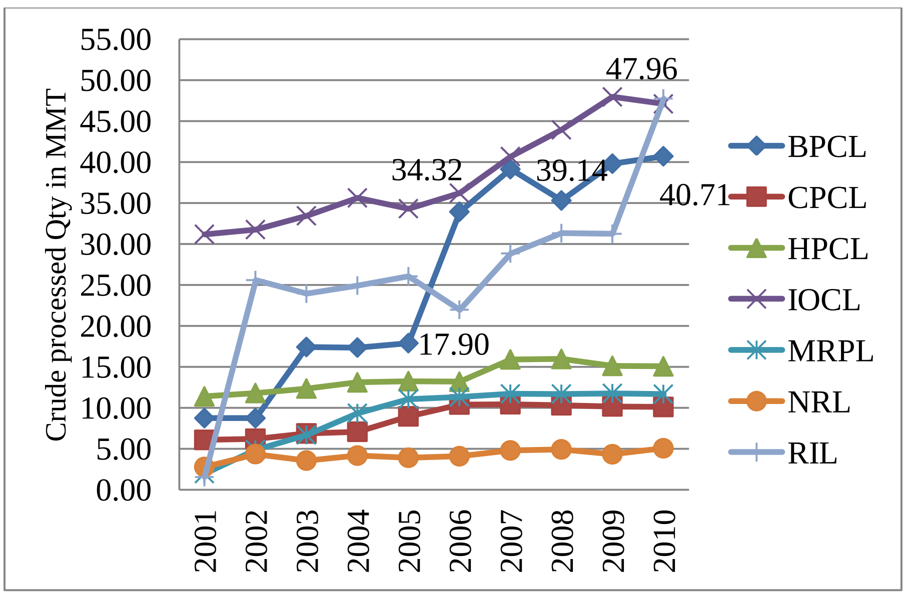

Fig 6.2: Comparative Study of Various Companies Output during the Study Period of 2000-2010

It is evident from the above figures 6.1 and 6.2 that, during the year 2002 – 2003, the output produced by NRL and RIL decreased, which was due to their low purchase of raw material in that year. The blast in hydro cracking unit in RIL during the year 2005-06, forced the management to close down 26 process units of the refinery, resulting in decrease in the crude processed in RIL. The planned shutdown of the Kochi refinery of BPCL during the year 2007-08, resulted in the reduction of output produced by BPCL that year. In 2008-09, the output produced by HPCL and NRL was reduced, as the raw material consumed by these refineries came down due to high crude oil prices at that time[64]. In 2009-10, the largest producers in Indian refining industry was IOCL which had a production share of 26.54% and RIL whose production share was 26.90%. In 2001 the IOCL's production was 31.2 MMT, which was about 48.92% of the total industry whereas RIL's share was only 2.45%. But as time passed, IOCL's share has decreased because of the policy changes[65], market dynamics and refinery capacity additions / effective refinery capacity utilization by various refineries resulting in the reduction of their production share from 48.92% in 2001 to 26.54% in 2009-10.

Output Value

The below table 6.2, shows the value of the output produced by the Indian refining industry and various companies in the industry, with their CAGR and its growth rate in 2009 - 2010 over 2008 - 2009. The value of the output produced by the Indian refining industry increased by 457% from INR 92,992 crores in 2000 - 2001 to INR 5,18,485 crores in 2009 - 2010 [with a CAGR 19%]. The study on CAGR of various companies 'value of

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[64] *From the interview of industry experts*
[65] *Deregulation of Indian Refining Industry*

output produced [in monetary units], can be explained in terms of output produced [in physical units] by them during the study period.

Table 6.2: Comparative Study of Various Companies & Industry Output Value during the Study Period 2000-2010 (in Million Crore Rupees)

	BPCL	**CPCL**	**HPCL**	**IOCL**	**MRPL**	**NRL**	**RIL**	**Industry**
2000-01	14.15	7.01	18.18	47.02	2.65	1.17	2.81	92.99
2001-02	13.87	6.27	18.49	48.70	5.49	2.08	33.89	128.79
2002-03	16.83	9.47	20.65	59.32	8.49	2.73	37.89	155.39
2003-04	17.69	9.05	25.32	67.32	12.76	3.46	43.74	179.34
2004-05	20.74	18.24	30.54	75.66	20.72	4.18	57.51	227.60
2005-06	46.63	27.31	37.32	98.19	27.84	5.80	78.33	321.43
2006-07	52.64	31.88	50.26	124.24	32.97	7.80	92.98	392.77
2007-08	43.07	35.21	51.62	138.99	36.94	8.70	108.30	422.83
2008-09	69.03	38.44	55.56	169.55	42.77	9.16	114.94	499.44
2009-10	66.30	32.91	50.43	153.90	35.95	8.25	170.73	518.49
Growth Rate 2009-10 over 2008-09	-4%	-14%	-9%	-9%	-16%	-10%	49%	4%
CAGR 2000–01 to 2009-10	17%	17%	11%	13%	30%	22%	51%	19%

The figures 6.3 and 6.4, illustrates the value of the output produced by the Indian refining industry and various companies in the industry. It was noticed that the share of the output value of BPCL, CPCL & NRL to the industry share is almost consistent whereas the share of output values of HPCL and IOCL decreased. The share of output values of MRPL and RIL to the industry share increased. These fluctuations in their share output value in the industry share can be explained in terms of output being produced by them. It was noticed that the output value of the Indian refineries increased, since 2001 – 2002, which can be attributed to the dismantling of the APM and also due to the changes in product mix. Even though this change in product mix increased the output produced by certain refineries, have decreased their output value[66].

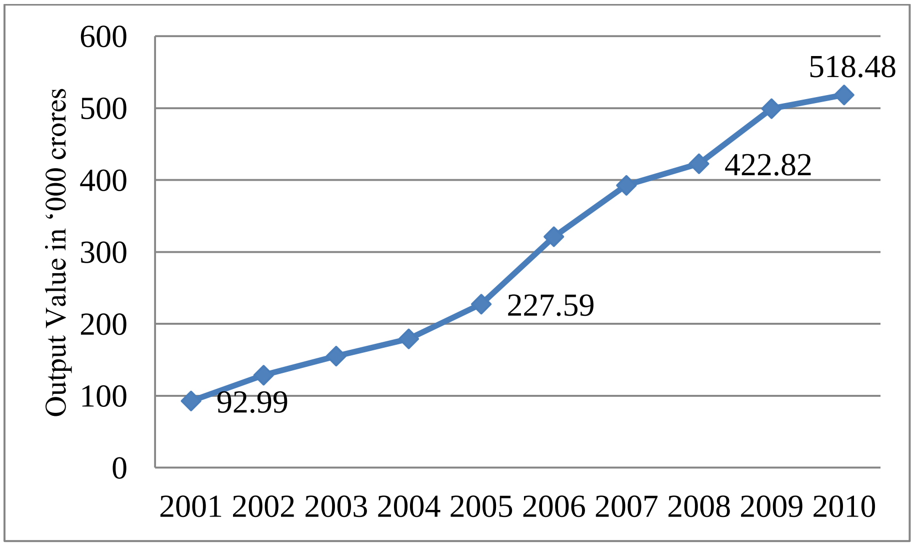

Fig 6.3: Indian Refining Industries Output Value during the Study Period 2000-2010 (in '000 crores)

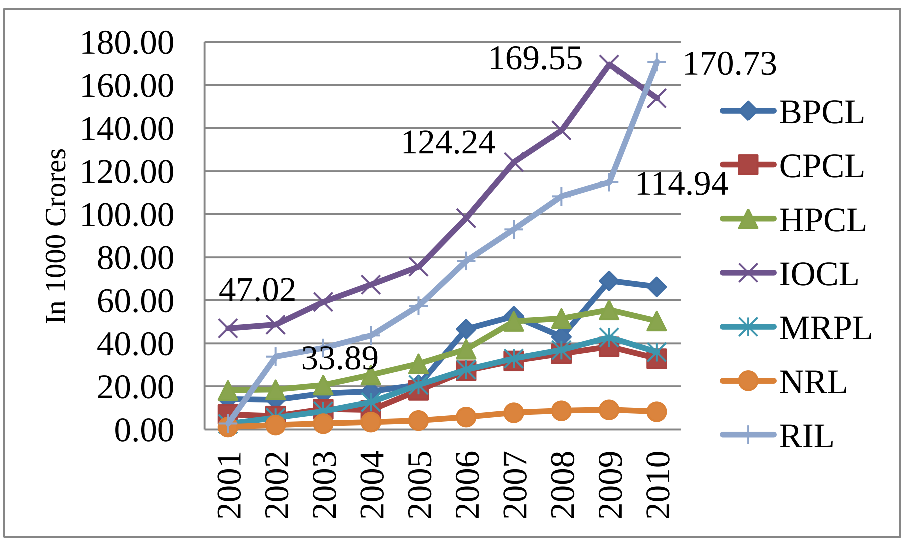

Fig 6.4: Comparative Study of Various Companies Output Value during the Study Period 2000-2010 (in '000 crores)

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[66] *The Government of India has pressurized some of the refineries to produce diesel so as to meet the market demand resulting in constant / increased output but decreased output value. From the interview of industry expert*

Energy Consumption (in trillion kcal)

Table 6.3: Comparative Study of Various Companies & Industry Energy Consumption during the Study Period 2000-2010 (in Trillion kcal)

	BPCL	**CPCL**	**HPCL**	**IOCL**	**MRPL**	**NRL**	**RIL**	**Industry**
2000-01	1457.08	116.02	1253.87	8442.70	1.61	1124.12	4.71	12400.11
2001-02	1568.73	917.15	1396.71	8903.13	4.02	1297.30	14.22	14101.26
2002-03	1403.96	909.36	1211.54	10299.79	5.12	1800.36	16.92	15647.04
2003-04	1404.75	1107.99	1444.38	9947.82	6.83	1904.73	13.66	15830.16
2004-05	1576.29	1467.16	1944.71	13678.74	8.16	1717.11	15.48	20407.64
2005-06	2559.70	1493.40	1952.08	14223.62	8.31	1892.73	13.92	22143.76
2006-07	3294.36	1362.78	2552.54	17808.24	8.49	2366.14	22.32	27414.85
2007-08	4799.11	1259.02	1765.86	19668.80	8.94	2456.55	21.89	29980.17
2008-09	4369.52	1423.78	2591.07	20193.03	8.52	2252.87	29.53	30868.32
2009-10	4063.04	1414.09	3132.70	19813.86	8.96	2379.39	18.88	30830.92
Growth Rate 2009-10 over 2008-09	-7%	-1%	21%	-2%	5%	6%	-36%	0%
CAGR 2000–01 to 2009-10	11%	28%	10%	9%	19%	8%	15%	10%

The above table 6.3, illustrates the energy consumed by various refineries during the study period and its growth rate in 2009 - 2010 over 2008 - 2009. The table also showcases the CAGR of the energy consumed by these refineries and the Indian refining industry. From this table its evident that, the growth rate in 2009 - 2010 over 2008 - 2009 of Indian refining industries energy consumption was 0%, which shows that the Indian refining industry has adopted some effective energy efficiency measures [even though the growth in output produced by Indian refining industry in 2009 - 2010 over 2008 - 2009 was 11%]. The case is no different with the companies in the Indian refining industry whose growth rate in 2009 - 2010 over 2008 - 2009 of energy consumption is less compared to the growth rate of the output produced by them.

Figure 6.5 and 6.6, illustrates the energy consumed by the Indian refining industry and various refineries during 2000 – 2010. Even though, the output of Indian refining industry increased by 178% during the study period, the energy consumption only increased by 149% from 12400.11 trillion kcal in 2000 - 2001 to 30,830.91 trillion kcal in 2009 - 2010. In most of the refineries it was noticed that during the years 2002 - 2003, 2004 - 2005 and 2007 - 2008 energy consumption was high compared to the previous year which was due to the addition of new energy intensive secondary processing units to improve the quality of the fuel as per government policy. It was also observed that the energy consumed by a refinery also has a direct relation with the output being produced by the refinery. In some years the energy consumed by the refineries was less but the output being produced for the corresponding year was higher or vice versa which were due to the product mix changes[67].

[67] *The energy required for producing gasoline is very less compared to the energy required to produce high speed diesel*

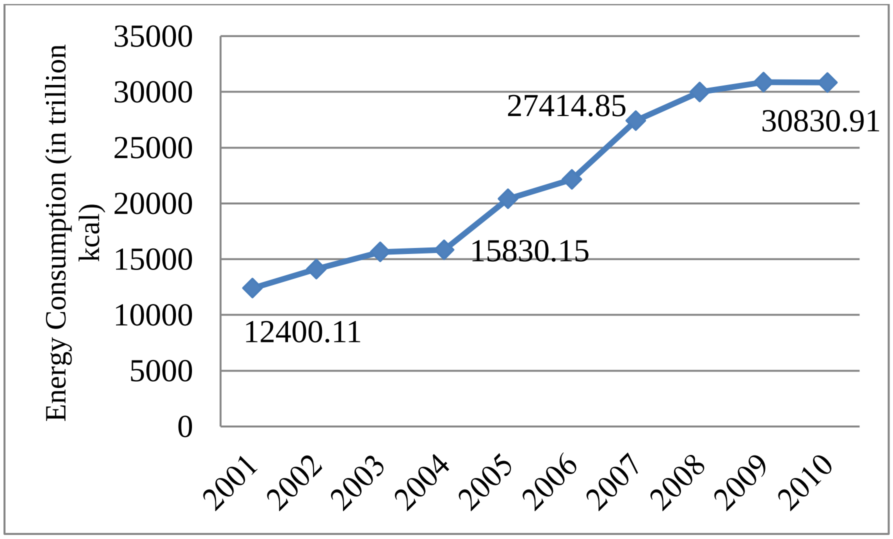

Fig 6.5: Indian Refining Industries Energy Consumption during the Study Period of 2000-2010

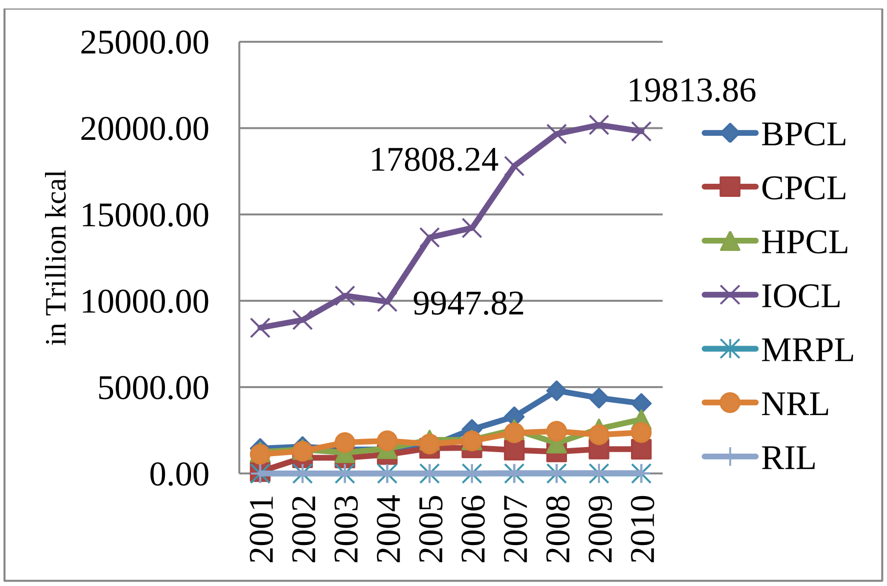

Fig 6.6: Comparative Study of Various Companies Energy Consumption during the Study Period of 2000-2010

Energy Value

Table 6.4: Comparative Study of Various Companies & Industry Energy Value during the Study Period 2000-2010 (in '000 Crore Rupees)

	BPCL	CPCL	HPCL	IOCL	MRPL	NRL	RIL	Industry
2000-01	0.20	0.03	0.55	2.29	0.23	0.24	0.88	4.43
2001-02	0.19	0.02	0.62	2.30	0.42	0.29	2.84	6.69
2002-03	0.24	0.02	0.66	6.47	0.48	0.31	3.28	11.46
2003-04	0.22	0.02	2.79	3.14	0.57	0.24	2.65	9.62
2004-05	0.27	0.76	1.13	3.09	0.32	0.31	4.21	10.09
2005-06	0.43	1.16	1.42	4.02	1.28	0.46	1.94	10.71
2006-07	0.61	1.27	1.52	5.60	1.46	0.61	3.57	14.63
2007-08	1.71	1.51	2.37	6.38	1.83	0.66	3.30	17.75
2008-09	1.96	1.66	1.71	8.81	2.15	0.65	4.63	21.58
2009-10	2.23	1.54	2.70	8.70	2.24	0.68	4.30	22.39
Growth Rate 2009-10 over 2008-09	14%	-7%	58%	-1%	4%	5%	-7%	4%
CAGR 2000–01 to 2009-10	27%	48%	17%	14%	26%	11%	17%	18%

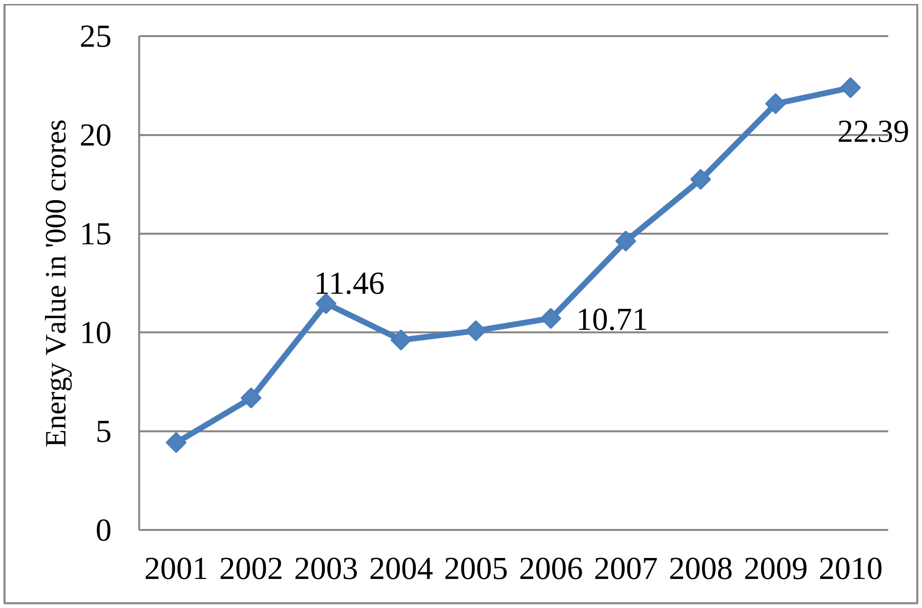

Fig 6.7: Indian Refining Industries Energy Value during the Study Period of 2000-2010 (in '000 Crore Rupees)

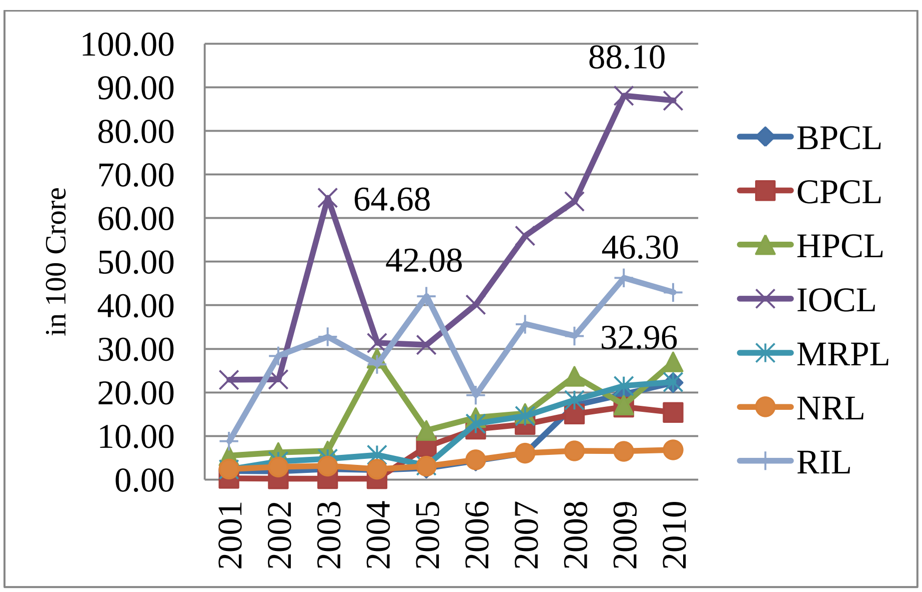

Fig 6.8: Comparative Study of Various Companies Energy Value during the Study Period of 2000-2010 (in '00 Crore Rupees)

The above table 6.4, showcases the cost incurred by various refineries on energy, its growth rate in 2009 - 2010 over 2008 - 2009 and the CAGR since 2000. The figures 6.7 and 6.8, illustrates the cost incurred by the Indian refining industry and various refineries on energy. During the study period, the cost incurred by the Indian refineries on purchasing energy increased by 405% from INR 4,428 crore in 2000 - 2001 to INR 22,391 crore in 2009 - 2010. It was observed that the cost incurred by the refineries were fluctuating and this can be attributed to the increase in the unit cost of the energy being used or of the high energy consumed by the refinery in the corresponding year[68].

Energy Consumption per Unit of Crude Processed

The below table 6.5, showcases the 'energy consumed per unit of output' by various refineries in India, its growth rate in 2009-10 over 2008-09 and its CAGR. It is evident from the table, that the refineries in India has implemented various energy efficiency measures, resulting in negative or less CAGR for all refineries except CPCL,which suggests that they are less energy efficienct.

Table 6.5: Comparative Study of Various Companies & Industries Energy Consumption per Unit of Crude Processed during the Study Period 2000-2010 (in trillion kcal/MMT)

	BPCL	CPCL	HPCL	IOCL	MRPL	NRL	RIL	Industry
2000-01	166.5	19.043	109.96	270.6	0.81	402.76	3.01	194.44
2001-02	179.41	147.18	118.18	280.27	0.82	297.09	0.55	150.93
2002-03	80.55	132.19	97.961	307.92	0.76	504.37	0.70	149.96
2003-04	80.90	156.32	110.1	279.18	0.73	455.46	0.54	141.76

[68] *From the interview of industry experts*

2004-05	88.03	163.64	146.58	398.56	0.73	438.56	0.59	176.68
2005-06	75.43	143.4	147.9	392.71	0.73	461.42	0.63	168.8
2006-07	84.17	130.36	160.31	437.73	0.72	492.17	0.77	180.87
2007-08	135.9	121.95	110.57	447.67	0.76	497.48	0.69	195.3
2008-09	109.76	139.81	171.22	421.06	0.72	518.8	0.94	192.38
2009-10	99.79	139.79	207.84	420.63	0.76	468.99	0.39	173.68
Growth Rate 2009-10 over 2008-09	-9%	0%	21%	0%	6%	-10%	-59%	-10%
CAGR 2000–01 to 2009-10	-5%	22%	7%	5%	-1%	2%	-18%	-1%

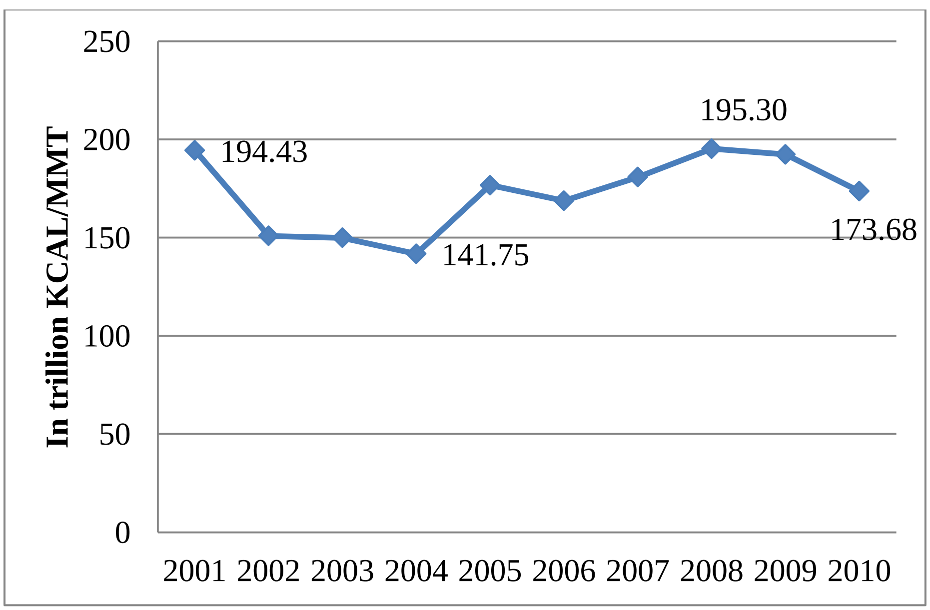

Fig 6.9: Indian Refining Industries Energy Consumption per Unit of Crude Processed during the Study Period of 2000-2010 (in trillion kcal/MMT)

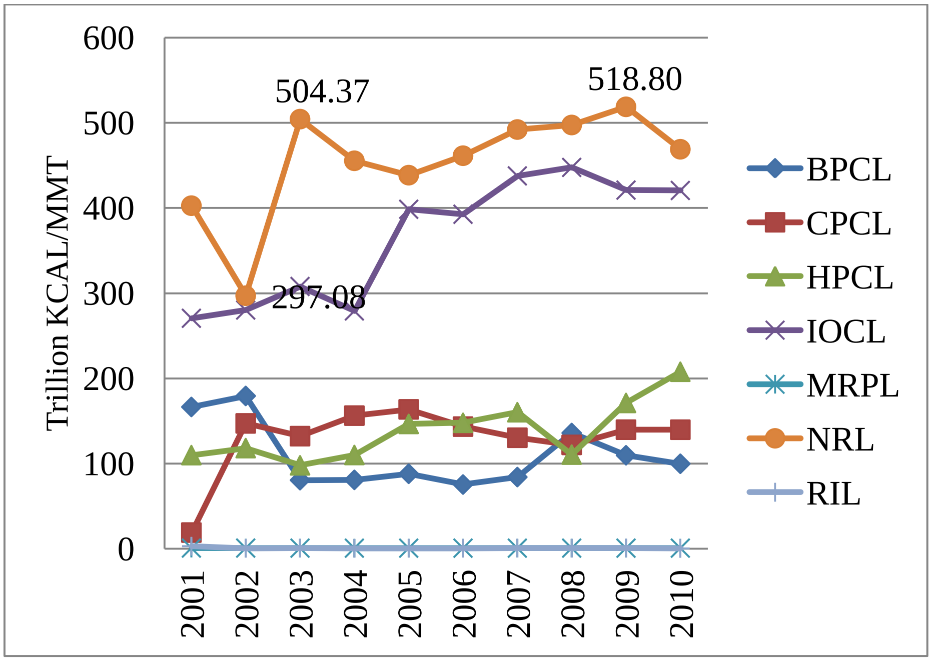

Fig 6.10: Comparative Study of Various Companies Energy Consumption per Unit of Crude Processed during the Study Period 2000-2010 (in trillion kcal/MMT)

Figures 6.9 and 6.10, illustrates the ‘energy consumed per unit of output’ by the Indian refining industry and various refineries in India Energy consumption per unit of crude processed refers to the use of energy in processing one unit of crude. During the study period of 2000 - 2010, it was noticed that the energy consumption per unit of crude processed decreased by 11% from 1,94,436.14 mkcal per thousand tons in 2000 - 2001 to 1,73,683.68 mkcal per thousand tons in 2009 - 2010. It was noticed that even after implementing the energy efficiency measures in the Indian refining industry, the energy consumption per unit of crude processed had increased for all the refineries except RIL and BPCL which was due to the addition of new energy intensive secondary processing units to improve the quality of the fuel as per government policy. An interesting phenomenon observed was that the energy consumption per unit of crude processed had increased in CPCL by 634% but decreased by 5% in the study period of 2001-2010. The energy consumption per unit of output in RIL's refinery had reduced by about 86% during the study period and it was found to be one among the best in the refining industry in India in terms of energy conservation[69]. The results of this research is contradictory to the assumptions that complex refineries are less energy efficient (Sathaye, Price, Can, & Fridley, 2005).

Incremental Energy Consumption per Unit of Increased Output

Table 6.6: Comparative Study of Various Companies & Industries Incremental Energy Consumption per Unit of Increased Output during the Study Period of 2000-2010 (in trillion kcal/MMT)

	BPCL	CPCL	HPCL	IOCL	MRPL	NRL	RIL	Industry
2001-02	-14756.26	5760.17	343.92	813.49	0.82	109.90	0.40	57.37
2002-03	-18.98	-12.03	-337.09	829.37	0.61	-631.02	-1.64	141.63
2003-04	-12.46	950.40	309.86	-161.31	0.65	170.40	-3.30	24.98
2004-05	317.13	191.25	3381.79	-2843.69	0.77	703.53	1.62	1193.89
2005-06	61.35	18.12	-107.99	286.93	0.59	940.76	0.38	110.74
2006-07	141.19	-3265.66	220.47	803.01	0.47	670.97	1.22	258.54
2007-08	-393.44	798.14	-16207.46	571.95	-61.68	693.13	-0.17	1325.50
2008-09	-95.53	-1176.87	-985.19	130.34	-5.79	342.00	-103.90	127.89
2009-10	-339.86	142.49	-8927.52	444.51	-4.67	173.08	-0.65	-2.19

[69] *From the interview of industry experts*

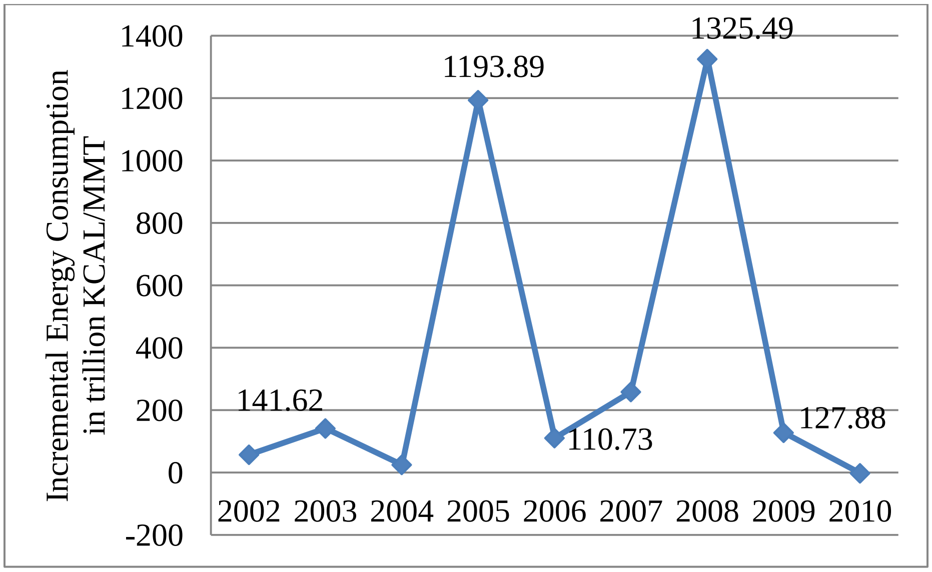

Fig 6.11: Indian Refining Industries Incremental Energy Consumption per Unit of Increased Output during the Study Period of 2000-2010 (in trillion kcal/MMT)

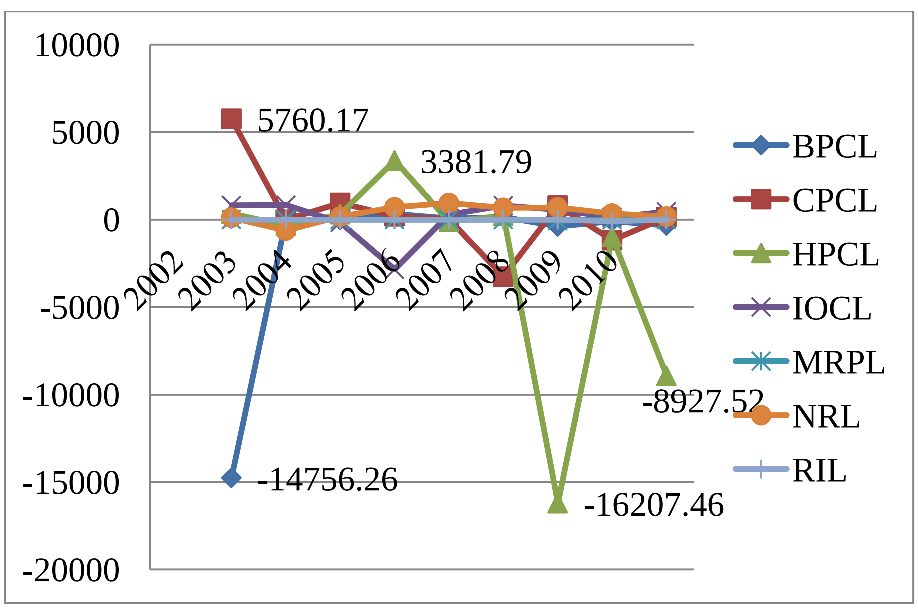

Fig 6.12: Comparative Study of Various Companies Incremental Energy Consumption per Unit of Increased Output during the Study Period of 2000-2010 (in trillion kcal/MMT)

The incremental energy consumption per unit of increased output has been calculated on the output produced, and the corresponding energy consumed by the refinery to measure the change in energy consumption to increase in every block of output for the study purpose during 2000-2010. The incremental energy consumption per unit of increased output for Indian refineries during the year 2000-01 was 57371.10 mkcal and was -2192.31 mkcal during the year 2009-10. The details of incremental energy consumption per unit of increased output for various refineries are showcased in the above table 6.6 and illustrated in figures 6.11 and 6.12.

Cumulative Energy Consumption per Unit of Output

The cumulative energy consumption per unit of crude processed was calculated. The cumulative energy consumption per unit of crude processed is used to find out the cumulative effect of energy efficiency measures on energy consumption per unit of crude processed over a period of time from 2000 to 2010. It has been noticed that the cumulative energy consumption per unit of crude processed has been decreasing in Indian refineries by 10%. This is a measure which is helpful for long term decisions so that overall 10% energy efficiency shows that Indian refining industry could conserve energy by 10% in spite of various external factors like; APM dismantling, Governmental policies, change in energy prices, economic slowdown, inter industry disruptions, capacity additions, fluctuating input prices etc. The cumulative energy consumption per unit of crude processed decreased in Indian refineries such as BPCL, MRPL and RIL. However, the cumulative energy consumption per unit of crude processed had increased for the other refineries[70].

[70] *From the interview of industry experts*

Table 6.7: Comparative Study of Various Companies & Industries Cumulative Energy Consumption per Unit of Output during the Study Period of 2000-2010 (in trillion kcal/MMT)

	BPCL	**CPCL**	**HPCL**	**IOCL**	**MRPL**	**NRL**	**RIL**	**Industry**
2000-01	166.50	19.04	109.96	270.60	0.82	402.76	3.02	194.44
2001-02	172.95	83.83	114.14	275.48	0.82	338.29	0.70	168.58
2002-03	126.84	101.16	108.52	286.73	0.79	393.56	0.70	161.15
2003-04	111.59	116.03	108.95	284.70	0.77	410.92	0.65	155.35
2004-05	105.58	128.14	117.00	308.19	0.76	416.67	0.64	160.39
2005-06	95.75	131.62	122.43	323.30	0.75	424.67	0.64	162.17
2006-07	92.59	131.38	129.05	342.43	0.75	436.37	0.66	165.84
2007-08	101.15	129.92	126.29	358.53	0.75	445.61	0.67	170.73
2008-09	102.72	131.23	131.86	367.48	0.75	454.20	0.71	173.93
2009-10	102.26	132.23	140.20	374.03	0.75	455.98	0.65	173.90

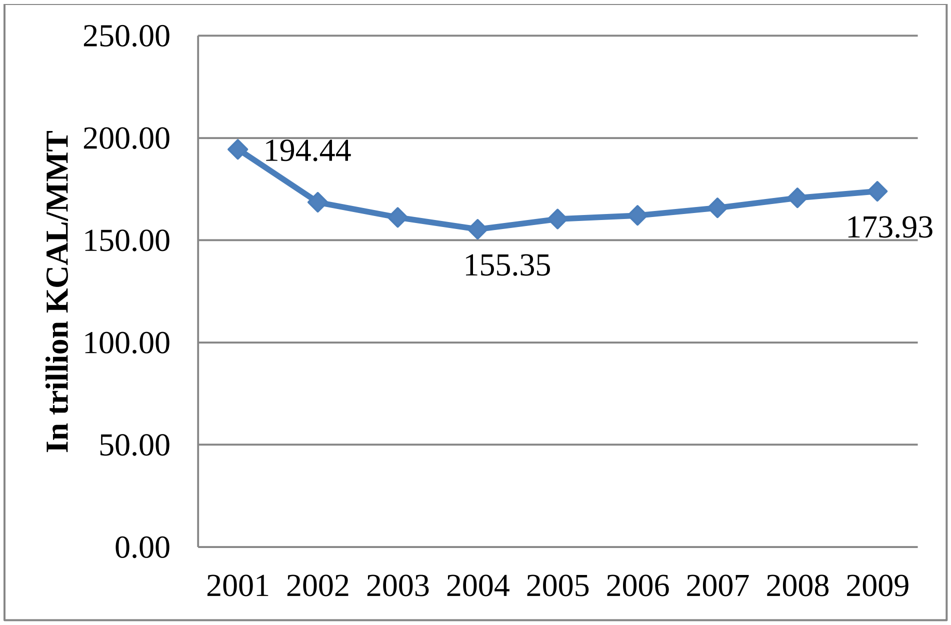

Fig 6.13: Indian Refining Industries Cumulative Energy Consumption per Unit of Output during the Study Period of 2000-2010 (in trillion kcal/MMT)

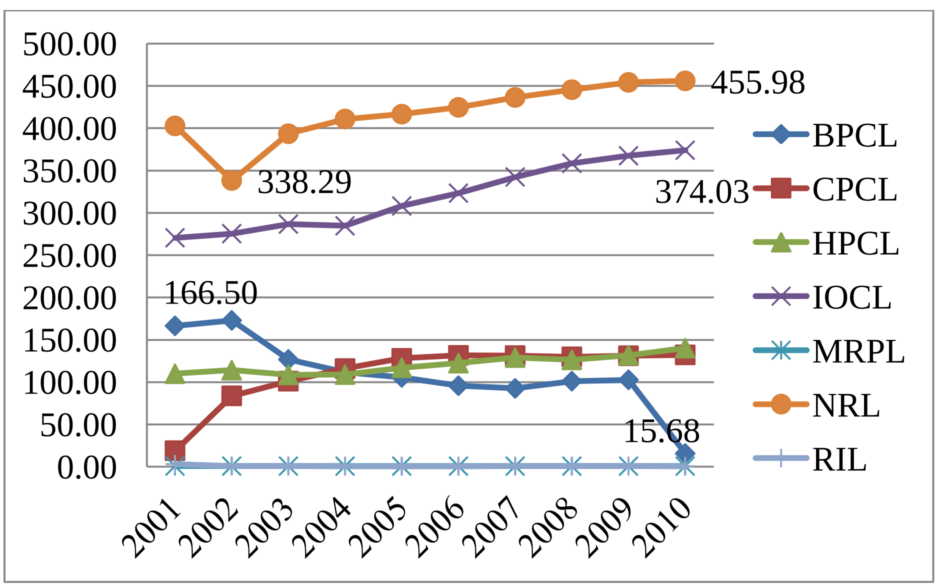

Fig 6.14: Comparative Study of Various Companies Cumulative Energy Consumption per Unit of Output during the Study Period 2000-2010 (in trillion kcal/MMT)

Energy Savings in Monetary terms[71]

From the studies it was identified that the refining industry saved 25937 trillion kcal of energy which corresponds to INR 15465 Crore.

Table 6.8: Energy Savings in Monetary Terms of Indian Refining Industry

Year	Output Quantity (MMT)	Energy Consumption (Trillion kcal) –Actual	Energy Consumption (Trillion kcal) -Expected	Energy Consumption (Trillion kcal) – Savings	Energy Cost in INR Per Mkcal	Savings in Crore Rupees
2000-01	63.77	12400.11	12400.11	0.00	3.57	0.00
2001-02	93.43	14101.26	18165.47	4064.21	4.74	1926.81
2002-03	104.34	15647.04	20287.62	4640.57	7.32	3398.96
2003-04	111.67	15830.16	21712.96	5882.81	6.08	3574.77
2004-05	115.51	20407.64	22458.45	2050.81	4.94	1013.82
2005-06	131.18	22143.76	25506.74	3362.98	4.84	1626.82
2006-07	151.57	27414.85	29470.97	2056.11	5.34	1097.10
2007-08	153.51	29980.17	29847.27	-132.90	5.92	-78.70
2008-09	160.45	30868.32	31197.57	329.25	6.99	230.22
2009-10	177.51	30830.92	34514.73	3683.81	7.26	2675.44
Total				**25937.65**		**15465.24**

[71] *Energy cost per mkcal was calculated by using the corresponding year's energy value upon the energy consumed in mkcal. The researcher has calculated the energy consumption per unit of output for the year 2000-01 and has assumed that for the next ten years, the energy consumption per unit of output is same as in the base year assuming no energy efficiency measures had been implemented in industry resulting in calculating the expected energy consumption for the decade. The difference in expected and actual consumption was multiplied with the corresponding years energy cost per unit of MKCAL and derived the savings in monetary values.*

It was also identified that the following companies saved energy and the energy being saved by them is calculated in monetary terms.

Table 6.9: Energy Savings in Monetary Terms of BPCL, MRPL & RIL

	BPCL	MRPL	RIL
Energy Saved in trillion kcal	16642	6.42	622
Corresponding value in INR (in Crore)	INR 4716.52	INR 1023.87	INR 119552

The following companies in the Indian refining industry were consuming excess[72] of energy when the study was conducted and they are as follows.

Table 6.10: Energy Savings in Monetary Terms of CPCL, HPCL, IOCL & NRL

	CPCL	HPCL	IOCL	NRL
Energy used in excess in trillion kcal	9818.7	4150	39538	2239.7
Corresponding value in INR (in Crore)	INR 6854	INR 2991	INR 14113	INR 549

Fuel Substitution

It has been noticed that in Indian refining industries, other than Reliance industries limited, Numaligarh Refinery Limited and Mangalore Refinery & Petrochemicals Limited, no other company was making efforts in energy conservation through energy substitution. This study had shown that the use of energy sources in producing one unit of output had come down substantially. It indicates that most of the companies in the Indian refining industry were making efforts for energy conservation through

[72] *Due to the addition of new energy intensive secondary processing units to improve the quality of the fuel as per government policy*

technical measures only. Figures 5.15, 5.16 and 5.17 gives a graphical representation of the share of energy sources in RIL, NRL and MRPL respectively during 2000 – 2010.

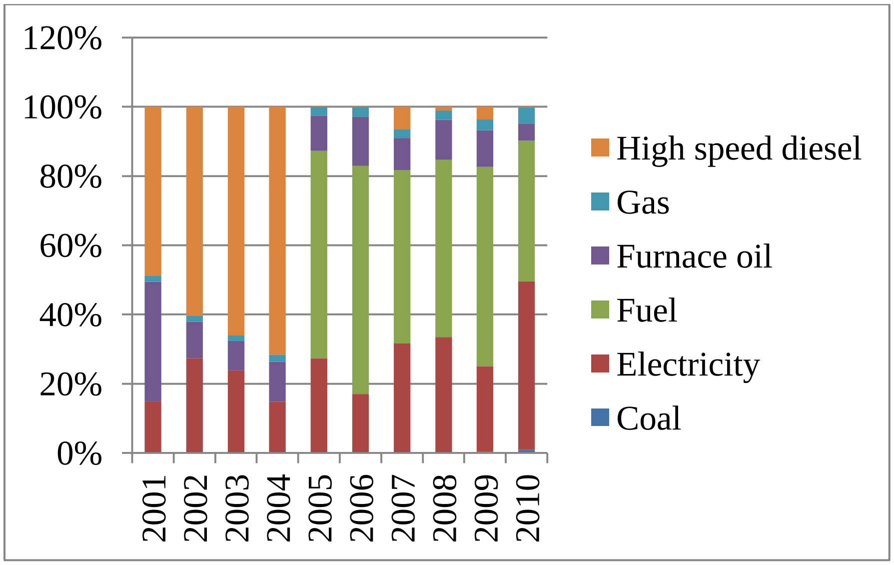

Fig 6.15: Share of Energy Sources in RIL during 2000 – 2010.

It was observed that during the decade 2000 – 2010, RIL used energy sources, such as, coal, electricity, fuel, furnace oil, gas and HSD. It's been noticed that in the year 2000 - 2001 the major source of energy being used in RIL refinery was high speed diesel and furnace oil but over a period of time the share of high speed diesel became very negligible whereas in case of furnace oil it reduced to a minimum quantity. It was also noticed that in the year 2000 - 2001 the share of electricity used as an energy source was about 15% which increased to about 49% in the year 2009 - 2010. The same was the case with fuel in that, during 2000 - 2001, no fuel was used as a source of energy but later in the year 2009 - 2010 the share was raised to 40.72%.

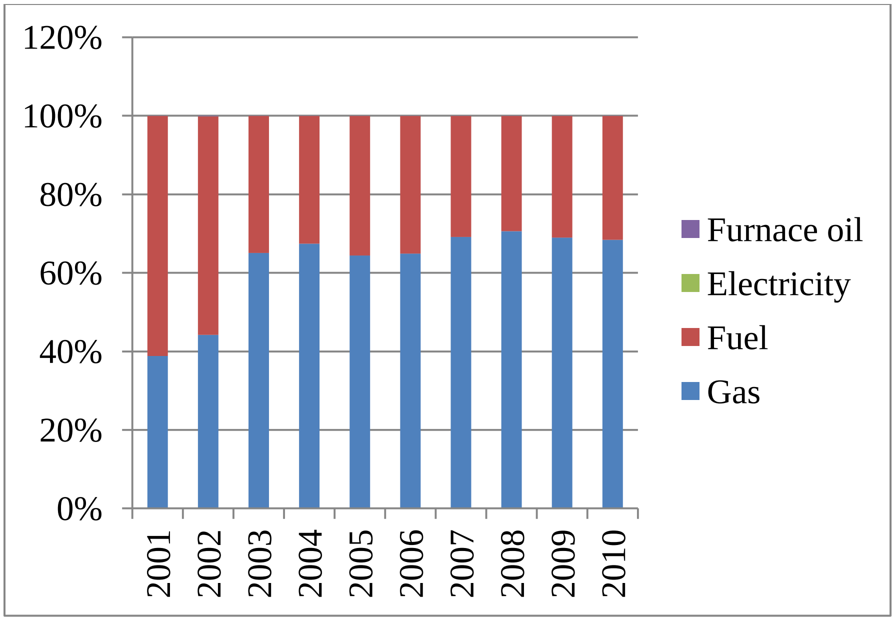

Fig 6.16: Share of energy sources in NRL during 2000 – 2010.

It was observed that during the decade 2000 – 2010, NRL used energy sources, such as, gas, fuel, furnace oil, and electricity but prominently they were using gas and fuel as the major sources of energy for their refining processes, whereas the other sources were used in a negligible quantity. In 2000 - 2001, the share of fuel as an energy source was 61.12%, whereas that of gas was 38.79%. During the study period, it was found out that NRL was substituting the fuel which was the major source of energy in the year 2000 - 2001 with gas. In 2009 - 2010 it was noticed that the share of gas had gone up to 68.42% whereas the share of fuel in the energy mix had gone down to 31.55%. On further analysis it was found out that NRL were paying INR 10 per unit of gas in 2000-01, and it was increasing over a period of time from 2000 - 2010 in which NRL paid Rs 23.82 per unit of unit of gas consumed whereas for fuel they paid Rs, 10.79 per unit in 2000 - 2001 and had increased to Rs 33.01 per unit of fuel consumed in 2009 - 2010. The reason for the shift was because the energy generated by 1 unit of gas is equivalent to the energy produced by about 1.3 units of fuel and in every year the fuel cost is more than that of gas cost.

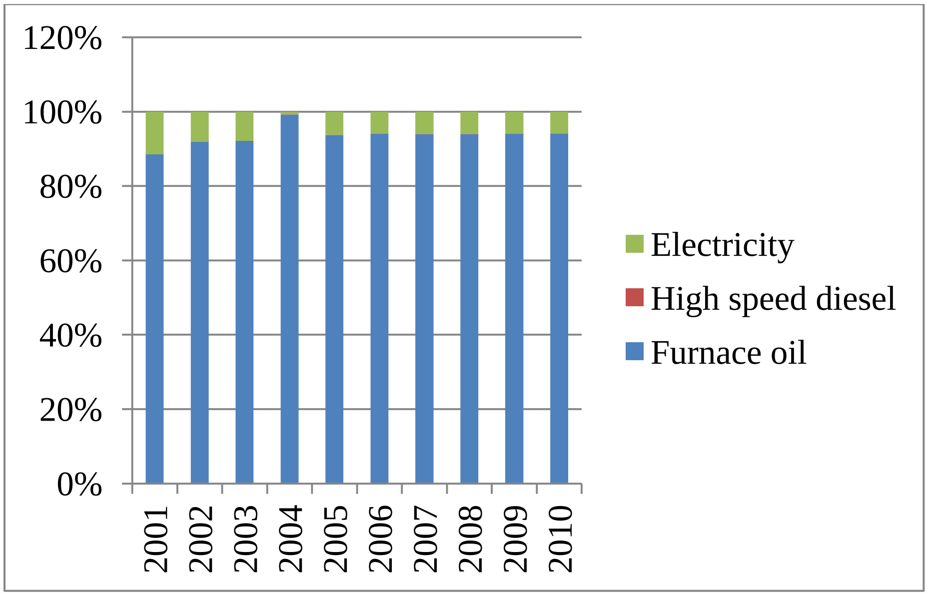

Fig 6.17: Share of energy sources in MRPL during 2000 – 2010.

It was observed that during the decade 2000 – 2010, MRPL used energy sources, such as, furnace oil, HSD and electricity but prominently they were using furnace oil as the major source of energy whose share is further increasing year by year. MRPL was also using electricity as another major source of energy but its share decreased since 2000 - 2001. The share of electricity being used by MRPL in the 2000 - 2001 was 11.44% which was decreasing since then, and in 2009 - 2010 the share of electricity being used by MRPL was 5.86%. Even though the use of energy sources in producing one unit of output has come down substantially, the energy substitution phenomenon is nominal. On further analysis it was found out that MRPL was paying INR 8.92 per unit of furnace oil in 2000 - 2001 and it was increasing over a period of time from 2000 - 2010 in which MRPL paid INR 21.16 per unit of furnace oil consumed, whereas for the electricity they paid INR 9.14 per unit of electricity in 2000 - 2001, which decreased to INR 5.94 per unit of electricity consumed in 2009 - 2010. The reason for the shift was because the energy generated by 1 unit of furnace oil is equivalent to the energy produced by about 13 units of electricity.

The below table 6.11 shows the cost benefit analysis on the investments made on energy efficiency measures in IOCL. This analysis shows that the company recovered their cost and had started saving money each year except for the investments made in 2008-09. But, it has to be considered that if we include the 2010-11 for the study purpose, the investments made during the year 2008-09 would also have made savings after the cost recovery during that year. As most of the investments made by IOCL during the study period has an Internal Rate of Return [IRR[73]] of more than 15% [which is more than the cost of capital], which shows that these investments are cost effective and also have the advantages of increased energy efficiency, such as, reduction in atmospheric pollution, boosting up of industrial competitiveness, generation of employment and better business opportunities, enhancing the productivity, increasing the security of supply and contribute to poverty alleviation along with other aspects. It was noticed that during the study period, IOCL has made a total savings of INR 552.72 crore with a payback period of seven years in most of the investments. This shows that the industry should consider energy efficiency not only as a legal obligation, but also as an opportunity to earn double edge benefits.

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[73] *An Investment is considered to be cost effective, if the IRR is more than their cost of capital*

Table 6.11: Cost Benefit Analysis of energy efficiency measures implemented in IOCL

Investments made during the year	Investments In Crore [INR]	Cash Flows (In Crore)										Ratio's		
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Payback Period	IRR	Total Cost savings
2000-2001	-434.75	46.70	44.08	55.25	54.79	60.23	73.09	81.31	84.66	112.41	114.46	7 years and 3 months	9%	292.22
2001-2002	-14.56		2.01	2.52	2.50	2.75	3.34	3.71	3.87	5.14	5.23	5 years and 5 months	15%	16.52
2002-2003	-176.12			20.67	20.50	22.53	27.34	30.42	31.67	42.05	42.82	6 years and 7 months	6%	61.87
2003-2004	No Measures being implemented during this year													
2004-2005	-118.73					26.42	32.06	35.66	37.13	49.30	50.20	3 years and 8 months	20%	112.04
2005-2006	-46.91						13.58	15.11	15.73	20.89	21.27	3 years and 2 months	22%	39.68
2006-2007	-12.01							10.72	11.16	14.82	15.09	1 year and 2 months	90%	39.79
2007-2008	-74.28								21.36	28.36	28.88	2 years and 11 months	3%	4.31
2008-2009	-141.13									54.82	55.82	Still not Recovered	-15%	-30.49
2009-2010	-68.93										85.71	10 months	24%	16.78

Section 6.3: Regression Analysis

The given below is an output of a regression method using double log model which is primarily used for measuring the elasticity between two variables. In this study this method is used for measuring the energy intensity in which energy consumption [independent variable] and output produced by the refineries [dependent variable] are studied.

The regression analysis (See Appendix D) can be further interpreted as follows:

Table 6.12: Results of Energy Intensity & R^2 using double log model of regression analysis

Company	R Square	Energy Intensity
BPCL	0.73	1
CPCL	0.46	0.20
HPCL	0.63	0.29
IOCL	0.87	0.42
MRPL	1	1
NRL	0.63	0.53
RIL	0.81	1.72
Industry	0.89	0.83

The above table 6.12, illustrates the energy intensity & R square using double log model [log-linear model] of regression analysis. For the Indian refining industry, the value R^2 = 0.89, which means that independent variable X [energy consumption in Mkcal] explain 89% of total variation in dependent variable Y [output quantity in '000 tons]. The Energy intensity or elasticity of the Indian refining industry 0.83 implies that 1% increase in energy will result in 0.83% increase in output produced in the industry (Gujarati, 2004). Table 6.12 also depicts that the RIL is the most energy efficient refinery in India [energy intensity value is 1.72], whereas CPCL and HPCL are the least energy efficient [energy intensity value is .20 and .29 respectievely].

Section 6.4: Barriers to the implementation of energy efficiency in Indian refineries

To identify the barriers which prevent the implementation of energy efficiency measures in Indian refineries, the responses received back from the sample are analyzed. Before starting the analysis the reliability of the scale was checked using Cronbach's Alpha (Statistical Tool) and the value greater than 0.7 is considered to be highly reliable (Nunally, 1978). The results achieved by this statistical test are portrayed below in Table 6.13.

Table 6.13: Reliability Statistics

Reliability Statistics	
Cronbach's Alpha	No of Items
0.83	41

The scale is highly reliable as the Cronbach's Alpha value is above 0.83. As the scale was accepted, factor analysis was used to reduce the data by grouping the similar parameters to a few manageable factors.

The Kaiser-Meyer-Olkin [KMO] statistic is used to evaluate whether the sample size being used for the study is adequate. This is to ensure the precision of factor analysis and the value of KMO statistic greater than .6 is considered to be adequate (Kaiser & Rice, 1974). The results achieved by this statistical test are portrayed below in Table 6.14.

Table 6.14: KMO and Bartlett's Test

KMO and Bartlett's Test[a*]				
Sl. No	**Test Statistics**		**Result**	**Interpretation**
	Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.68	Significant
	Bartlett's Test of Sphericity	Approx. Chi-Square	3192.64	
		Df	820	
		Sig.	0	Significant
[a] Based on correlations				
[*] SPSS 16				

As the value of KMO statistic is greater than .6 the sample size considered to be adequate and the aptness of factor analysis is ensured.

The Principle Component Analysis [PCA] method is used to analyze the identified 41 variables. In this PCA Eigen Value Method and Scree Plot Method are used to determine and justify the factors.

Using Principle Component Analysis, 12 factors were determined (Appendix E) whose cumulative percentage of variances are explained by 66.88%. Figure 6.18 below portrays the Scree plot which was drawn.

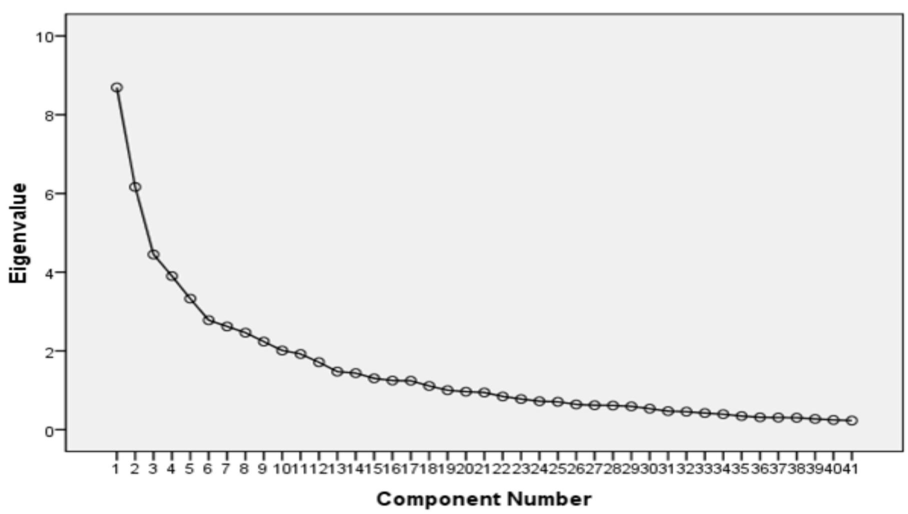

Fig 6.18: Scree Plot

After the determination of these 12 factors using Principle Component Analysis, all the variables are loaded into these factors by preparing the factor matrix (Appendix E). Further, these factors were rotated using Varimax procedure which is an orthogonal method of factor rotation to prepare a factor rotation matrix (Appendix F).

Cronbach's Alpha of each 12 factors were calculated to establish the internal consistency and it was found to be 0.811, 0.768, 0.692, 0.694, 0.727, 0.640, 0.693, 0.693, 0.618, 0.657, 0.649 and 0.671 respectively for the studied factors and are found to be consistent.

By using factor analysis, all the 41 variables were reduced to 12 major factors which act as barriers to the implementation of energy efficiency measures in Indian refineries. Table 6.15 below portrays the total variance explained for each factor and their Cronbach's Alpha value and the factor loadings of each identified variable.

Table 6.15: Barriers to Implementation of Energy Efficiency Measures in Indian Refineries and Variables Loaded into those Barriers

Factors	**Factor Interpretation**	**Factor Loading**	**Variables included in Factor**
Factor 1	Non Market Barriers (7.15%) Cronbach's Alpha: 0.811	0.542	It is difficult to access the capital for energy efficient technology
		0.781	Costs incurred due to production disruptions
		0.843	Other organizational priorities for capital investments
		0.810	Costs incurred on replacement of staff and retraining of the new staff
		0.604	Costs incurred to identify various energy efficiency opportunities

Factor 2	Problems of focus & Attention (7.11%) Cronbach's Alpha: 0.768	0.673	No specific person/committee is available to deal with the energy
		0.746	Non availability of energy conservation targets in the organization
		0.788	Non importance / less priority of energy management in the organization
		0.603	Non Importance of energy as a factor of production
		0.488	Non influential position of the energy manager in the organization
Factor 3	Lack of incentives (6%) Cronbach's Alpha: 0.692	0.838	Difficulty in obtaining the funds for energy efficiency projects
		0.695	Non availability of enough funds
Factor 4	Organizational policy Barriers (5.77%) Cronbach's Alpha: 0.694	0.678	The objectives of energy are not incorporated into operating, maintenance or purchasing procedures
		0.707	The organization is lacking policies, procedures and systems for energy efficiency
		0.691	The workers in the organization is not accountable for the energy costs
Factor 5	Distortionary fiscal and regulatory policies (5.54%) Cronbach's Alpha: 0.727	0.699	Non strict attitude of the government in enforcing environmental regulations
		0.828	Weak environmental policies and legislation relating to energy
		0.739	Government does not support with financial incentives for being energy efficient
Factor 6	Precedence Barriers (5.54%) Cronbach's Alpha: 0.640	0.631	Lack of time or other priorities
		0.727	Concerns of management on time consumed/required for improving the energy efficiency
		0.612	Production is considered more important than any other process

Factor 7	Technical Barriers (5.40%) Cronbach's Alpha: 0.693	0.531	Inappropriateness of Technology in the site
		0.807	Risks related to disruptions in productions
		0.840	Risks related to poor/non performance of the equipment
Factor 8	Behavioral barriers (5.22%) Cronbach's Alpha: 0.693	0.709	Managements perception that there is no/less scope for energy efficiency improvement
		0.812	Resistance from employees to shift from one technology to another or to change the way they work
		0.657	The perception of people that the energy efficiency can only be improved with new expensive technology
Factor 9	Organizational barriers (5.02%) Cronbach's Alpha: 0.618	0.398	Companies' culture does not encourage staff to give suggestions for improvement
		0.773	The future of the company is uncertain
		0.776	Decision making takes a lot of time or decision making chains are longer
Factor 10	Coordination related barriers (5%) Cronbach's Alpha: 0.657	0.639	Conflicts of interest within the company
		0.763	Departmental coordination in an organization is less
		0.759	Slim organizational structure
		0.454	Coordination between the external organizations is less
Factor 11	Awareness barriers (4.99%) Cronbach's Alpha: 0.649	0.632	Less awareness in the organization on energy efficiencies importance
		0.801	Technical knowledge among the employees in the organization is limited
		0.573	Less awareness of the staff
		0.461	It is much difficult to obtain technical information and expertise

Factor 12	Bounded rationality (4.13%) Cronbach's Alpha: 0.671	0.540	Difficult to get information on energy consumed by the new purchased equipment
		0.557	Poor information quality regarding energy efficiency opportunities
		0.638	The energy efficiency benefits cannot be quantified

Discussions

Factor 1: The (Thollander & Ottossom, 2008) has categorized the hidden costs and the lack of access to capital as Non Market Barriers whereas (Rohdin & Thollander, 2006a) has categorized costs incurred due to production disruptions; other organizational priorities for capital investments; costs incurred on replacement of staff and retraining of the new staff; costs incurred to identify various energy efficiency opportunities as hidden costs. Hence, factor one is termed as 'non-market barriers'.

Factor 2: The variables which have been loaded in factor two showcase that organizational management is very much preoccupied with many other responsibilities and low priority has been given for cost cutting projects which also includes energy saving ones (DeCanio S. , 1993). Hence, factor two is being termed as 'problems of focus and attention'.

Factor 3: The variables which have been loaded in factor three showcase the lack of incentives pertaining to energy efficiency measures. Hence, factor three has been termed as 'lack of incentive'.

Factor 4: The variables which have been loaded in factor four, such as, the objectives of energy are not incorporated into operating, maintenance or purchasing procedures, the organization is lacking policies, procedures and systems for energy efficiency, and the workers in the organization is not accountable for the energy costs showcases the barriers pertaining to organizational policies. Hence, factor four has been termed as ‘organizational policy barriers’.

Factor 5: Factor five has been termed as distortionary fiscal and regulatory policies (Brown, 2001) as the variables loaded in this factor showcase various barriers pertaining to ‘governmental policies’.

Factor 6: The variables which have been loaded in factor six, such as, lack of time or other priorities; concerns of management on time consumed/required for improving the energy efficiency; production is considered more important than any other process have termed factor six as ‘precedence barriers’.

Factor 7: This factor has been termed as the ‘technical barriers’, due to the loading of various variables such as inappropriateness of technology in the site, risks related to disruptions in productions and risks related to poor/non-performance of the equipment.

Factor 8: The variables which have been loaded in factor eight, such as, managements perception that there is no/less scope for energy efficiency improvement, resistance from employees to shift from one technology to another or to change the way they work and perception of people that the energy efficiency can only be improved with new expensive technology showcase barriers pertaining to the behavioural patterns of employees and management. Hence, this factor is termed as ‘behavioral barriers’.

Factor 9: This factor has been termed as ‘organizational barriers’ as the variables being loaded into this factor pertain to the organizations impact on implementing energy efficiency measures (Rohdin & Thollander, 2006a).

Factor 10: The various variables being loaded on this factor, such as conflicts of interest within the company, departmental coordination in an organization is less, slim organizational structure and coordination between the external organizations is less indicate the non-coordination among the internal and external environment. Hence, this factor has been termed as ‘co-ordination related barriers’.

Factor 11: This factor has been termed as ‘awareness barriers’ as various variables being loaded into this factor reveal various hindrances pertaining to insufficient/incorrect information on the implementation of energy efficiency measures

Factor 12: The variables being loaded on this factor, such as, difficulty to get information on energy consumed by the new purchased equipment, poor information quality regarding energy efficiency opportunities and the energy efficiency benefits cannot be quantified categorizes itself into the barrier term of bounded rationality (Sorrell, Mallett, & Nye, 2011)

Section 6.5: Driving Forces for the Implementation of Energy Efficiency in Indian Refineries

To identify the driving forces for the implementation of energy efficiency measures in refineries a total of 194 responses were analyzed. The reliability of the scale was checked using the statistical tool Cronbach’s Alpha. Table 6.16 shown below, presents the SPSS output data for Cronbach’s Alpha and a cutoff of 0.7 is considered to be highly reliable (Nunally, 1978).

Table 6.16: Reliability Statistics

Reliability Statistics	
Cronbach's Alpha	No of Items
0.841	31

The scale was found to be highly reliable as the Cronbach's Alpha value is above 0.7. Following the general acceptability of the scale, the scores obtained were further analyzed by using the factor analysis which reduced the data by grouping similar parameters to a few manageable factors.

The aptness of the factor analysis was evaluated by examining the sampling adequacy through Kaiser-Meyer-Olkin (KMO) statistic. Table 6.17 shown below presents the SPSS output data for KMO statistic and a cutoff of 0.6 is considered to be adequate (Kaiser & Rice, 1974).

From the below table it can be seen that KMO value is acceptable.

Table 6.17: KMO and Bartlett's Test

KMO and Bartlett's Test[a*]				
Sl. No	**Test Statistics**		**Result**	**Interpretation**
	Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.721	Significant
	Bartlett's Test of Sphericity	Approx. Chi-Square	2479.43	
		Df	465	
		Sig.	0	Significant
[a] Based on correlations				
[*] SPSS 16				

For analyzing the underlying factors in 31 variables, the PCA method was used. In PCA method the said factors were determined and justified by using two methods of determination such as Eigen Value Method and Scree Plot Method.

In the initial solution using the PCA method, 9 factors were determined (Appendix G) whose cumulative percentage of variances are explained by 68.835% which reaches the satisfactory level. The scree plot was drawn as shown below in figure 6.19.

After determining the nine factors, the factor matrix was prepared which loaded all the 31 variables on the factors (Appendix G). Thereafter factor rotation matrix was prepared by rotating the factors using varimax procedure which is an orthogonal method of factor rotation (Appendix H). Cronbach's Alpha of each nine factors was calculated to establish the internal consistency and it was found to be 0.725, 0.782, 0.768, 0.768, 0.780, 0.677, 0.668, 0.663 and 0.610 respectively for the studied factors and is found to be consistent.

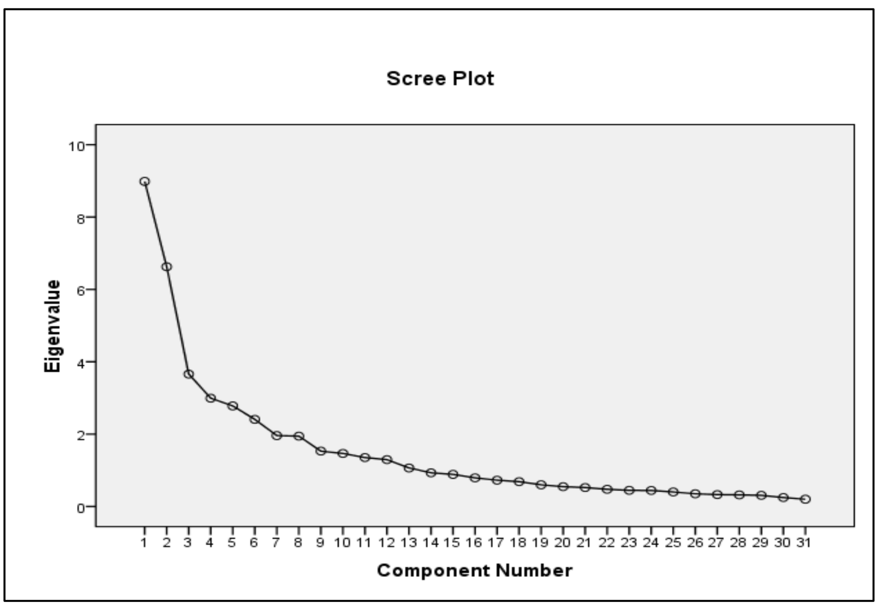

Fig 6.19: Scree Plot

By the application of factor analysis, 31 identified variables were reduced to nine major factors which act as major driving forces for the implementation of energy efficiency measures in Indian refinery. The significant factor loadings of each identified variable, the total variance explained for each factor and the Cronbach's Alpha for each factor is shown below in table 6.18.

Table 6.18: Driving Forces for Implementation of Energy Efficiency Measures in Indian Refineries and Variables Loaded into those Factors

Factors	**Factor Interpretation**	**Factor Loading**	**Variables included in Factor**
F1	Drivers from stakeholders end (9.31%) Cronbach Alpha: 0.725	0.725	Customer questions and demands
		0.774	Demand from owner
		0.626	Improved working conditions
F2	Organization policy oriented driver (9.01%) Cronbach Alpha: 0.782	0.877	Network within the company/group
		0.812	Environmental company profile
		0.734	Beneficial loans for energy efficiency investments
		0.523	Environmental Management system
		0.455	Long-term energy strategy of the organization
F3	Incentive oriented driver (7.87%) Cronbach Alpha: 0.768	0.735	Electricity Certificate System [ECS]
		0.812	Emission Trading Scheme
		0.712	Energy audit subsidy
F4	Individual oriented driver (7.63%) Cronbach Alpha: 0.768	0.647	Influential position of the energy manager in the organization
		0.798	Availability of real ambitious people in the organization
		0.827	Commitment from top management
F5	Literature oriented driver (7.50%) Cronbach Alpha: 0.780	0.563	General energy advices through journal or Booklet
		0.777	General energy advices through Seminar
		0.828	Detailed support from the energy experts
		0.680	Information and support through the sector organization
F6	Appraisal oriented driver (7.49%) Cronbach Alpha: 0.677	0.560	Publicly financed energy audits by Energy consultants
		0.792	Publicly financed energy audits by sector organized experts
		0.625	The public sector as role-model

		0.598	Voluntary agreements with tax exemption
F7	Financial benefits oriented driver (7.02%) Cronbach Alpha: 0.668	0.481	Third party financing
		0.822	Cost reductions due to less energy consumed
		0.774	Investment subsidies for energy efficiency technologies
F8	Legal oriented driver (6.73%) Cronbach Alpha: 0.663	0.642	Annual environmental report to BEE including an energy plan
		0.769	Energy efficiency requirements due to Energy Conservation Act,2001
		0.541	Pressure from different environmental NGOs
F9	Competition oriented driver (6.27%) Cronbach Alpha: 0.610	0.652	International competition
		0.710	Threat of rising energy prices
		0.558	Local authority energy consultancy

Discussions

Factor 1: The variables which have been loaded in factor one showcase customer questions and demands, demand from the owner and improved working conditions. Hence, factor one has been termed as drivers from 'stake-holder's end'.

Factor 2: Factor two has been termed as 'organizational policy oriented driver' as the variables been loaded on this factor, such as, network within the company/group, environmental company profile, beneficial loans for energy efficiency investments, environmental management system and long-term energy strategy of the organization highlight various drivers pertaining to organizational policies

Factor 3: The variables which have been loaded in factor three showcase the ECS, emission trading scheme and energy audit subsidy. Hence, factor three has been termed as 'incentive oriented driver'.

Factor 4: Factor four has been termed as ‘individual oriented driver’ as the variables loaded in this factor are indicative of various drivers are pertaining to individuals in the organization.

Factor 5: The variables which have been loaded in factor five are pertaining to the literature on energy efficiency. Hence, factor five has been termed as ‘literature oriented driver’.

Factor 6: The variables, such as, publicly financed energy audits by energy consultants, publicly financed energy audits by sector organized expert, the public sector as role-model and voluntary agreements with tax exemption are related to appraisal oriented. Hence, factor six has been termed as ‘appraisal oriented driver’.

Factor 7: Factor seven is termed as ‘financial benefits oriented driver’ as the variables loaded on this factor, such as, third party financing, cost reductions due to less energy consumed and investment subsidies for energy efficiency technologies reveal various drivers pertaining to financial benefits of implementing the energy efficiency measures.

Factor 8: The variables which have been loaded in factor eight are pertaining to the compliance related aspects on energy efficiency. Hence, factor eight has been termed as ‘legal oriented driver’.

Factor 9: The variables, such as, international competition, threat of rising energy prices and local authority energy consultancy are related to competition oriented. Hence factor nine has been termed as ‘competition oriented driver’.

Chapter 7

Recommendations and Conclusion

This study has tried to understand the entire spectrum of energy efficiency in Indian refineries demand side management [see fig 7.1]. It has studied the economic effectiveness of the energy efficiency measures implemented by the Indian refineries using secondary data, and has also identified various barriers to and driving forces for implementing energy efficiency measures in Indian refineries.

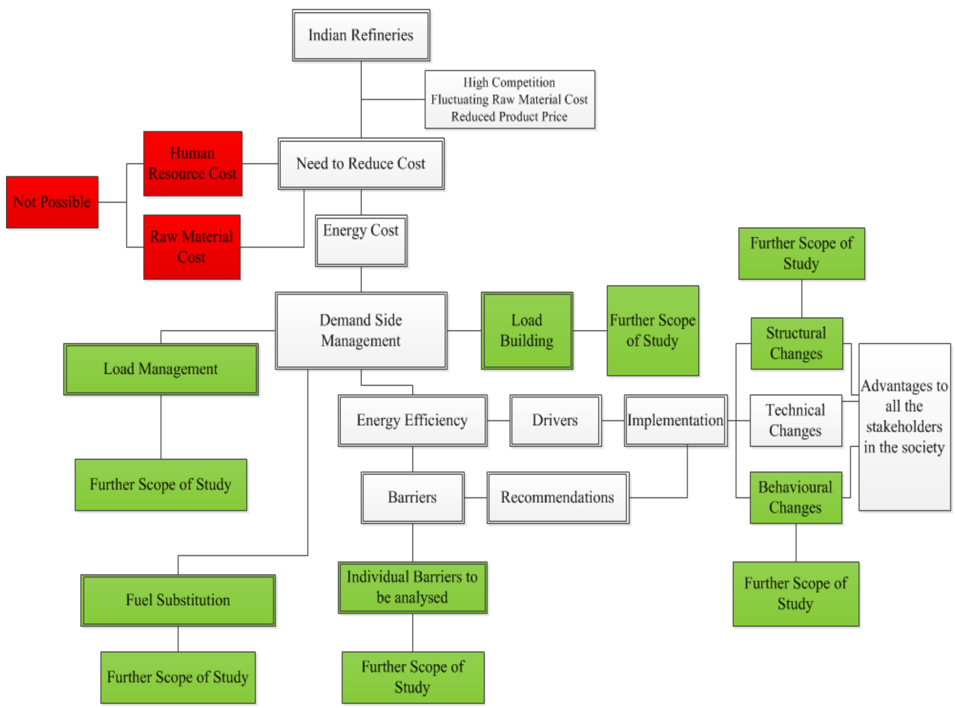

Fig 7.1: Understanding Demand Side Management in Indian refineries

It is noticed from the previous chapters that the implementation of these measures has not only reduced the energy consumed by a refinery, resulting in an annual saving, but also increased the efficiency of the processes with better product yield, and has also increased the production. The above studies showcase that the Indian refineries can economically improve the energy efficiency and the potential of savings in the millions of INR per annum depending on the size and efficiency of the refinery.

During the study period of 2000 - 2010, the overall energy intensity has reduced in Indian refineries which highlight the effectiveness of the implementation of energy efficiency measures. This was noticed in terms of various parameters, such as, the energy consumption per unit of crude processed, incremental concept, cumulative concept, cost benefit analysis, cost effectiveness, energy utilization index and energy cost index etc.

These parameters show clear cut energy conservation in the industry during the decade which can be attributed to various energy efficiency measures implemented by Indian refineries during the ibid. decade. Broadly, with the analysis of the energy efficiency measures it is brought out that in the Indian refining industry mainly technical measures were taken for energy conservation than structural or behavioral measures. It is also observed that investing in these measures can be much more attractive with the structural changes and also with the changes in the attitude and behavior of the employees, and the employees of the organization should be aware of the energy use and energy efficiency improvement objectives.

It is commendable that in spite of various internal and external impedements, the Indian refineries have reduced the energy intensity by about 10%. But, still there is more to do with regard to building energy efficient environment.

The review of has shown that there is a need for the effective implementation of legislative tool in India. Although NMEEE has been implemented, but as of now only nine industries have been specified as designated consumers in which oil refining industry is not included [oil refineries are among the designated consumers as per EC Act 2001]. This study has noticed that the companies in the Indian refining industry are considering the implementation of energy efficiency measures and are reporting as a legal obligation rather than an opportunity to save the costs. Various companies have only mentioned the energy efficiency measures implemented by them in the energy notes (annual report) and no other information, such as, investments made, energy saved etc., are considered. Hence, the researcher suggests the following framework for reporting the energy efficiency measures being implemented in the company [Table 7.1].

Table 7.1: Suggestive Framework for Reporting the Energy Efficiency Measures Implemented by Indian Refineries in Annual Report

Sl. No	Energy Efficiency Measure Implemented	Expenditure on EE Measure / Investments (in INR)	Operating Cost (in INR)	Maintenance Cost (in INR)	Life cycle of the Measure (in years)	Discounting factor (in %)	Savings		CO2 emissions reduced
							Energy (in a common unit kcal / Btu)	Money (in INR)	
Technical Measures									
1									
2									
Structural Measures									
1									
2									
Behavioral Measures									
1									
2									
Total									

The study has identified various barriers which prevent the implementation of energy efficiency measures in Indian refining context and they are as follows:

- Non-market barriers
- Problems of focus & attention
- Lack of incentives
- Organizational policy barriers
- Distortionary fiscal and regulatory policies
- Precedence barriers, technical barriers
- Behavioral barriers
- Organizational barriers
- Co-ordination related barriers
- Awareness barriers
- Bounded rationality

These key barriers were further classified as barriers pertaining to management, knowledge information, financing and policy for better understanding the barriers and to recommend a suggestive framework to remove/minimize these barriers and for better implementation of energy efficiency measures in Indian refineries. The following measures are recommended with the help of literature review and also by interviewing the industry experts, academicians and policy makers (Table 7.2).

Table 7.2: Recommendations to Minimize the Barriers to Energy Efficiency Implementation in Indian Refineries

Key Barriers	Solutions
Management • Problems of focus and attention • Organizational policy barriers • Precedence barriers • Technical barriers • Behavioral barriers • Organizational barriers • Coordination related barriers	• Training/Capacity building of employees • Display of projects which has achieved their goals • Awards & recognitions • Dissemination of success stories • Documentation & Sharing of experiences • Comparative studies • Government Notes • Incentives from governments
Knowledge Information • Awareness barriers • Bounded rationality	• Training or demonstration of energy efficiency technologies. • Establishment of knowledge management. • Research & development activities • Inter and intra regional research • Mapping of gaps and strengths • Information sharing among companies • Documentation & sharing of experiences • Comparative studies
Financing • Non market barriers • Lack of incentives	• Ensuring the availability of literature pertaining existing financial packages/institutions • Companies being assisted by financial institutions • Agencies supporting organizations to develop proposals which are bankable
Policy • Distortionary Fiscal and regulatory policies	• The fiscal & economic policies aiming at aligning energy, environment and economic policies • Designing policies which can actually be enforced, monitored and complied with • Transparency of policies in relation to demand side management, energy efficiency, investments etc.

The following factors have been identified as the various driving forces for the implementation of energy efficiency measures in Indian refineries:

- Drivers from stakeholders end
- Organization policy oriented drivers
- Incentive oriented drivers
- Individual oriented drivers
- Literature oriented drivers
- Appraisal oriented drivers
- Financial benefits oriented drivers
- Legal oriented drivers and
- Competition oriented drivers

These identified driving forces help the energy managers, policy makers, academicians and various stakeholders of the Indian refining industry to take better decisions on the implementation of the same. The driving forces, such as, the drivers from stakeholders end, organization policy oriented drivers, incentive oriented drivers, and financial benefits oriented drivers indicate to the internal organizational factors. If the top level management takes their decisions keeping these factors in mind, better implementation of energy efficiency in refineries can be achieved. Factors, such as, individual oriented drivers, literature oriented drivers and appraisal oriented drivers may focus on policy development within the organization which positively affects the organization. From an energy manager point of view, not only do these factors encourage the staff in the organization, but also implement the energy efficiency measures better. The government can also design and adopt new policies taking these factors into consideration. This study has showcased that in Indian refineries, energy efficiency measures have been implemented, and the driving forces, that have contributed to the implementation of these measures, are not solely policy related but are also due to various other factors.

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Appendix A

Table A.1: List of Refineries in India

[Arranged as per their capacities of their output]

Sl. No.	Name of the Company / Refinery under study	Location of the refinery	Capacity, MMTPA
1	Reliance Industries Ltd. (RIL)	Jamnagar, Gujarat	33
2	Reliance Petroleum Limited (SEZ)	Jamnagar, Gujarat	27
3	Indian Oil Corporation Limited (IOCL)	Panipat, Haryana	15
4	Indian Oil Corporation Limited (IOCL)	Koyali, Vadodara, Gujarat	13.7
5	Bharat Petroleum Corporation Limited (BPCL)	Mumbai, Maharashtra	12
6	Mangalore Refinery & Petrochemicals Ltd. (MRPL)	Mangalore, Karnataka	11.82
7	Chennai Petroleum Corporation Limited	Manali, Tamil Nadu	10.5
8	Essar Oil Limited (EOL)	Jamnagar, Gujarat	10.5
9	Bharat Petroleum Corporation Limited (BPCL)	Kochi, Kerala	9.5
10	Hindustan Petroleum Corporation Limited (HPCL)	Visakhapatnam, Andhra Pradesh	8.3
11	Indian Oil Corporation Limited (IOCL)	Mathura, Uttar Pradesh	8
12	Indian Oil Corporation Limited (IOCL)	Haldia, West Bengal	7.5
13	Hindustan Petroleum Corporation Limited (HPCL)	Mumbai, Maharashtra	6.5

14	Indian Oil Corporation Limited (IOCL)	Barauni, Bihar	6
15	Bharat Petroleum Corporation Limited & Oman Oil Company, joint venture, Bina	Bina, Madhya Pradesh	6
16	Numaligarh Refinery Ltd.(NRL)	Numaligarh, Assam,	3
17	Indian Oil Corporation Limited (IOCL)	Bongaigaon, Assam	2.35
18	Indian Oil Corporation Limited (IOCL)	Guwahati, Assam	1
19	Chennai Petroleum Corporation Limited (CPCL)	Nagapattnam, Tamil Nadu	1
20	Indian Oil Corporation Limited (IOCL)	Digboi, Assam	0.65
21	Tatipaka Refinery (ONGC)	Tatipaka, Andhra Pradesh	0.066
22	HMEL (HPCL & Mittal Energy)	Bhatinda	9

Source: (http://petroleum.nic.in/refinery.pdf dated 29/09/2011 and http://www.thehindu.com/business/companies/article3363837.ece dated 28/04/2012)

Appendix B

Table A.2: Energy Conversion Factors

Sl. No.	Energy Type	Energy Unit	Conversion into (Kilo Calorie)
1	Agro aste	Tones	1598929.9704
2	Baggage	Tones	1598929.9704
3	Baggage/Fire-wood/Paddy/tusic	000 Liters	1598929.9704
4	Charcoal	Tones	7395051.1130
5	Coal	Kgs	6195.8536
6	Coal	Kwh	859.8450
7	Coal	Million Cal	1,00,000.0000
8	Coal	Tone	6195853.6352
9	Coal & lignite	MKCal	1,00,000.0000
10	Coal & lignite	Tones	6195853.6352
11	Coconut Shell	Tones	1848762.7700
12	Coke	Tones	6195853.6352
13	Diesel	Liters	9244.8860
14	Diesel	Tones	10093245.4380
15	Dissolved Acety lene	000 liters	6541033.7250
16	Electricity	Kwh	859.8452
17	Fire wood	Tone	3797458.6797
18	Fuel	Kls	9109.8050
19	Furnace Oil	000 liters	9819819.8198
20	Furnace Oil	Tones	10900000.0000
21	Furnace oil & HSD	kls	9244885.5696
22	Furnace oil & LSHS	Tones	10093245.4380
23	Gas	000 cu.mts.	238845.8960
24	Gas	Tones	14106238654.7906
25	Hard & Coke	Tones	6195853.6352
26	HSD	Kls	9244885.5696
27	Husk	Tones	975000.0000
28	Kerosene	Kls	8972309.0909
29	LDO & LSHS	Kls	9244885.5696

Sl. No.	Energy Type	Energy Unit	Conversion into (Kilo Calorie)
30	LDO & LSHS	Tones	10093245.4380
31	LPG & Natural Gas	Tones	10792777.3001
32	Lignite	Tones	3665090.2837
33	LPG	Kls	637457.5943
34	LPG	Therms	26142.0177
35	Liquid oxygen	000Cumeters	579854.1600
36	Low sulphur heavy stock	Kls	166215960.0000
37	Low sulphur heavy stock	Tones	10533104.0413
38	Lubricants	Kls	162447840.0000
39	Lubricants	Tones	10365911.9136
40	Naphtha	Kls	13145520.0000
41	Naphtha	Tones	11488487.6278
42	Natural Gas	000 Cu meters	9509.8882
43	Nitrogen	000 Cu meters	59472.6283
44	Non-Coking Coal	Tones	6448839.2889
45	Oxygen	000 Cu meters	57985416.0000
46	Petrol	Kls	143188560.0000
47	Petroleum Coke	Tones	6448839.2089
48	Propane	Tones	10792777.3001
49	Rice Husk	Kgs	90075.0000
50	Saw Dust	Tones	2600000.0000

Source: (Dwivedi & Diwan, 2008)

Appendix C

Name:

E Mail Address:

Category: Energy Manager/ Industry Expert/ Energy Auditors/ Academicians/ MoPNG Representative

Barriers to the Implementation of energy efficiency measures in Indian refineries

According to the aggregated experience, how do you value the following factors impact on the implementation of cost-effective energy efficiency measures in Indian refineries

Table A.3: Questionnaire to identify the barriers to the Implementation of energy efficiency measures in Indian refineries

Types of Barriers	Strongly Disagree [1]	Disagree [2]	Neutral [3]	Agree [4]	Strongly agree [5]
Conflicts of interest within the company					
Departmental coordination in an organisation is less					
Slim organizational structure					
Coordination between the external organizations is less					

Non strict attitude of the government in enforcing environmental regulations					
Weak environmental policies and legislation relating to energy					
Government does not support with financial incentives for being energy efficient					
The objectives of energy are not incorporated into operating, maintenance or purchasing procedures					
The organization is lacking policies, procedures and systems for energy efficiency					
The workers in the organization is not accountable for the energy costs					
Difficult to get information on energy consumed by the new purchased equipment					

Poor information quality regarding energy efficiency opportunities					
The energy efficiency benefits cannot be quantified					
Difficulty in obtaining the funds for energy efficiency projects					
Non availability of enough funds					
It is difficult to access the capital for energy efficient technology					
Costs incurred due to production disruptions					
Other organizational priorities for capital investments					
Costs incurred on replacement of staff and retraining of the new staff					
Costs incurred to identify various energy efficiency opportunities					
Companies' culture does not encourage staff to give suggestions for improvement					

No specific person/committee is available to deal with the energy					
Non availability of energy conservation targets in the organization					
Non importance / less priority of energy management in the organization					
Non Importance of energy as a factor of production					
Non influential position of the energy manager in the organization					
Future of the company is uncertain					
Decision making takes a lot of time or decision making chains are long					
Lack of time or other priorities					
Concerns of management on time consumed/required for improving the energy efficiency					
Production is considered more important than any other process					

Inappropriateness of Technology in the site					
Risks related to disruptions in productions					
Risks related to poor/non performance of the equipment					
Managements perception that there is no/less scope for energy efficiency improvement					
Resistance from employees to shift from one technology to another or to change the way they work					
Perception of people that the energy efficiency can only be improved with new expensive technology					
Less awareness in the organization on energy efficiencies importance					
Technical knowledge among the employees in the organization is limited					

Less awareness of the staff					
It is much difficult to obtain technical information and expertise					

Driving forces for the Implementation of energy efficiency measures in Indian refineries

According to the aggregated experience, how do you value the following factors impact on the implementation of cost-effective energy efficiency measures in Indian refineries

Table A.4: Questionnaire to identify the driving factors for the Implementation of energy efficiency measures in Indian refineries

Types of Driving Forces	Strongly Disagree [1]	Disagree [2]	Neutral [3]	Agree [4]	Strongly agree [5]
Network within the company/group					
Environmental company profile					
Beneficial loans for energy efficiency investments					
Environmental Management system					

Long-term energy strategy of the organization					
Customer questions and demands					
Demand from owner					
Improved working conditions					
Electricity Certificate System (ECS)					
Emission Trading Scheme					
Energy audit subsidy					
Influential position of the energy manager in the organization					
Availability of real ambitious people in the organization					
Commitment from top management					
General energy advices through journal or Booklet					
General energy advices through Seminar					

Detailed support from energy experts					
Information and support through the sector organization					
International competition					
Threat of rising energy prices					
Local authority energy consultancy					
Third party financing					
Annual environmental report to BEE including an energy plan					
Energy efficiency requirements due to Energy Conservation Act,2001					
Pressure from different environmental NGOs					
Publicly financed energy audits by Energy consultants					
Publicly financed energy audits by sector organised expert					

The public sector as role-model					
Cost reductions due to less energy consumed					
Investment subsidies for energy efficiency technologies					
Voluntary agreements with tax exemption					

Appendix D

Table A.5: Regression Analysis Summary of Industry

Regression Statistics	
Multiple R	0.95
R Square	0.89
Adjusted R Square	0.88
Standard Error	0.11
Energy Intensity	0.83
Observations	10

Table A.6: Regression Analysis Summary of BPCL

Regression Statistics	
Multiple R	0.85
R Square	0.73
Adjusted R Square	0.70
Standard Error	0.34
Energy Intensity	1.00
Observations	10

Table A.7: Regression Analysis Summary of CPCL

Regression Statistics	
Multiple R	0.68
R Square	0.46
Adjusted R Square	0.39
Standard Error	0.18
Energy Intensity	0.20
Observations	10

Table A.8: Regression Analysis Summary of HPCL

Regression Statistics	
Multiple R	0.79
R Square	0.63
Adjusted R Square	0.58
Standard Error	0.08
Energy Intensity	0.29
Observations	10

Table A.9: Regression Analysis Summary of IOCL

Regression Statistics	
Multiple R	0.93
R Square	0.87
Adjusted R Square	0.86
Standard Error	0.06
Energy Intensity	0.42
Observations	10

Table A.10: Regression Analysis Summary of MRPL

Regression Statistics	
Multiple R	1.00
R Square	1.00
Adjusted R Square	1.00
Standard Error	0.03
Energy Intensity	1.00
Observations	10

Table A.11: Regression Analysis Summary of NRL

Regression Statistics	
Multiple R	0.80
R Square	0.63
Adjusted R Square	0.59
Standard Error	0.11
Energy Intensity	0.53
Observations	10

Table A.12: Regression Analysis Summary of RIL

Regression Statistics	
Multiple R	0.90
R Square	0.81
Adjusted R Square	0.78
Standard Error	0.44
Energy Intensity	1.72
Observations	10

Appendix E

Table A.13: Total variance explained using Principle Component Analysis
[Barriers to the implementation of energy efficiency measures in Indian refineries]

Total Variance Explained									
Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.69	13.84	13.84	5.65	13.77	13.77	2.93	7.15	7.15
2	6.16	9.82	23.66	4.00	9.75	23.52	2.91	7.11	14.26
3	4.45	7.09	30.74	2.87	7.01	30.53	2.46	6.00	20.26
4	3.90	6.21	36.95	2.60	6.34	36.86	2.36	5.77	26.03
5	3.33	5.30	42.25	2.08	5.07	41.94	2.27	5.54	31.57
6	2.78	4.43	46.68	1.76	4.29	46.22	2.27	5.54	37.11
7	2.62	4.17	50.85	1.77	4.32	50.54	2.21	5.40	42.51
8	2.46	3.92	54.77	1.57	3.82	54.36	2.14	5.22	47.73
9	2.24	3.56	58.34	1.46	3.55	57.91	2.06	5.02	52.76
10	2.01	3.20	61.54	1.34	3.27	61.18	2.05	5.00	57.75
11	1.92	3.06	64.60	1.23	2.99	64.17	2.05	4.99	62.75
12	1.71	2.73	67.33	1.11	2.71	66.88	1.69	4.13	66.88

13	1.47	2.35	69.67							
14	1.44	2.29	71.96							
15	1.30	2.07	74.03							
16	1.25	1.99	76.02							
17	1.24	1.98	78.00							
18	1.11	1.77	79.76							
19	1.00	1.60	81.36							
20	0.96	1.54	82.90							
21	0.94	1.50	84.40							
22	0.84	1.34	85.74							
23	0.78	1.24	86.98							
24	0.72	1.15	88.13							
25	0.71	1.12	89.25							
26	0.64	1.02	90.27							
27	0.62	0.99	91.26							
28	0.61	0.98	92.24							
29	0.59	0.94	93.18							
30	0.53	0.85	94.02							
31	0.47	0.75	94.77							
32	0.46	0.73	95.50							
33	0.42	0.67	96.17							
34	0.39	0.62	96.79							

35	0.35	0.55	97.34							
36	0.31	0.50	97.84							
37	0.31	0.49	98.33							
38	0.30	0.48	98.81							
39	0.27	0.43	99.24							
40	0.25	0.39	99.64							
41	0.23	0.36	100.00							
Extraction Method: Principle Component Analysis										

Appendix F

Table A.14: Factor rotation matrix using Principle Component Analysis
[Barriers to the implementation of energy efficiency measures in Indian refineries]

actor Matrix*												
	Component											
	1	2	3	4	5	6	7	8	9	10	11	12
Conflicts of interest within the company	0.053	0.415	0.466	-0.278	-0.051	-0.273	-0.026	-0.015	0.341	-0.002	0.090	0.108
Departmental coordination in an organisation is less	0.267	0.352	0.464	-0.163	0.093	-0.267	0.089	0.035	0.414	-0.050	0.102	-0.122
Slim organizational structure	0.141	0.235	0.389	0.203	-0.005	-0.146	0.171	-0.092	0.442	0.158	0.223	-0.213
Coordination between the external organizations is less	0.272	0.248	0.164	0.427	0.018	-0.127	-0.037	-0.226	0.191	0.188	0.070	-0.142

Non strict attitude of the government in enforcing environmental regulations	-0.021	0.153	0.403	0.584	-0.050	0.126	-0.230	-0.044	-0.095	0.290	-0.040	-0.013
Weak environmental policies and legislation relating to energy	0.087	0.093	0.167	0.626	0.043	-0.087	-0.418	0.161	-0.025	0.192	-0.080	0.211
Government does not support with financial incentives for being energy efficient	0.079	0.217	0.373	0.351	0.085	-0.036	-0.451	0.156	-0.144	-0.018	-0.159	0.235
The objectives of energy are not incorporated into operating, maintenance or purchasing procedures	0.375	0.178	0.422	-0.145	0.079	-0.235	-0.140	0.063	-0.286	-0.062	-0.172	0.223

The organization is lacking policies, procedures and systems for energy efficiency	0.352	0.395	-0.035	-0.134	0.269	-0.434	0.157	-0.162	-0.146	-0.077	-0.134	0.191
The workers in the organization is not accountable for the energy costs	0.361	0.379	0.262	-0.325	0.162	-0.188	0.089	-0.022	-0.252	0.047	-0.049	0.116
Difficult to get information on energy consumed by the new purchased equipment	0.411	0.421	-0.014	-0.022	-0.056	-0.214	0.240	-0.089	-0.337	0.147	0.155	-0.143
Poor information quality regarding energy efficiency opportunities	0.365	0.302	0.395	-0.086	-0.204	0.081	-0.111	0.060	-0.372	-0.027	0.148	-0.146
The energy efficiency benefits cannot be quantified	0.360	0.399	0.021	0.290	-0.306	0.091	0.063	-0.120	-0.374	0.073	0.117	-0.181

Difficulty in obtaining the funds for energy efficiency projects	0.286	0.278	-0.280	0.491	-0.354	0.005	0.205	-0.068	-0.149	-0.303	0.123	0.004
Non availability of enough funds	0.318	0.443	-0.137	0.285	-0.274	-0.033	0.161	0.141	-0.002	-0.308	-0.140	-0.009
It is difficult to access the capital for energy efficient technology	0.512	0.395	-0.115	0.077	0.039	0.162	0.216	0.059	0.169	-0.196	-0.193	0.071
Costs incurred due to production disruptions	0.352	0.490	-0.051	-0.160	0.180	0.453	0.150	0.069	0.060	0.016	-0.191	0.050
Other organizational priorities for capital investments	0.292	0.367	-0.034	-0.212	0.323	0.608	0.019	0.154	0.012	0.163	0.018	0.035
Costs incurred on replacement of staff and retraining of the new staff	0.492	0.507	-0.306	-0.083	0.195	0.312	-0.050	-0.055	0.198	0.084	0.041	0.092

Costs incurred to identify various energy efficiency opportunities	0.452	0.326	-0.351	-0.010	0.024	0.241	-0.200	-0.076	0.096	0.153	0.072	0.117
Companies' culture does not encourage staff to give suggestions for improvement	0.491	-0.027	-0.270	0.126	-0.176	-0.011	-0.397	0.137	0.319	0.006	0.105	0.137
No specific person/committee is available to deal with the energy	0.544	-0.228	-0.223	0.097	-0.398	-0.166	-0.054	0.121	0.192	0.025	-0.178	0.038
Non availability of energy conservation targets in the organization	0.512	-0.249	-0.139	-0.070	-0.431	-0.114	-0.041	-0.028	0.131	0.250	-0.167	0.087
Non importance / less priority of energy management in the organization	0.476	-0.278	-0.211	-0.070	-0.246	-0.149	0.289	0.065	0.054	0.365	-0.171	-0.014
Non Importance of	0.452	-	0.017	-	0.034	-	0.056	0.328	-	0.432	-	-

energy as a factor of production		0.258		0.221		0.080			0.131		0.115	0.155
Non influential position of the energy manager in the organization	0.500	-0.277	-0.095	-0.157	0.094	-0.160	-0.006	0.192	-0.130	0.256	0.050	-0.011
Future of the company is uncertain	0.496	-0.138	-0.364	0.005	0.264	-0.230	-0.065	0.264	-0.040	-0.075	0.326	-0.246
Decision making takes a lot of time or decision making chains are long	0.412	-0.246	-0.060	-0.139	0.169	-0.078	-0.237	0.451	-0.107	-0.188	0.334	0.025
Lack of time or other priorities	0.395	-0.259	0.218	-0.197	-0.062	0.113	-0.241	0.200	0.021	-0.370	-0.122	0.054
Concerns of management on time consumed/required for improving the energy efficiency	0.460	-0.242	0.310	-0.045	-0.196	0.159	0.111	0.153	0.049	-0.338	-0.140	-0.223

Production is considered more important than any other process	0.204	-0.316	0.517	0.094	-0.230	0.202	0.194	0.151	0.092	-0.036	-0.186	-0.049
Inappropriateness of Technology in the site	0.292	-0.333	0.244	0.135	-0.073	0.220	0.385	0.053	-0.035	0.154	-0.069	0.062
Risks related to disruptions in productions	0.209	-0.325	0.280	0.440	0.257	0.097	0.374	0.197	0.074	-0.047	0.252	0.101
Risks related to poor/non performance of the equipment	0.048	-0.395	0.236	0.379	0.407	0.097	0.328	0.120	-0.014	0.074	0.198	0.282
Managements perception that there is no/less scope for energy efficiency improvement	0.410	-0.196	-0.181	0.279	0.521	-0.228	0.088	-0.137	0.016	-0.198	-0.194	-0.018

Resistance from employees to shift from one technology to another or to change the way they work	0.424	-0.307	-0.117	0.159	0.389	-0.098	-0.084	-0.417	0.007	0.030	-0.279	-0.127
Perception of people that the energy efficiency can only be improved with new expensive technology	0.363	-0.265	0.173	0.056	0.270	0.161	-0.195	-0.254	-0.004	-0.085	-0.215	-0.390
Less awareness in the organization on energy efficiencies importance	0.497	-0.286	0.165	-0.048	0.020	0.125	-0.300	-0.398	0.019	-0.053	0.170	-0.089
Technical knowledge among the employees in the organization is limited	0.415	-0.283	0.130	-0.145	-0.178	0.182	-0.076	-0.419	-0.028	-0.004	0.423	0.082

Less awareness of the staff	0.281	-0.384	0.291	-0.331	-0.119	0.103	0.049	-0.272	-0.132	-0.018	0.004	0.284
It is much difficult to obtain technical information and expertise	0.347	-0.227	-0.237	0.028	-0.138	-0.072	0.179	-0.257	0.047	-0.104	0.114	0.431
Extraction Method: Principal Component Analysis.												
* 12 components extracted.												

Appendix G

Table A.15: Total variance explained using Principle Component Analysis
[Driving forces for implementation of energy efficiency measures in Indian refineries]

Component	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**	**Total**	**% of Variance**	**Cumulative %**
1	8.98	18.99	18.99	5.80	18.70	18.70	2.89	9.31	9.31
2	6.63	14.01	33.00	4.15	13.38	32.08	2.79	9.01	18.32
3	3.66	7.74	40.74	2.45	7.89	39.97	2.44	7.87	26.19
4	2.99	6.33	47.07	1.87	6.04	46.01	2.36	7.63	33.82
5	2.78	5.88	52.95	1.75	5.65	51.66	2.32	7.50	41.31
6	2.41	5.09	58.04	1.64	5.29	56.94	2.32	7.49	48.81
7	1.96	4.14	62.18	1.34	4.34	61.28	2.18	7.02	55.83
8	1.95	4.11	66.30	1.29	4.15	65.43	2.09	6.73	62.56
9	1.53	3.24	69.53	1.05	3.40	68.84	1.95	6.27	68.84
10	1.47	3.10	72.63						
11	1.35	2.86	75.49						
12	1.30	2.74	78.23						
13	1.07	2.25	80.48						

14	0.93	1.97	82.45						
15	0.89	1.88	84.33						
16	0.79	1.68	86.01						
17	0.73	1.54	87.55						
18	0.69	1.45	89.00						
19	0.60	1.27	90.27						
20	0.55	1.16	91.43						
21	0.52	1.11	92.54						
22	0.48	1.00	93.54						
23	0.45	0.94	94.49						
24	0.44	0.94	95.43						
25	0.40	0.85	96.27						
26	0.35	0.74	97.02						
27	0.33	0.70	97.72						
28	0.32	0.68	98.40						
29	0.31	0.65	99.05						
30	0.25	0.52	99.57						
31	0.20	0.43	100.00						
Extraction Method: Principle Component Analysis									

Appendix H

Table A.16: Factor rotation matrix using Principle Component Analysis
[Driving forces for implementation of energy efficiency measures in Indian refineries]

Factor Matrix*										
Sl. No	**Variable**	**Factors**								
		1	2	3	4	5	6	7	8	9
1	Network within the company/group	0.072	0.715	-0.024	-0.516	-0.209	-0.024	-0.153	0.015	-0.096
2	Environmental company profile	0.185	0.657	0.103	-0.372	-0.227	-0.033	0.009	0.057	-0.155
3	Beneficial loans for energy efficiency investments	0.307	0.547	0.248	-0.388	-0.127	0.033	0.100	0.086	0.023
4	Environmental Management system	0.137	0.526	0.196	-0.056	0.019	-0.141	0.299	0.162	-0.133

5	Long-term energy strategy of the organization	0.032	0.572	0.259	0.051	0.036	-0.286	0.105	0.118	0.043
6	Customer questions and demands	0.559	-0.086	0.250	-0.036	-0.260	-0.381	-0.112	-0.234	-0.045
7	Demand from owner	0.599	-0.105	0.148	0.100	-0.125	-0.496	0.120	-0.010	-0.087
8	Improved working conditions	0.614	-0.106	0.065	-0.080	0.075	-0.387	0.227	-0.106	0.137
9	Electricity Certificate System (ECS)	0.609	-0.114	-0.140	-0.184	0.357	-0.329	0.164	-0.011	0.147
10	Emission Trading Scheme	0.587	-0.152	-0.172	-0.215	0.493	-0.109	0.000	0.196	0.163
11	Energy audit subsidy	0.509	0.003	-0.374	-0.097	0.452	-0.095	-0.145	-0.006	0.076
12	Influential position of the energy manager in the organization	0.192	0.587	-0.438	0.117	0.182	-0.071	-0.169	-0.153	0.156

13	Availability of real ambitious people in the organization	0.303	0.514	-0.302	0.321	-0.198	-0.003	-0.269	-0.164	0.171
14	Commitment from top management	0.325	0.415	-0.307	0.355	-0.331	-0.013	-0.245	-0.118	0.288
15	General energy advices through journal or Booklet	0.626	-0.149	-0.127	0.172	-0.348	0.021	0.180	-0.296	0.001
16	General energy advices through Seminar	0.594	-0.261	-0.246	-0.075	-0.355	0.254	0.333	-0.101	0.150
17	Detailed support from energy experts	0.381	0.077	-0.378	-0.138	-0.179	0.432	0.453	0.104	0.014
18	Information and support through the sector organization	0.415	-0.073	-0.531	-0.073	0.029	0.327	0.244	-0.013	-0.285
19	International competition	0.099	0.584	-0.323	0.177	0.328	0.009	0.220	0.130	-0.235
20	Threat of rising energy prices	0.235	0.434	-0.272	0.404	0.212	0.110	-0.107	-0.001	-0.335

21	Local authority energy consultancy	0.568	0.040	0.046	0.458	-0.019	-0.066	-0.256	0.140	-0.366
22	Third party financing	0.210	0.389	0.170	0.468	-0.097	0.128	0.175	0.371	0.053
23	Annual environmental report to BEE including an energy plan	0.679	-0.233	0.302	0.116	-0.193	0.083	0.009	0.276	0.001
24	Energy efficiency requirements due to Energy Conservation Act,2001	0.564	-0.285	0.105	0.114	-0.160	0.008	-0.155	0.506	0.019
25	Pressure from different environmental NGOs	0.294	0.099	-0.032	-0.169	-0.133	0.233	-0.355	0.337	0.376
26	Publicly financed energy audits by Energy consultants	0.486	-0.242	0.014	-0.302	0.096	0.320	-0.305	-0.018	0.098

27	Publicly financed energy audits by sector organised expert	0.561	-0.128	0.184	-0.147	0.160	0.281	-0.199	-0.344	-0.240
28	The public sector as role-model	0.482	0.155	0.397	0.041	0.143	0.211	-0.022	-0.379	-0.075
29	Cost reductions due to less energy consumed	0.128	0.399	0.542	0.285	0.169	0.208	0.184	-0.267	0.240
30	Investment subsidies for energy efficiency technologies	-0.045	0.501	0.403	0.146	0.346	0.252	0.152	0.045	0.288
31	Voluntary agreements with tax exemption	0.477	-0.128	0.391	-0.077	0.253	0.270	-0.143	0.055	-0.137
Extraction Method: Principal Component Analysis.										
* 9 components extracted.										

Profile of the Author

Geo Jos Fernandez, a faculty and a researcher in Energy Efficiency and its economics, has more than five years of Industry/Research experience. He obtained university rank in MBA [Upstream Asset Management] from university of Petroleum and Energy Studies and 90% marks for his graduation [B.Sc Petrochemicals] from M.G University which coupled with his inquisitive mind has fueled him to be in research and development domain.

Earlier he was working with a service provider in Oil and Gas sector as a an Asst. Manager [Projects & Business Development] and was instrumental in setting up various offices/acquiring businesses in Houston, Dubai and Mundra. He has presented numerous papers in various international conferences and has conducted workshops and guest lecturers for curious minds in various institutions.

An avid reader and a painter, is working with the University of Petroleum & Energy studies as a ‘Research Fellow’ to pursue his passion for research and teaching.