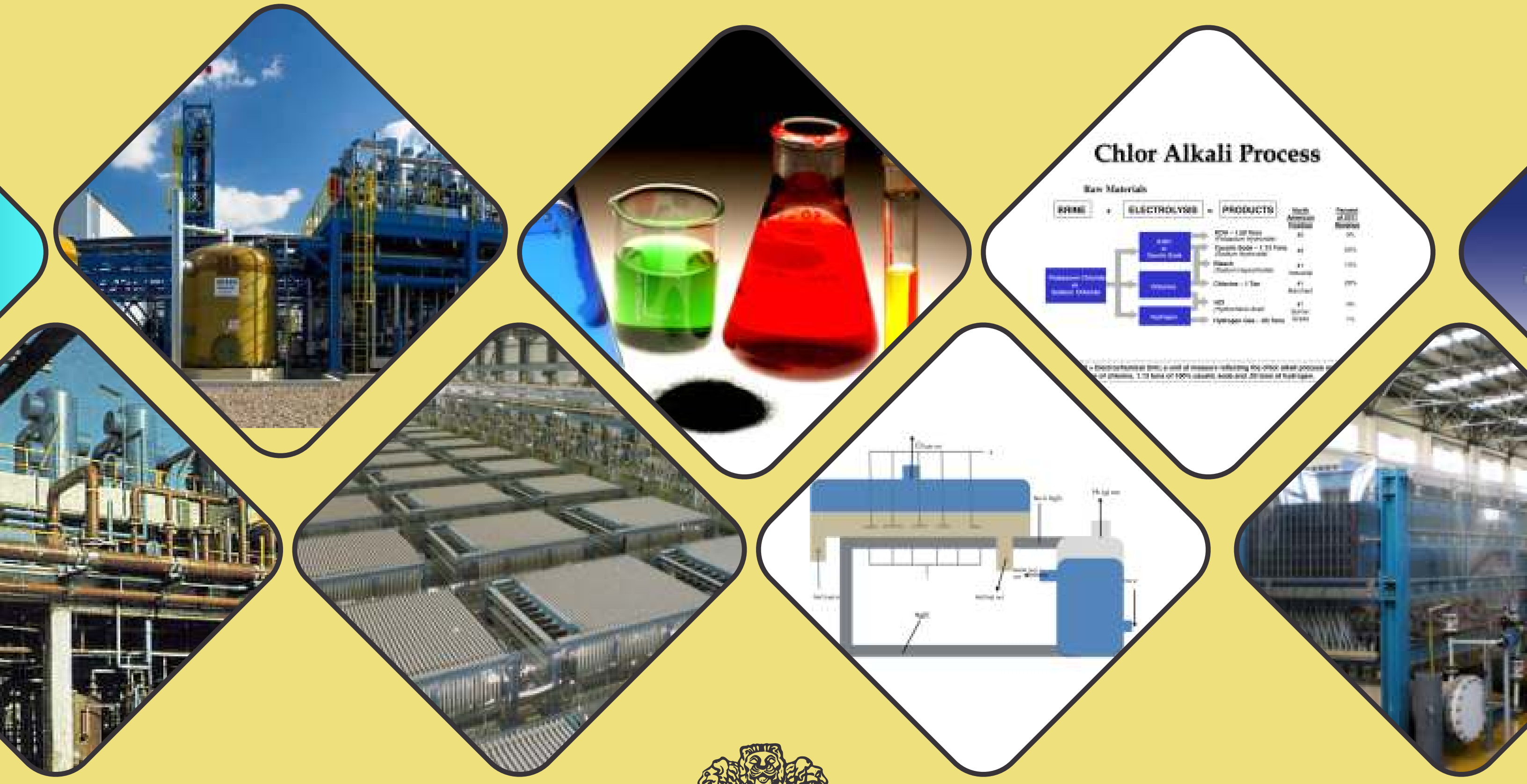
PAT SCHEME
PERFORM, ACHIEVE, TRADE

NORMALIZATION DOCUMENT AND MONITORING & VERIFICATION GUIDELINES

Chlor Alkali Sector



सत्यमेव जयते

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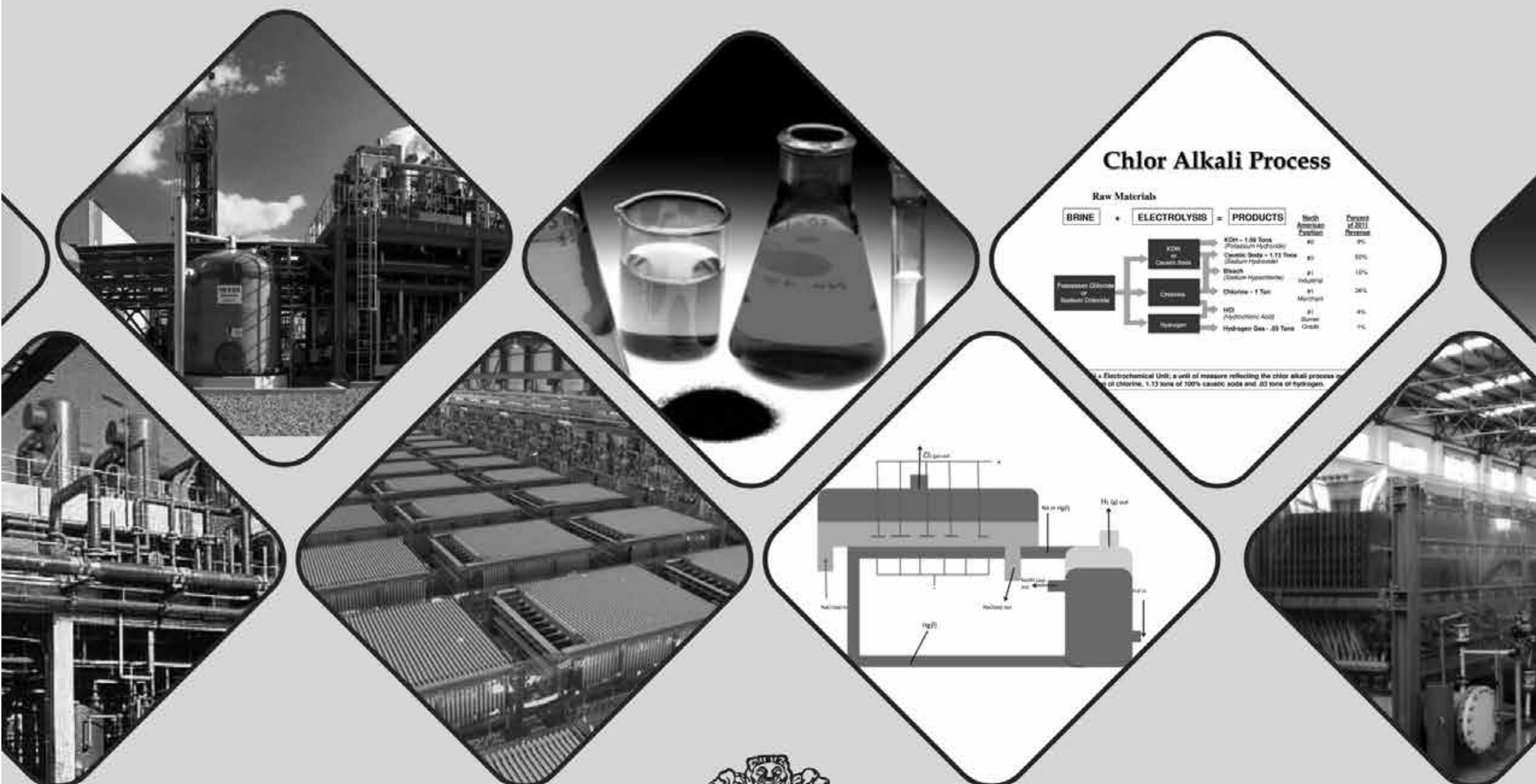

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Disclaimer

This document has been developed after an extensive consultation with a number of experts and stakeholders of the scheme. BEE disclaim any liability for any kind of loss whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, or reliance on this document.

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BUREAU OF ENERGY EFFICIENCY
(Government of India, Ministry of Power)

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Ajay Mathur, Ph.D.
Director General

Foreword

Perform Achieve and Trade (PAT), a flagship initiative under National Mission for Enhanced Energy Efficiency (NMEEE), is a regulatory intervention for reduction of specific energy consumption, with an associated market based mechanism through which additional energy savings can be quantified and traded as ECSerts.

Chlor-Alkali sector is one of the 8 notified energy intensive sectors under which a total of 22 plants are participating in this program. These plants have been mandated to reduce their Specific Energy Consumption (SEC) from baseline year of 2009-2010. It is expected that these plants may save 0.054 million tons of oil equivalent annually by the end of PAT cycle –I.

The publication of **“Normalization Document and M&V Guidelines” for Chlor-Alkali** is an effort to facilitate the DCs to comply with notified PAT rules to participate with the PAT scheme and contribute towards achieving national target of energy savings. This document will also be helpful to all empanelled Accredited Energy Auditors (EmAEAs) and State Designated Agencies (SDAs) in the monitoring and verification process of PAT.

I want to record my appreciation for members of the Sectoral Expert Committee on Chlor-Alkali Sector, chaired by Shri S. K. Agrawal, Advisor (Ex- Executive Director), DSCL, Shri Saurabh Diddi, Energy Economist, BEE, Shri Ravi Shankar Prajapati, Project Engineer, BEE and Shri P.N. Parikh, Sector Expert, who worked tirelessly to put together the baseline data, normalization factors and M&V methodology for the sector. I especially want to record my appreciation for Shri S. Vikash Ranjan, Technical Expert, GIZ who has put together the data and methodology associated with normalization.

I also compliment the efforts of all participating industrial units towards their endeavor in contributing to the national energy saving targets.

(Ajay Mathur)

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3.	Shri O. P. Sharma	Joint Industrial Advisor, Department of Chemicals & Petrochemicals	Member
4.	Shri K. Srinivasan	Secretary General, Alkali Manufacturers' Association of India	Member
5.	Ms Harjeet K. Anand	Dy. Director (Technical), Alkali Manufacturers' Association of India	Invitee

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Special Thanks to Team NMEEE

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1. Introduction

The National Action Plan on Climate Change (NAPCC) released by the Prime Minister on 30 June, 2008, recognises the need to maintain high economic growth to raise the living standards of India's vast majority of people and simultaneously reducing their vulnerability to the impacts of climate change.

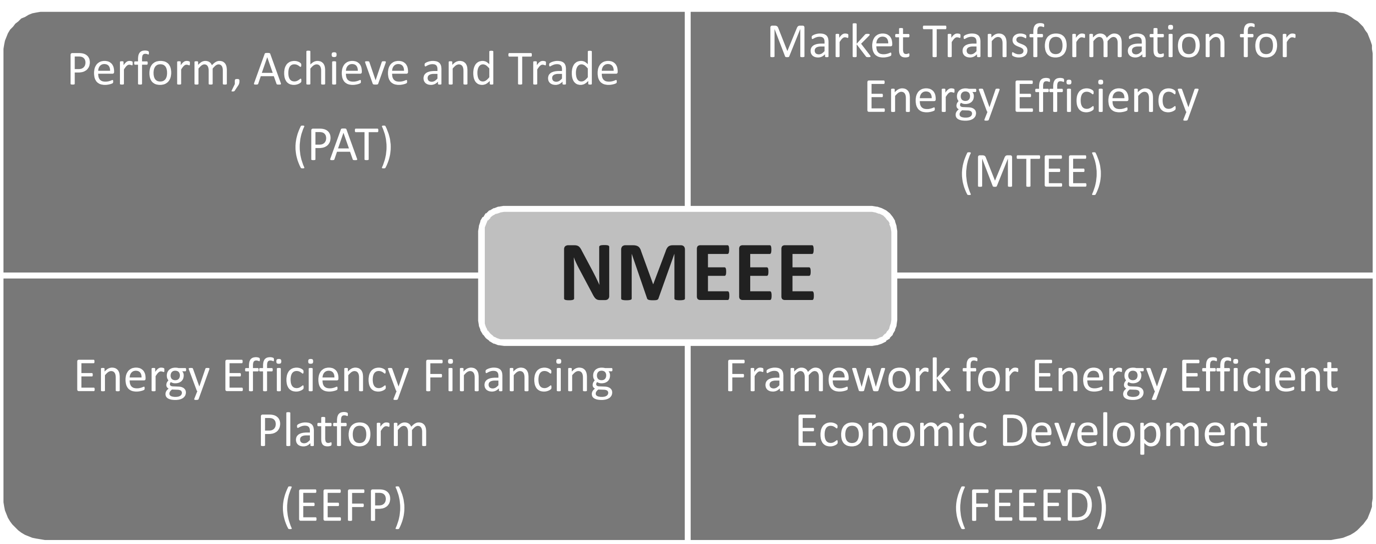
The National Action Plan outlines eight national missions that represent multi-pronged, long-term, and integrated strategies for achieving key goals to mitigate the impact of climate change. These missions are listed below:

- National Solar Mission
- National Mission for Enhanced Energy Efficiency
- National Mission on Sustainable Habitat
- National Water Mission
- National Mission for Sustaining the Himalayan Ecosystem
- National Mission for a Green India
- National Mission for Sustainable Agriculture
- National Mission for Strategic Knowledge for Climate Change

1.1 National Mission for Enhanced Energy Efficiency

The National Mission for Enhanced Energy Efficiency (NMEEE) is one of the eight national missions with the objective of promoting innovative policy and regulatory regimes, financing mechanisms, and business models which not only create, but also sustain, markets for energy efficiency in a transparent manner with clear deliverables to be achieved in a time bound manner. It also has inbuilt provisions for monitoring and evaluation so as to ensure transparency, accountability, and responsiveness. The Ministry of Power (MoP) and Bureau of Energy Efficiency (BEE) were tasked to prepare the implementation plan for NMEEE.

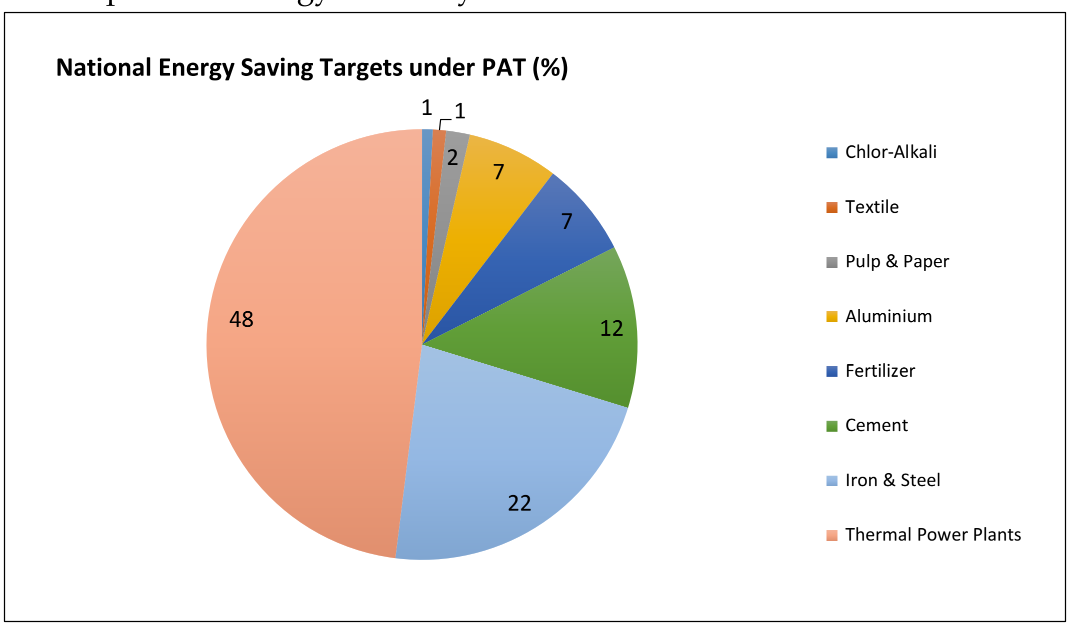
NMEEE spelt out the following four new initiatives to enhance energy efficiency, in addition to the programmes on energy efficiency being pursued. These are:



- **Perform, Achieve and Trade (PAT),** a market based mechanism to make improvements in energy efficiency in energy-intensive large industries and to make facilities more cost – effective by certification of energy saving that can be traded.
- **Market Transformation for Energy Efficiency (MTEE)** accelerates the shift to energy-efficient appliances in designated sectors through innovative measures that make the products more affordable.
- **Energy Efficiency Financing Platform (EEFP),** a mechanism to finance demand side management programmes in all sectors by capturing future energy savings.
- **Framework for Energy Efficiency Economic Development (FEEED),** for developing fiscal instruments to promote energy efficiency.

1.2 Perform, Achieve and Trade (PAT) Scheme

Under the National Mission on Enhanced Energy Efficiency (NMEEE), a market based mechanism known as **Perform, Achieve and Trade (PAT)** has been developed and launched to improve energy efficiency in the large energy intensive industries. It is envisaged that 6.686 million tonnes of oil equivalent will be reduced by 2014-15, which is about 4% of energy consumed by these industries. Under the PAT scheme, targets have been specified for all energy intensive industries notified as designated consumers (DCs) under the Energy Conservation Act, including thermal power stations.



1.3 Background

The methodology of setting targets for designated consumers is transparent, simple and easy to use. It is based on reduction of specific energy consumption (SEC) on a gate-to-gate (GtG) basis to achieve targeted savings in the first commitment period of 3 years (2012-2015); the reduction in this phase is of about 4.1% which is estimated at 6.686 million tonnes of oil equivalent (mtoe). Of the 23 mtoe set as target from NMEEE, the PAT scheme is focussed on achieving 6.686 mtoe by 2015.

The threshold limit of 12,000 tonnes of oil equivalent (toe) has been marked as the cut-off limit criterion for any unit in the chlor-alkali sector to be identified as designated consumer

(DC)under PAT. Cycle 1 of the scheme has identified 22 plants as designated consumers in the chlor-alkali sector.

The total reported energy consumption of these designated consumers is about 0.889 million tonnes of oil equivalent. By the end of the first PAT cycle it is expected to reduce the energy consumption by 0.054 million tonnes of oil equivalent which is around 1 % of the total energy savings.

1.4 Categorisation and Distribution

For the establishment of energy consumption norms and standards in the chlor-alkali sector, designated consumers have been grouped based on similar processes and profiles. DCs are suitably grouped based on similaritiesin the available data. This is to arrive at a logical and acceptable spread of SECs among the DCs which may be compared in setting targets.

The categorisation of the DCs under PAT cycle is shown below.

Chlor-Alkali Sector		Nos of DCs		
S. No.	Sector	With CPP	Non-CPP	Total
1	Chlor-Alkali	4	18	22

2. Overview of Indian Chlor-Alkali Industry

The chlor-alkali industry consists of the production of three inorganic chemicals:

Caustic Soda (NaOH), Chlorine (Cl2) and Soda Ash (Na2CO3). Caustic soda and chlorine are produced simultaneously while soda ash is produced during a different process.

The caustic soda industry in India is approximately 65 years old. Of the 35 plants across the country, 56% of capacity is located in western India. Most units are merchant units with an average plant size of 150 tonnes per day (TPD); some are world scale – up to 900 TPD. During the last five years, caustic soda capacity and demand compound annual growth rate (CAGR) were 4% and 3.5%, respectively with plant capacity utilisation around 80%. In 2013-14, production of caustic soda was 2.6 mMTPA with an installed capacity of 3.3 mMTPA. With the sincere effort and will of the chlor-alkali industry the expected capacity by 2015-16 is estimated at 3.7 mMTPA @ CAGR of 4.4%.

In India almost all chlor-alkali plantsare now based on green state-of-the-art membrane technology.

The production of caustic soda is associated with chlorine. This inevitable co-production has been an issue for the chlor-alkali industry. Both products are used for very different end users with differing market dynamics and it is only by rare chance that demand for the two coincides. The Indian chlor-alkali industry is driven by the demand for caustic soda, and chlorine is considered a by-product. In the market driven by the demand for caustic soda the demand for chlorine is subdued as bulk users in chlorine derivatives are not there yet. The low chlorine demand therefore sets a limit to capacity growth.

2.1 Products of Chlor-Alkali Industry

Caustic Soda: Vital Input for Alumina, Textiles, viscose fibre, Pulp & Paper, Soaps & Detergents, pharmaceuticals, etc.
Chlorine: Basic Building Block for PVC Plastics, Host of Petro, Specialty & Agro Chemicals

2.2 Growth Drivers for Caustic Soda Industry

A. ALUMINA INDUSTRY

- Alumina Industry in India is strategically well placed and ranks seventh largest in the world with discernible growth plans and prospects for future. India's primary aluminium consumption is expected to grow by 8%.
- India's rich bauxite mineral base of "3,076 million tonnes" renders a competitive edge to the industry as compared to its global counterparts
- Aluminium demand is rapidly growing as its use is diversified and has wide applications in various areas such as transport, building and architectural sectors, packaging, food and chemical industries, electrical sector, machinery and equipment, consumer durables and also in defence sector and wagon making by Indian Railways, automobile industry, electrification and power infrastructure projects.

B. TEXTILE SECTOR

- Domestic consumption for Man Made Fibres to grow @ CAGR 9% in next one decade.
- Textile fibre per capita consumption of 4-5kg in India as compared to 11.5kg globally indicates huge potential for textile fibres demand and thus growth of textile industry is evident.
- Demand for polyester and viscose fibre/yarns growing especially in technical and home textiles.
- Exports grew @ 15% YOY in 2013. Increasing exports are based on demand inthe US and Europe with accelerated growth in their economy besides incentives from the Indian government.

2.3 Chlorine Derivatives and Their Growth In India

- Globally, caustic chlorine industry is driven by demand-supply of chlorine; however, in India, the key demand driver is caustic soda.
- There is an urgent need to promote chlorine derivatives industry; a vibrant bulk chlorine consuming petro-chemical industry is needed to use surplus chlorine, in products like PVC, Chloro-Methanes/ HCFC/PTFE, Propylene Oxide/Glycol, Epichlorohydrin, Polycarbonates, TDI/ MDI, TiO2, DCP,CaCl2, etc.
- There is enormous potential to produce chlorine compounds by utilising surplus chlorine. India can be a manufacturing base to meet regional demands. A huge surge in demand is expected from the rapid shift of almost 50% of the population (over 600 million) to middle and upper middle classesand their urge to spend. India's per capita chlorine consumption is around 1.85kgs against Germany's 55kg, US's 45kg, China's 13kg and Brazil's 7.8kg.
- The issue in India is that most plants are merchant units; integrated plants with downstream chlorine derivatives only 41% of capacity. There is a need to promote integration of units with chlorine derivatives production and also to minimise transportation risks.

- There is also a need to promote widespread chlorine usage for disinfection of drinking water.

2.4 Journey towards Improved Safety, Health & Environment, Green Manufacturing and Sustainable Growth

A. SAFETY COMPLIANCE

- Safety is a high priority area for Alkali Manufacturers' Association of India (AMAI); the Safety Health and Environment (SHE) Committee formed in November 2008, to encourage adoption of best safety practices, bring in responsible care, address issues on climate change, and the like.
- The industry conducts hazard and operability (HAZOP) and hazard identification (HAZID) studies, onsite and offsite.It makes plans for emergencies, carries out periodic safety audits, safety workshops, regular training programmes on safe handling of chlorine for plant operators, transporters, drivers, consumers, support staff, etc.
- The industry is acquiring quality, environment, safety, health and energy management system certifications — almost 100% units have ISO 9001 & ISO 14001, 70% have OHSAS 18001, and some units also have SA 8000 & ISO 50001 certification.
- The entire industry is signatory to World Chlorine Council (WCC) safety commitment and represented at the Global Safety Team of WCC.

2.5 Environment Management through Green Manufacturing

A. USE OF CLEAN ENERGY

- Hydrogen is a by-product in the process of making caustic soda, which proves to be a boon for the industry. Promotion on gainful use of hydrogen has led to almost 90% utilisation as fuel in flakes plants, in boilers and as sale as compressed hydrogen.

B. WATER CONSERVATION AND LONG TERM VISION TO ACHIEVE ZERO EFFLUENT DISCHARGE

- The industry is working towards Zero Effluent Discharge Mission and recycle the entire liquid effluents generated within a plant
- Units have installed RO plants to recycle water recovered from liquid effluents back to the system and use reject water for toilets, gardening, hydrant systems, etc.

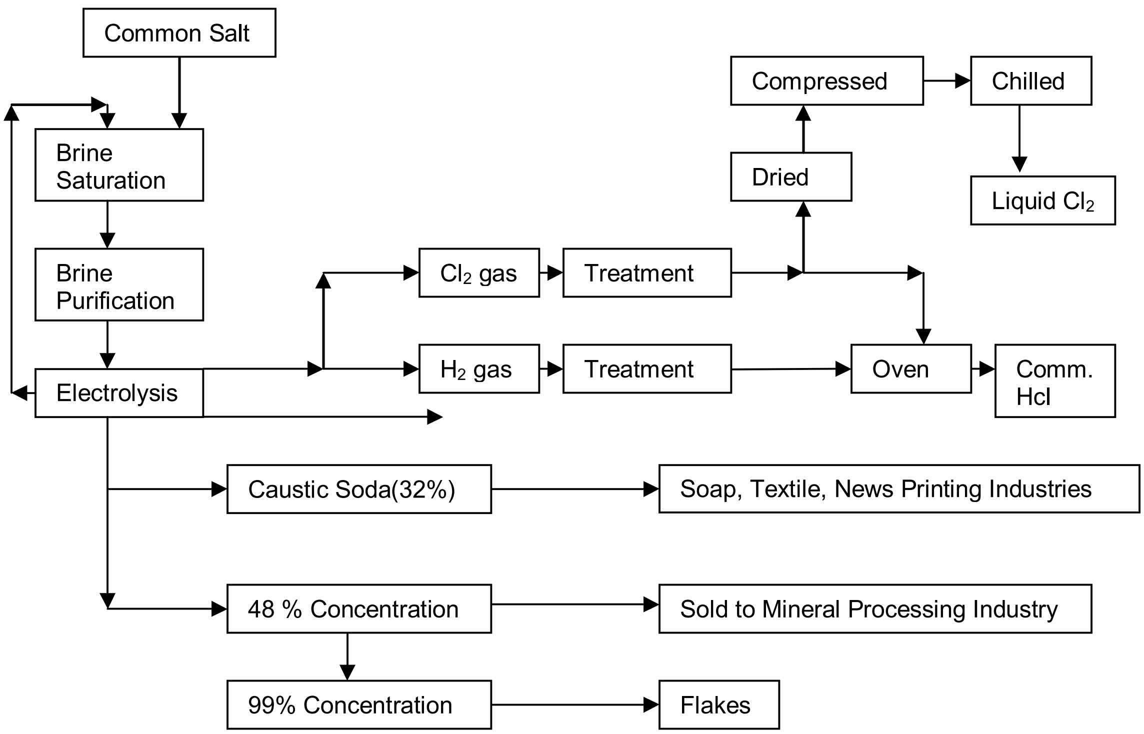
C. RE-USE OF FLY ASH AND BRINE SLUDGE :

- Brine sludge from membrane plants is non-hazardous— it is used to make construction bricks/blocks.
- The fly ash generated is reused in in coal based captive power plants. Over 60% of the fly ash generated today is being utilised gainfully.

D. TECHNOLOGICAL SUSTAINABILITY

- Today almost the entire Indian chlor alkali industry is based on membrane cell technology, achieved throughCREP(Corporate Responsibility for Environmental Protection) voluntary agreement with Government of India and proactive approach of the industry.
- Continuous adoption of advanced generation of cells and newly developed most energy efficient membranes, improved coating of electrodes, advanced materials of construction, etc., ensures a "state-of-the-art" industry.

2.6 Process Diagram



Process Flow Chart for Caustic Soda, Liq. Cl_2 & Hcl Production in Caustic soda plant.

3. Chlor-Alkali Industry and PAT

The chlor-alkali sector has been categorised on the basis of their processes into two subsectors – membrane based and mercury based. Due to environmental concernsthe chlor-alkali industry started a change-over from mercury to membrane technology, which is eco-friendly and energy efficient. The total reported energy consumption of these designated consumers is about 0.88 million tonne of oil equivalent/year. Chlor-alkali plants are further divided into two categories – captive power plant (CPP) based plants and non-CPP i.e. only grid connected plants. The specific energy consumption varies from 0.262to 0.997 toe/t of the 22 designated consumers in the sector. By the end of the first PAT cycle, the energy savings of 0.054 million tonne of oil equivalent/year is expected to be achieved, which is 0.81% of total national energy saving targets assessed under PAT.

3.1 Status of Designated Consumers

Threshold limit for becoming a DC = 12,000 tonnes of oil equivalent (toe) per annum
Total number of identified DCs = 22
Estimated Energy Consumption = 884,949 tonne of Oil Equivalent (toe)

3.2 General Rules for Establishing Baseline Values

3.2.1 Definitions

1. **Baseline Year:** Baseline year is declared as 2009-10.
2. **Baseline Period:** Baseline period is declared as 2007-08, 2008-09 & 2009-10
3. **Baseline Production (P_{base}):**The arithmetic average of Production figures of 2007-08, 2008-09 and 2009-10
4. **Baseline Specific Energy Consumption (SEC_{base}):** The arithmetic average of SEC figures of 2007-08, 2008-09 and 2009-10
5. **Baseline Capacity Utilisation in % (CU_{base})**
6. The arithmetic average of CU figures of 2007-08, 2008-09 and 2009-10

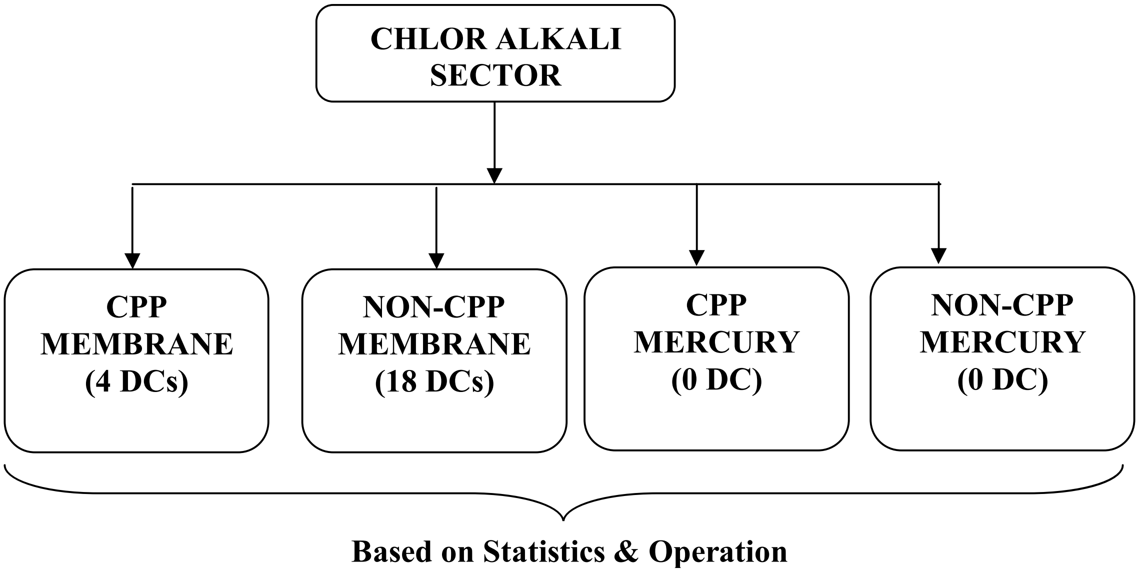
3.2.2. Data Consideration

1. In case of plants more than 5 years old, data for the last 3 financial years will be considered provided the CU is uniform. Data for the financial year where capacity utilisation is less that 70%,will be excluded.
2. In case of plants more than 5 years old and with less than 3 years of data, the same will be considered provided the CU is uniform. If the CU is abnormally low (less than 70%)in any of the years, the same will not be considered. However, if all the 3 years show low and uniform capacity utilisation, the data for all the years may be considered.
3. In case of plants less than 5 years old and with less than 3 years of data, the available year's (or years') data will be considered provided the CU is uniform. If the CU is abnormally low (less than 70%)in any of the years, the same will not be considered.
4. In case of new plants, (provided data is available minimum for one complete year) the data would be considered for the years where the CU is greater than 70%. If data is reported for only one year, the same will be considered irrespective of the CU.

3.2.2 Grouping of DCs

DCs are suitably grouped based on similar characteristics with the available data. This is to arrive at a logical and acceptable spread of SECs among the DCs which may be compared in target setting approach.

For Chlor Alkali Sector, the following groupings are done:



3.2.3 Estimation of Gate-to-Gate SEC in Base Year:

1. Gate to Gate SEC (Specific Energy Consumption) Calculation:

$$\text{GtG SEC (Energy Input)} = \frac{\text{All forms of energy converted to tonne of oil equivalent (toe)}}{\text{Equivalent Caustic Soda}}$$

a To calculate total energy consumed, conversion of all forms of energy to tonne of oil equivalent (toe) has been done as follows:

i) The imported electricity from Grid (Million kCal) = Million kWh*860 kCal/kWh

ii) For Solid fuels (Indian Coal, Imported Coal, lignite etc.)
= Amount used in power generation + process (tonne)*Gross Calorific Value of the fuel (kCal/kg)*1000/10^6

iii) For Liquid fuels (HSD, LDO,LSHS, FO etc.)
= Amount used in power generation + process (kL)*Average Density (kg/ltr)*Gross Calorific Value of the fuel (kCal/kg)*1000/10^7

iv) For Gaseous fuel (CNG, LPG, Hydrogen etc.)
= Amount used in power generation + process (Million SCM)*Gross Calorific Value of the fuel (kCal/SCM)

v) For Steam = Amount used in process (Tonne)*Enthalpy of Steam (kCal/SCM)*1000/ 10^6

vi) Energy Input (toe) = {Adding point (i+ii+iii+iv+v) – Electricity Exported to Grid*2717 kCal / kwh}/10

Note: Hydrogen has been taken as source of energy for Calculating SEC and Enthalpy of Steam is taken as 660 kCal/kg or as reported by plant.

b. Calculation of Equivalent Caustic Soda:

In Chlor-Alkali Industry various products are manufactured but in PAT Cycle-1 only four major energy intensive products are considered and thus following factors have been developed to convert other product into Equivalent Caustic Soda:

Caustic Soda	:	1.0 of Equivalent Caustic Soda
Liquefied Chlorine (T)	:	0.0615 of Equivalent Caustic Soda
Compressed Hydrogen (Lac NM^3)(sold)	:	13.889 of Equivalent Caustic Soda
Caustic Soda Flakes (T)	:	0.219 of Equivalent Caustic Soda

Equivalent Caustic Soda (tonne) = CS on 100 % basis (tonne) + Liquefied Chlorine (tonne) *0.0615 + Compressed Hydrogen (Lac NM^3)* 13.889 + Caustic Soda Flakes (tonne)* 0.219

c Correction factor for Membrane & Electrode Life:

60 kWh/tonne per year is added into Specific Energy Consumption in the baseline year for each plant.

For example

Let's actual GtG SEC in Baseline Year= 0.707 toe/tonne

Addition of 60 kWh per year:

60 kWh x 860 kCal x 3 years / 10^7 **(Non-CPP)** 60 kWh x 2717 kCal x 3 years / 10^7 **(CPP)**

Final Baseline SEC = Actual GtG SEC in Base line year + Correction Factor for ageing cell electrolyte (**0.0155** for Non-CPP & **0.0489** for CPP)

So, Revised SEC in Baseline Year: 0.723 toe/tonne for Non-CPP 0.756 toe/tonne for CPP

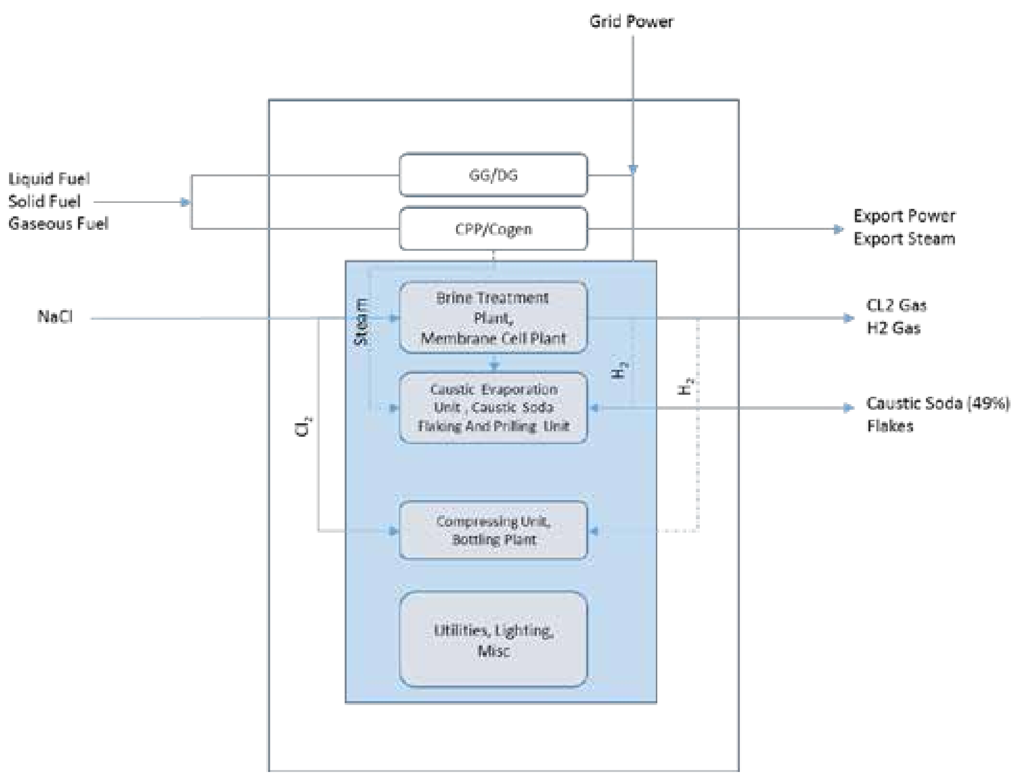
d. The following conversions table is used to convert to equivalent MKcal

Parameter	Multiplication Factor	Remark (if otherwise not reported by plant)
Purchased Electricity (kWh) from Grid	860 kCal/kWh	---
Coal (kg)	GCV as reported	3000 kCal/kg for Indian Coal 5000 kCal/kg for Imported Coal
FO (kg)	GCV as reported	10050 kcal/kg
HSD (kg)	GCV as reported	11840 kcal/kg
LDO (kg)	GCV as reported	10050 kCal/kg
FO (ltr) to FO(kg)	Density as reported	0.96 kg/ltr
HSD(ltr) to HSD(kg)	Density as reported	0.89 kg/ltr

LDO(ltr) to LDO(kg)	Density as reported	0.85 kg/ltr
Hydrogen	GCV as reported	3050kcal/Nm3
Steam	Calorific value as reported	660kcal/kg
Electricity (kwh) supplied to Grid from CPP	2717 kCal/kwh	----

3.2.4 Battery Limit

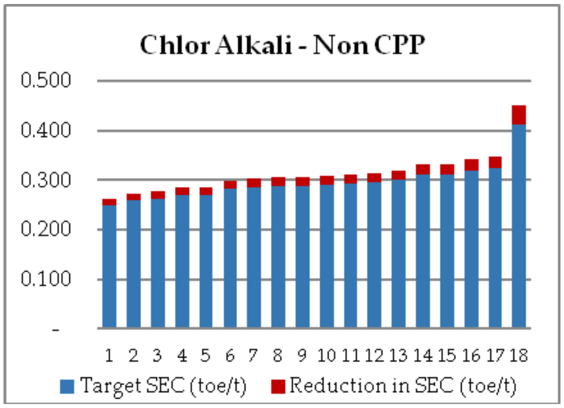
The following plant boundaries are considered in different sub-sectors of this sector as per the data reported by DCs

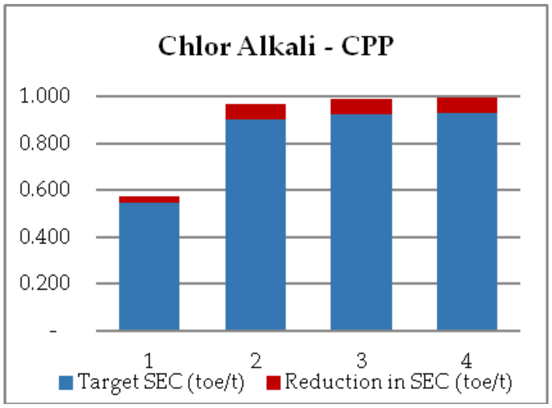


3.2.5 Target Setting

1. Sectoral target is allocated based on a pro-rata basis of total energy consumption in the Chlor Alkali sector among all the 8 sectors under PAT scheme.
2. Sub-Sectoral target is allocated based on a pro-rata basis of total energy consumption in the sub-sector among the total Chlor Alkali sector.
3. The DC level target is allocated based on a statistical analysis derived from 'Relative SEC' concept. This approach will be applicable to all the DCs of a sub-sector only.
4. Hydrogen as fuel, which would be countable in SEC calculation as addition fuel rather than waste energy.
5. Energy consumed in internal transportation was excluded.

Specific Energy Consumption and Targets- Chlor -Alkali





4. Normalisation and Calculation

Normalization factors for the following areas have been developed in Chlor-Alkali Sector.

1. **Power Mix** (Import & Export from/to the grid and self-generation from the captive power plant)
2. **Fuel Quality in CPP & Cogen**
3. **Low PLF in CPP**
4. **Hydrogen Mix** (consideration for reducing venting of Hydrogen)
5. **Normalization Others**

   5.1 Environmental Concern

   (Additional Environmental Equipment requirement due to major change in government policy on Environment)

   5.2 Biomass/Alternate Fuel Unavailability

   5.3 Construction Phase or Project Activities

   5.4 Addition of New Line/Unit (In Process & Power Generation)

   5.5 Unforeseen Circumstances

   5.6 Renewable Energy

4.1 Power Mix Normalization methodology

- **Power Sources and Import**
  - The baseline year power mix ratio shall be maintained for the Assessment year also.
  - The Normalized Weighted Heat Rate calculated for the baseline year power mix ratio will be compared with the assessment year weighted heat rate and the Notional energy will be deducted from the Total energy assessed.
  - The Thermal Energy difference of electricity consumed in plant in baseline year and assessment year shall be subtracted from the total energy, considering the same % of power sources consumed in the baseline year.
  - However, any efficiency increase (i.e. reduction in Heat Rate) in Assessment year in any of the power sources will give benefit to the plant.

- **Power Sources and Export**
  - ➢ In case of Power export, the plant will be given advantage or disadvantage by comparing the heat rate of CPP in assessment year with the baseline year and will be deducted the same by taking the heat rate of 2717 kcal/kwh.
  - ➢ CPP Actual Net Heat Rate will be considered for the net increase in the export electricity from the baseline.

Power Mix Normalization Calculation

- **Normalization for Power Sources**

The Normalized Weighted Heat Rate of Plant for Assessment year (kcal/kwh) is given as:

$$\boldsymbol{Normalised\ Weighted\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right)}$$
$$= GridHeat\ Rate\ \left(\frac{kcal}{kWh}\right) in\ AY\ X\ \left(\frac{Grid\ Energy\ Consumption\ in\ BY\ (MU)}{Energy\ Consumed\ \ from\ all\ Power\ Soure\,(Mkcal)}\right)$$
$$+ CPP\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right) in\ AY\ X\ \left(\frac{CPP\ Energy\ Consumption\ in\ BY\ (Mkcal)}{Energy\ Consumed\ from\ all\ Power\ Source\ (Mkcal)}\right)$$
$$+ DG\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right) in\ AY\ X\ \left(\frac{DG\ Energy\ Consumption\ in\ BY\ (MU)}{Energy\ Consumed\ from\ all\ Power\ Source\,(Mkcal)}\right) + \ldots$$

Where,

MU = Million kWh

Mkcal = Million kcal

BY = Baseline Year,

AY = Assessment Year

Power Source = Power from Grid, CPP, DG Set etc.

(**Note:** Any addition in the power source will attract the same fraction to be included in the above equation.)

The Electricity Consumption from WHR shall not be considered for Power Mix Normalization. Energy consumption from WHR in the assessment year (Mkcal) shall be subtracted from the total Energy Consumption of the Plant,

$$\boldsymbol{Energy\ Correction\ from\ All\ Power\ Source}$$
$$= Energy\ Cunsumption\ from\ All\ Power\ Source\ (Mkcal)\ X$$
$$\left(Actual\ Weighted\ Heat\ \mathrm{Rate}\ \left(\frac{\mathrm{kcal}}{\mathrm{kWh}}\right) \mathrm{in\ AY} - \mathrm{\ Normalized\ Weighted\ Heat\ Rate}\ \left(\frac{\mathrm{kcal}}{\mathrm{kWh}}\right) in\ AY\right)$$

- **Normalization for Power Export**

  The Net Heat Rate (NHR) of Captive Power Plant (CPP) shall be considered for the normalization of Export of Power from CPP. (Instead of 2717 kcal/kWh)

  The Export Power Normalization would be

  - Actual CPP heat rate would be considered for the net increase in the export of power from the baseline.
  - The exported Energy will be normalized in the assessment year as following calculation:

$$\begin{aligned} &Energy\ to\ be\ subtratec\ in\ AY\ (Mkcal) \\ &\quad = \big(Exported\ Power\ In\ AY\ (MU) \\ &\quad - Exported\ Power\ in\ BY(MU)\big)\ X \left(\left(\frac{Gross\ Heat\ Rate\ (\frac{kcal}{kWh})\ in\ AY}{\left(1 - \frac{\%\ APC}{100}\right)} \right) \right. \\ &\quad \left. - 2717 \right) \end{aligned}$$

Where,
MU = Million kWh
Mkcal = Million kcal
AY = Assessment Year
BY = Baseline Year

Documentation

a. Electricity Bills from Grid
b. Energy Generation Report from CPP/DG/WHR/Co-Gen
c. Power Export Bills from Grid and ABT Meter Reading
d. Fuel Consumption Report [DPR, MPR, Lab Report]
e. Fuel GCV Test Report- Internal and External (As received or As fired basis as per baseline methodology)

The Plant is compared with their operational efficiencies only in the Assessment year, hence keeping the energy consumption same in both the period, the performance has been assessed by changing the power source mix with change in export quantity from the baseline year

Table: Production and Performance Indicators

Sr No	Description	Unit	Baseline Year [BY]	Assessment Year [AY]
1	Caustic Soda Production	Million Tonne	0.1	0.1
2	Thermal SEC for Equivalent Caustic Soda Production	kcal/kg	5000	5000
3	Electrical SEC up to Caustic Soda	kWh/Tonne	2500	2500
4	Total Thermal energy used in Process	Million kcal	500000	500000

Table: Heat Rate of Power sources

Sr No	Description	Unit	Baseline Year [BY]	Assessment Year [AY]
5	Grid heat rate	kcal/kWh	860	860
6	Co-Gen heat rate	kcal/kWh	2200	2200
7	DG heat rate	kcal/kWh	2196	2196
8	Exported Power Heat rate	kcal/kWh	2717	2717

The heat rates from all the power sources remain same in the assessment year for the purpose of developing normalization. However, the normalization calculation should be sensitive enough to accommodate any change in the heat rate w.r.t. the SEC of the Plant.

In the above table all the power sources in a plant are not considered, however for example purpose power sources like Grid import, Co-Gen and DG are considered the same has been replicated in the original normalization factors.

Table: Energy Data from Power Sources

Sr No	Description	Unit	Baseline Year [BY]	Assessment Year [AY]
9a	Electricity imported from the grid	Million kWh	50.00	55.00
9b	Electricity generated from Co-Gen	Million kWh	200.00	200.00
9c	Electricity generated from DG	Million kWh	5.00	10.00
10	Electricity exported to the grid	Million kWh	5.00	15.00
11	Co-Gen generated Electricity Consumption within the plant	Million kWh	195.00	185.00

The normalization calculation is to be developed to cater the change in power import and export. The above table shows the increase in exported power from 5 MU to 10 MU. The additional export power of 5MU is being generated from the Co-Gen. Hence power is generated with heat rate @ 2200 kcal/kwh, while power export is being taking place @ 2717 kcal/kwh. This difference in heat rate i.e., @ 517 kcal/kWh will be a advantageous proposition for the exporting plant. Since, the same is contributing in the plant Specific Energy Consumption. In this situation, the plant will consume less thermal energy [5MU @ (2200-2717) kcal /kWh] for same electricity consumption with in plant. Therefore the SEC of plant will decrease. This disadvantageous position to be normalized and plant should not suffer with change in export power from the baseline year.

The electricity generated from WHR is not being considered in the total energy consumption of the plant for power mix normalization. Hence, it will be excluded from the Power Mix calculation in the Plant's energy consumption itself. The power produced by WHR and exported has been subtracted from the total available electricity of power sources.

The generated electricity consumption in the plant from different power sources is being calculated after taking the exported electricity into account. The exported electricity is being deducted from the major generated electricity automatically.

Table: Plant Energy Consumption

Sr No	Description	Unit	Baseline Year [BY]	Assessment Year [AY]
15	Thermal Energy Equivalent of Electricity Consumed Within Plant	Million kcal	493979	509258
16	Grid Share of electricity consumption of plant	Factor	0.20	0.22
17	Co-Gen Share of electricity consumption of plant	Factor	0.78	0.74
18	DG Share of electricity consumption of plant	Factor	0.02	0.04
19	Weighted Average heat rate of plant	kcal/kWh	1932	1905

The share of energy has been taken from the plant electricity consumption excluding WHR generation and Power export. For Example- Grid share factor will be 15 MU /100 MU = 0.15 or 15% of the total electricity consumption of the plant.

The weighted heat rate is heat rate of different power sources in the baseline as well as in the assessment year. It is the summation of average of the multiplication of heat rate and generation.

Calculation for Heat Rate in the Baseline Year

- **Total Energy Consumed in Baseline year**
  = Energy consumed in process + (Grid Imported electricity X 860 kcal/kWh) + (Co-Gen generated electricity X Co-Gen heat rate) + (DG generated electricity X DG heat rate) – (Grid exported electricity X 2717 kcal/kwh)
  = 500000 + (50 *860) + (200*2200)+(5*2196) – (5*2717)
  =980394 million kcal

❖ **Gate to Gate SEC in the baseline year**
= Total energy consumed in baseline year/ (Equivalent Caustic Soda production *1000)
= 980394/ (0.1 *10^7)
= 0.980 toe/tonne of eq. Caustic Soda

The change in assessment year in the power has been observed as

- Grid import decreased from 50 MU to 55 MU
- Grid export increased from 5 MU to 10 MU
- Plant electricity consumption from Co-Gen increased from 195 MU to 185 MU
- Co-Gen Generation remains constant at 200 MU

If plant decreases the use of electricity from Co-Gen generation (10MU @2200kcal/kWh) and increases the import power from grid (5MU @ 860 kcal/kWh). In this condition, the plant will consume less thermal energy [5MU @ (2200-860) kcal /kWh] for same electricity consumption with in plant. Therefore the SEC of plant will decrease.

Without normalization in the Assessment year, the plant will get advantage as per following calculation

❖ **Total Energy Consumed in Assessment year would have been without Normalization**

= Energy consumed in process + (Grid Imported electricity X 860 kcal/kWh) + (Co-Gen generated electricity X Co-Gen heat rate) + (DG generated electricity X DG heat rate) – (Grid exported electricity X 2717 kcal/kwh)
= 500000 + (55 x 860) + (200x2200) + (10x2196) – (15x2717)
= 968505 million kcal
= 968505/ (0.1 x 10^7)
= 0.9685 toe/tonne of eq. Caustic Soda

❖ **Gate to Gate SEC in the baseline year**

= Total energy consumed in baseline year/ (Equivalent Caustic Soda production*1000)
= 980395/ (0.1 x10^7)
= 0.980 toe/tonne of eq. Caustic Soda

It may be concluded that the plant will be on the advantageous side and enjoy a gain of 0.980 - 0.9685 = 0.0115 toe/ton of eq. Caustic Soda only by increasing grid import and export power.

This affect will be nullified through normalization in Power source mix and Power exports as per following calculation

1. **For Power Source Mix:** The additional imported electricity in assessment year as compared to baseline year calculated with the Co-Gen heat rate [5MU @ (2200-860) kcal/kWh=6700 Million kcal] will also be added to total energy of the plant
2. **For Power Export:** The additional exported electricity in assessment year as compared to baseline year calculated with the actual Co-Gen heat rate [5MU x (2200-2717) kcal/kWh= -2585 Million kcal] will also be subtracted from total energy of the plant

The above effect takes place for single power source and power export. There could be multiple power sources in any plant, hence effective calculation could be evaluated through normalizing and maintaining the same share of source in the assessment year, maintained in the baseline year as per following equation

- **Normalized Weighted Average heat rate of plant in assessment year**

  = Grid Share of electricity consumption in baseline year X Grid heat rate + Co-Gen Share of electricity consumption in baseline year X Co-Gen heat rate + DG Share of electricity Consumption in baseline year X DG heat rate
  = 0.220 *860 + 0.740* 2200 + 0.040*2196 = 1905.03 kcal/kWh

The Normalised weighted heat rate then subtracted to the weighted heat rate of the plant for assessment year to get the net increase or decrease in combined weighted heat rate. The same would be multiplied with the plant electricity consumption for Normalisation as per following equation

- **Notional energy added in total energy due change in power source mix**

  = Total electricity consumed within plant X (Normalized Wt. Average heat rate – Wt. Average heat rate of plant in assessment year)
  = 250*(1931.92 – 1905.03)
  =6722.5 million kcal

Similarly, for power export normalization, actual heat rate of the Co-Gen for calculating the exported electricity from the plant, since the same was calculated @2717 kcal/kwh in the baseline year, hence the equation has been derived by taking into the consideration of baseline export electricity also as per following formulae

- **Notional energy for exported electricity to grid subtracted from total energy**

  = (Exported electricity in Assessment year – Exported electricity in Baseline year) X (Co-Gen heat rate in Assessment year -2717 kcal/kWh)
  = (15-5)* (2200-2717)
  = -5170 million kcal

If exported power goes down in the assessment year w.r.t. baseline year: In the baseline year; the exported power is taken as 2717 kcal/kwh, which is greater than the Co-Gen heat rate. The difference in the heat rate is then multiplied with the exported power automatically gets added in the total energy consumption of Plant in the base line year.

Now in the assessment year, if the exported power goes down in comparison to the baseline values, the same quantity of energy which was added in the baseline year shall be added in the total energy consumption of the Plant. By doing this, the SEC of Plant remains same for equal condition for all situations.

The situation in terms of SEC of the plant remains unchanged if the energy of exported power would have been subtracted in the baseline year so as in the assessment year. This situation is matched in the assessment year by Power normalizations.

❖ **Total Energy Consumed in Assessment year**

= Energy consumed in process + (Grid Imported electricity X 860 kcal/kWh) + (Co-Gen generated electricity X Co-Gen heat rate) + (DG generated electricity X DG heat rate) – (Grid exported electricity X 2717 kcal/kWh) + Notional Energy for Power mix - Notional Energy for exported electricity to grid

= 500000 + (55 *860) + (200*2200) + (10*2196) – (15*2717) + 6722.5 – (-5170)
= 980395 million kcal

❖ **Gate to Gate SEC in the assessment year**

= Total energy consumed in assessment year/ (Equivalent Chlor-Alkali production*1000)
= 980395/ (0.1 *10^7)
= 0.980 toe/tonne of eq. Caustic Soda

Table: SEC in Baseline and Assessment year

Sr No	Description	Unit	Baseline Year [BY]	Assessment Year [AY]
20	Notional Energy for Power Mix	Mkcal	0.00	6722.50
21	Notional Energy for Exported Electricity to Grid	Mkcal	0.00	-5170.00
22	Total Energy Consumed	Mkcal	980395	980395
23	SEC	Toe/Tonne	**0.980**	**0.980**

After Normalisation in assessment year with power source mix and power export, the Gate-to-Gate Energy stand at 0.980 toe/tonne of eq. Caustic Soda, which is equivalent to baseline SEC.

Benefit of increasing efficiency in Co-Gen

If a plant increases its efficiency i.e., decreased its heat rate from 2200 kcal/kwh to 2100 kcal/kwh in the assessment year, the Specific Energy Consumption of the Plant will come down as per the equation discussed above.

Table: Heat Rate of Power sources- Co-Gen Heat Rate decreased

Sr No	Description	Unit	Baseline Year [BY]	Assessment Year [AY]
11	Grid heat rate	kcal/kWh	860	860
12	Co-Gen heat rate	kcal/kWh	2200	2100
13	DG heat rate	kcal/kWh	2196	2196
14	Exported Power Heat rate	kcal/kWh	2717	2717

Table: Plant energy Consumption

Sr No	Description	Unit	Baseline Year [BY]	Assessment Year [AY]
15	Thermal Energy of Electricity Consumed Within Plant	Million kcal	493979	489260
16	Grid Share of electricity consumption of plant	Factor	0.20	0.20
17	Co-Gen Share of electricity consumption of plant	Factor	0.78	0.78
18	DG Share of electricity consumption of plant	Factor	0.02	0.02
19	Wt. Average heat rate of plant	Kcal/kWh	1932	1854

Table: SEC

Sr No	Description	Unit	Baseline Year [BY]	Assessment Year [AY]
20	Notional Energy for Power Mix	Mkcal	0.00	-5712
21	Notional Energy for Exported Electricity to Grid	Mkcal	0.00	-6170
22	Total Energy Consumed	Mkcal	980395	960393
23	SEC	Toe/Tonne	0.980	0.960

The SEC has been decreased with the decrease in Heat Rate of Co-Gen as stated in the above table.

4.2 Fuel Quality Normalization (Quality of Coal in CPP & Co-Gen)

Coals are extremely heterogeneous, varying widely in their content and properties from country to country, mine to mine and even from seam to seam. The principle impurities are ash-forming minerals and sulphur. Some are interspersed through the coal seam; some are introduced by the mining process, and some principally organic sulphur, nitrogen and some minerals salts.

These impurities affect the properties of the coal and the combustion process, therefore the plant's boiler efficiency & Turbine Efficiency. The generating companies have no control over the quality of coal supplied. The raw coal mainly being supplied to the power stations could have variation in coal quality. Further, imported coal is also being used and blended with Indian coal by large number of stations, which could also lead to variations in coal quality.

Table: Fuel Quality

Sr No	Sub-Group	Elements	Reason/ Requirement	Impact	Documents
3	Coal	Use of coal with different calorific value in AY and BY	Coal quality is beyond the control of plant	Boiler Efficiency, Auxiliary Power Consumption	Fuel Quality and Quantity documentation, Energy consumption of mills in AY and BY
	Gas	Use of Gas with different calorific value in AY and BY	Gas quality may be compromised due to limited availability	Net Heat Rate	Fuel Quality and Quantity documentation

The methodology should have provisions to take care of the impact of variations in coal quality. Therefore, average "Ash, Moisture, Hydrogen and GCV" contents in the coal during the baseline period as well as for assessment year is considered for Normalization and the correction factor has been worked out based on the following boiler efficiency formula:

$$\text{Boiler Efficiency} = 92.5 - \frac{[50 * A + 630 (M + 9 H)]}{G.C.V}$$

Where:

A = Ash percentage in coal
M = Moisture percentage in coal
H = Hydrogen percentage in coal
G.C.V = Gross calorific value in kcal/kg

Station Unit Heat Rate (Kcal/kWh) = Turbine heat rate/Boiler efficiency

Fuel Quality Normalization

- Change in coal GCV, moisture%, Ash% affect the properties of the coal and the combustion process, resulting in loss/ gain in the plant's boiler efficiency. To compensate for the change in efficiency of boiler with change in coal quality, the energy loss to be subtracted from the Total Energy consumption
- The plant/generating companies have no control over the quality of coal supplied, with Coal Linkage agreements.
- Further, variation in mix of imported coal with Indian coal could also lead to variations in coal quality. The normalization factor shall take care of the impact of variations in coal quality
- The Coal quality have impact on Boiler Efficiency of a captive Power Plant, with decrease in coal quality the efficiency of boiler will also decrease and hence the gross heat rate of CPP will also decease as per above formulae.

Pre-Requisite

- The Proximate and Ultimate analysis of coal for baseline should be available to compare the same with the assessment year
- In case of unavailability of Ultimate analysis of coal in baseline year, the %H will be taken constant for baseline year as per assessment year data.

Coal Quality Normalization Methodology

- The Boiler Efficiency will be calculated for the baseline as well as for assessment year with the help of Coal quality analysis constituents like GCV, %Ash, %Moisture, %H and Boiler Efficiency Equation provided to calculate the Boiler efficiency.
- Hence, by keeping the Turbine heat rate constant for both the years, the CPP heat hate will be calculated for the respective year

Normalization Formula

a. For CPP

1. Boiler efficiency in baseline year= 92.5-[{50xA+630 (M+9H)} / GCV]
2. Boiler efficiency in assessment year= 92.5-[{50xA+630 (M+9H)} / GCV]
3. The CPP heat rate in assessment year due to fuel quality-----(i)
4. = CPP heat rate in baseline year x (Boiler Efficiency in baseline year / Boiler Efficiency in assessment year) (kcal/kWh)
5. Increase in the CPP heat rate of assessment year due to fuel quality = (i) - Actual CPP heat rate in Baseline Year

Notional energy to be subtracted from total energy $_{\text{(Million kcal)}}$ = CPP generation in assessment year X increase in CPP heat rate

b. For Co-Gen

1. Boiler efficiency in baseline year = 92.5-[{50xA+630 (M+9H) } /GCV]
2. Boiler efficiency in assessment year = 92.5-[{50xA+630 (M+9H)} /GCV]
3. Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler) in BY = {$\sum_{n=1}^{5}$ (Operating Capacity of all Boilers used for Steam generation in TPH x Percentage of Coal Energy Used in steam Generation in all the boilers for Steam generation in %) / $\sum_{n=1}^{5}$Operating Capacity of all Boilers used for Steam generation}
4. Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler) in AY = {$\sum_{n=1}^{5}$ (Operating Capacity of all Boilers used for Steam generation in TPH x Percentage of Coal Energy Used in steam Generation in all the boilers for Steam generation in %) /$\sum_{n=1}^{5}$ Operating Capacity of all Boilers used for Steam generation}
5. Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler) in BY = {$\sum_{n=6}^{10}$ (Operating Capacity of all Boilers used for Steam generation in TPH x Percentage of Coal Energy Used in steam Generation in all the

boilers for Steam generation in %) / $\sum^{10}_{n=6}$ Operating Capacity of all Boilers used for Steam generation}

6. Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler) in AY
   = {$\sum^{10}_{n=6}$ (Operating Capacity of all Boilers used for Steam generation in TPH x Percentage of Coal Energy Used in steam Generation in all the boilers for Steam generation in %) / $\sum^{10}_{n=6}$ Operating Capacity of all Boilers used for Steam generation}
7. Weighted Average Specific Steam Consumption in BY & AY $_{\text{(kcal/kg of Steam)}}$ = $\sum^{5}_{n=1}$ (Total Steam Generation at Process Boiler x Specific Energy Consumption for Steam Generation in Process Boilers) + $\sum^{10}_{n=6}$ (Total Steam Generation at Co-Gen Boiler x Specific Energy Consumption for Steam Generation in Co-Gen Boiler)} / $\sum^{10}_{n=1}$ Total Steam generation at all the boilers
8. Normalized Specific Energy Consumption for Steam Generation $_{\text{(kcal/kg of Steam)}}$ = Weighted Average Specific Steam Consumption in BY x (Boiler efficiency at BY/Boiler Efficiency at AY)
9. Difference Specific Steam from BY to AY $_{\text{(kcal/kg of Steam)}}$ = Normalized Specific Energy Consumption for Steam Generation in AY - Weighted Average Specific Steam Consumption in BY
10. **Energy to be subtracted w.r.t. Fuel Quality in Co-Gen $_{\text{(Million kcal)}}$ = Difference Specific Steam from BY to AY x {(Total Steam Generation at Process Boiler in AY x Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler) in AY)+(Total Steam Generation at Co-Gen Boiler in AY x Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler) in AY)}/1000**

Where:
A: Ash in %
M= Moisture in %
H= Hydrogen in %
GCV: Coal Gross Calorific Value in kcal/kwh
AY = Assessment year
BY = Baseline Year
CPP= Captive Power Plant
TPH=Tonne per Hour

Normalization Calculation

- $CPP\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right) in\ AY = \frac{Turbine\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right)}{Boiler\ Efficiency\ (\%)\ in\ AY}$
- $CPP\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right) in\ AY = \frac{Turbine\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right)}{Boiler\ Efficiency\ (\%)\ in\ AY}$

Therefore,

- $CPP\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right) in\ BY = \frac{Turbine\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right)}{Boiler\ Efficiency\ (\%)\ in\ BY}$
- $CPP\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right) in\ BY = \frac{Turbine\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right)}{Boiler\ Efficiency\ (\%)\ in\ BY}$
- $CPP\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right) in\ AY = CPP\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right) in\ BY\ X\ \left(\frac{Boiler\ Efficiecny\ (\%)\ in\ BY}{Boiler\ Efficiency\ (\%)\ in\ AY}\right)$
- $\textbf{Energy to be deducted in AY} = \left(CPP\ Heat\ Rate\ \left(\frac{kcal}{kWH}\right) in\ AY - CPP\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right)\right) X\ CPP\ Generation\ (MU)\ in\ AY$
- $\textbf{Energy to be deducted in AY} = \left(CPP\ Heat\ Rate\ \left(\frac{kcal}{kWH}\right) in\ AY - CPP\ Heat\ Rate\ \left(\frac{kcal}{kWh}\right)\right) X\ CPP\ Generation\ (MU)\ in\ AY$

Documentation

- Fuel Linkage Agreement
- Operating Coal Quality- Monthly average of the lots (As Fired Basis), Test Certificate for Coal Analysis including Proximate and Ultimate analysis (Sample

Test from Government Lab for cross verification)

- ➢ Performance Guarantee Test (PG Test) or Report from Original Equipment Manufacturer (OEM) Design /PG test Boiler Efficiency documents
- ➢ Design/PG Test Turbine Heat Rate documents

Note on Proximate and Ultimate Analysis of Coal

If the ultimate analysis has not been carried out in the baseline year for getting H% result, following conversion formulae from Proximate to Ultimate analysis of coal could be used for getting elemental chemical constituents like %H.

Relationship between Ultimate and Proximate analysis is given below:

%C = 0.97C+ 0.7(VM+0.1A) – M (0.6-0.01M)

%H_2= 0.036C + 0.086 (VM -0.1xA) - 0.0035M2 (1-0.02M)

%N_2= 2.10 -0.020 VM

Where

C= % of fixed carbon

A= % of ash

VM= % of volatile matter

M= % of moisture

Sr No.	Description	Units	Baseline Year [BY]	Assessment Year [AY]
1	CPP Generation	Lakh kWh	1721	1726
2	Actual CPP Heat Rate	kcal/kWh	3200	3250
3	Ash	%	42	39
4	Moisture	%	18	18
5	Hydrogen	%	5	5
6	GCV	kcal/kg	3500	3200

- ❖ **Boiler efficiency in baseline year**
  =92.5-[{50xA+630 (M+9H)} /GCV]
  =92.5 – [{50 x 42 + 630 x (18+9x5)} / 3500]
  =80.56 %

- ❖ **Boiler efficiency in assessment year**
  =92.5-[{50xA+630 (M+9H)} /GCV]
  =92.5 – [{50 x 39 + 630 x (18+9x5)} / 3200]
  =79.4875 %

- ❖ **The CPP heat rate in assessment year due to fuel quality**
  = CPP heat rate in baseline year x (Boiler Efficiency in baseline year / Boiler Efficiency in assessment year)
  =3200 x (80.56/79.4875)
  =3243.17 kcal/kWh

- ❖ **Increase in the CPP heat rate of assessment year due to fuel quality**
  =3247.17 – 3200
  =43.17 kcal/kWh

- ❖ **Notional energy to be subtracted from total energy**
  = (CPP generation in assessment year

(Lakh kWh) * Increase in CPP heat rate)/10
= (1726x47.17)/10 Million kcal
=7452.2811 Million kcal

Note on Proximate and Ultimate Analysis of Coal

If the ultimate analysis has not been carried out in the baseline year for getting %H result, following conversion formulae from Proximate to Ultimate analysis of coal could be used for getting elemental chemical constituents like %H
Relationship between Ultimate and Proximate analysis

$\%C = 0.97C + 0.7(VM+0.1A) - M(0.6-0.01M)$

$\%H_2 = 0.036C + 0.086\ (VM - 0.1xA) - 0.0035M^2(1-0.02M)$

$\%N_2 = 2.10 - 0.020\ VM$

Where
C= % of fixed carbon
A=% of ash
VM=% of volatile matter
M=% of moisture

Normalization Coal Quality in Co-Gen

- **Boiler efficiency in baseline year**
  =92.5-[{50xA+630 (M+9H)} /GCV]

  =92.5 – [{50 x 42 + 630 x (18+9x5)} / 3500]

  =80.56 %

- **Boiler efficiency in assessment year**
  =92.5-[{50xA+630 (M+9H)} /GCV]

  =92.5 – [{50 x 39 + 630 x (18+9x5)} / 3200]

  =79.48 %

  The steam may be generated in the plant from Co-Gen Boilers and Process Boilers sources. However, for example purpose two Co-Gen boilers and two Process Boilers are considered. The calculation was done w.r.t. the weighted value of Cogen and Process boilers separately. The same will be reflected for all the Co-Gen and Process Boilers.

  Due to degradation of coal quality in the assessment year the SEC will increase which is disadvantage to plant, as the quality of coal is not in control of plant therefore the difference in the SEC due to fuel quality is considered in Normalization.

As the boilers may use multi – fuels as input for producing steam and it may be noted that the normalization is provided only for the coal used in the boiler. In this context, percentage of coal energy used is considered in the Normalization. As the boilers may use multi – fuels as input for producing steam, the provision is provided for 4 types of fuels. If the types of fuels are more than 4 the rest of the fuels should be converted to equivalent of fuel type-4.

Details of Co-Gen Boiler – 1.

For Co-Gen Boiler (1)				
S.no	**Description**	**Units**	**Base Line Year (BY)**	**Assessment Year (AY)**
(i)	Type			

(ii)	Rated Capacity	TPH	50.0	50.0
(iii)	Total Steam Generation	Tonne	321669.0	291836.0
(iv)	Running hours	Hrs	8411.0	7892.0
(v)	Coal Consumption	Tonne	37752.0	46701.0
(vi)	GCV of Coal	kcal/kg	4838.0	4649.0
(vii)	Type of Fuel - 2 Name : Consumption	Tonne	19801.0	16861.0
(viii)	GCV of any Fuel -2	kcal/kg	3200.0	3200.0
(ix)	Type of Fuel - 3 Name : Consumption	Tonne	18533.0	42130.0
(x)	GCV of any Fuel -3	kcal/kg	2000.0	2000.0
(xi)	Type of Fuel - 4 Name : Consumption	Tonne	3417.0	0.0
(xii)	GCV of any Fuel -4	kcal/kg	12064.0	
(xiii)	Operating Capacity	TPH	38.2	37
(xiv)	Specific Energy Consumption	kcal/kg of Steam	1008.2	1217.6
(xv)	Percentage of Coal Energy Used in steam Generation	%	0.56	0.61

- **Specific Energy Consumption for Steam Generation Boiler (Co-Gen Boiler -1) in BY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2(Tonne) * GCV of Fuel – 2(kcal/kg)) + (Type of Fuel – 3(Tonne) * GCV of Fuel – 3(kcal/kg)) + (Type of Fuel – 4(Tonne) * GCV of Fuel – 4(kcal/kg))] / [(Total Steam Generation (Tonne))]
  = [(37752*4838) + (19801*3200) + (18533*2000) + (3417*12064)]/321669
  = 1008.2 kcal/kg of Steam
- **Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler – 1) in BY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg))]/ [(Coal Consumption (Tonne) * GCV of Coal) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))]
  = [(37752*4838)] / [(37752*4838) + (19801*3200) + (18533*2000) + (3417*12064)]
  = 0.56
- **Specific Energy Consumption for Steam Generation Boiler (Co-Gen Boiler -1) in AY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2

(Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))] / [(Total Steam Generation (Tonne))]
= [(46701*4649) + (16861*3200) + (42130*2000)]/ 291836
= 1217.6 kcal/kg of Steam

❖ **Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler – 1) in AY**

= **[(**Coal Consumption (Tonne) * GCV of Coal (kcal/kg))]/ [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/ kg))]
= [(46701*4649)]/ [(46701*4649) + (16861*3200) + (42130*2000)]
= 0.61

Details of Co-Gen Boiler – 2.

For Co-Gen Boiler (2)				
S.no	**Description**	**Units**	**Base Line Year (BY)**	**Assessment Year (AY)**
(i)	Type			
(ii)	Rated Capacity	TPH	60.0	60.0
(iii)	Total Steam Generation	Tonne	351689.0	331846.0
(iv)	Running hours	Hrs	8411.0	8416
(v)	Coal Consumption	Tonne	38752.0	38701.0
(vi)	GCV of Coal	kcal/kg	4838.0	4649.0
(vii)	Type of Fuel - 2 Name : Consumption	Tonne	18911.0	26891.0
(viii)	GCV of any Fuel -2	kcal/kg	3200.0	3200.0
(ix)	Type of Fuel - 3 Name : Consumption	Tonne	19533.0	33130.0
(x)	GCV of any Fuel -3	kcal/kg	2000.0	2000.0
(xi)	Type of Fuel - 4 Name : Consumption	Tonne	3417.0	936.0
(xii)	GCV of any Fuel -4	kcal/kg	12064.0	12064.0
(xiii)	Operating Capacity	TPH	41.812	46.55
(xiv)	Specific Energy Consumption	kcal/kg of Steam	933.45	1035.2
(xv)	Percentage of Coal Energy Used in steam Generation	%	0.571	0.523

❖ **Specific Energy Consumption for Steam Generation Boiler (Co-Gen Boiler -2) in BY**
= [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))] / [(Total Steam Generation (Tonne))]
= [(38752*4838) + (18911*3200) + (19533*2000) + (3417*12064)]/ 351689
= 933.45 kcal/kg of Steam

❖ **Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler – 2) in BY**
= [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg))]/ [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))]
= [(38752*4838)]/ [(38752*4838) + (18911*3200) + (19533*2000) + (3417*12064)]
= 0.571

❖ **Specific Energy Consumption for Steam Generation Boiler (Co-Gen Boiler -2) in AY**
= [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))] / [(Total Steam Generation (Tonne))]
= [(38701*4649) + (26891*3200) + (33130*2000) + (936*12064)]/ 331846
= 1035.2 kcal/kg of Steam

❖ **Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler – 2) in AY**
= [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg))]/ [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))]
= [(38701*4649)]/ [(38701*4649) + (26891*3200) + (33130*2000) + (936*12064)]
= 0.523

Details of Process Boiler – 1.

For Process Boiler (3)				
S.no	**Description**	**Units**	**Base Line Year (BY)**	**Assessment Year (AY)**
(i)	Type			
(ii)	Rated Capacity	TPH	6.0	6.0
(iii)	Total Steam Generation	Tonne	15968.0	16274.0
(iv)	Running hours	Hrs	4990.0	5249.0
(v)	Coal Consumption	Tonne	2563.0	2579.0
(vi)	GCV of Coal	kcal/kg	5050.0	4935.0

(vii)	Type of Fuel - 2 Name : Consumption	Tonne	1368.0	1459.0
(viii)	GCV of any Fuel -2	kcal/kg	3200.0	3200.0
(ix)	Type of Fuel - 3 Name : Consumption	Tonne	934.0	972.0
(x)	GCV of any Fuel -3	kcal/kg	1100.0	1100.0
(xi)	Type of Fuel - 4 Name : Consumption	Tonne	132.0	152.0
(xii)	GCV of any Fuel -4	kcal/kg	2300.0	2300.0
(xiii)	Operating Capacity	TPH	3.2	3.1
(xiv)	Specific Energy Consumption	kcal/kg of Steam	1168.1	1156.1
(xv)	Percentage of Coal Energy Used in steam Generation	%	0.69	0.68

- **Specific Energy Consumption for Steam Generation Boiler (Process Boiler -1) in BY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))] / [(Total Steam Generation (Tonne))]
  = [(2563*5050) + (1368*3200) + (934*1100) + (132*2300)]/ 15968
  = 1168.1 kcal/kg of Steam

- **Percentage of Coal Energy Used in steam Generation (Process Boiler – 1) in BY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg))]/ [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))]
  = [(2563*5050)]/ [(2563*5050) + (1368*3200) + (934*1100) + (132*2300)]
  = 0.69

- **Specific Energy Consumption for Steam Generation Boiler (Process Boiler -1) in AY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))] / [(Total Steam Generation (Tonne))]
  = [(2579*4935) + (1459*3200) + (972*1100) + (152*1100)]/ 16274
  = 1156.1 kcal/kg of Steam

- **Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler – 2) in AY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))] / [(Total Steam Generation (Tonne))]
  = [(2579*4935)]/ [(2579*4935) + (1459*3200) + (972*1100) + (152*1100)]
  = 0.68

Details of Process Boiler - 2

For Process Boiler (4)				
S.no	**Description**	**Units**	**Base Line Year (BY)**	**Assessment Year (AY)**
(i)	Type			
(ii)	Rated Capacity	TPH	12.0	12.0
(iii)	Total Steam Generation	Tonne	55655.0	57986.0
(iv)	Running hours	Hrs	6788.0	7343.0
(v)	Coal Consumption	Tonne	12707.0	13540.0
(vi)	GCV of Coal	kcal/kg	4520.0	4230.0
(vii)	Type of Fuel - 2 Name : Consumption	Tonne	435.0	487.0
(viii)	GCV of any Fuel -2	kcal/kg	2500.0	3200.0
(ix)	Type of Fuel - 3 Name : Consumption	Tonne	0	0
(x)	GCV of any Fuel -3	kcal/kg		
(xi)	Type of Fuel - 4 Name : Consumption	Tonne	0	0
(xii)	GCV of any Fuel -4	kcal/kg		
(xiii)	Operating Capacity	TPH	8.2	7.9
(xiv)	Specific Energy Consumption	kcal/kg of Steam	1051.5	1014.6
(xv)	Percentage of Coal Energy Used in steam Generation	%	0.981	0.974

- **Specific Energy Consumption for Steam Generation Boiler (Process Boiler -1) in BY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))] / [(Total Steam Generation (Tonne))]
  = [(12707*4520) + (435*2500)]/ 55655
  = 1051.5 kcal/kg of Steam

- **Percentage of Coal Energy Used in steam Generation (Process Boiler – 1) in BY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg))]/ [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))]
  = [(12707*4520)]/ [(12707*4520) + (435*2500)]
  = 0.981

- **Specific Energy Consumption for Steam Generation Boiler (Process Boiler -1) in AY**
  = [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel (Tonne) – 2 * GCV of Fuel – 2(kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3(kcal/

kg)) + (Type of Fuel – 4 (kcal/kg) * GCV of Fuel – 4 (kcal/kg))] / [(Total Steam Generation(Tonne))]
= [(13540*4230) + (487*3200)]/ 57986
= 1014.6 kcal/kg of Steam

❖ **Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler – 2) in AY**
= [(Coal Consumption (Tonne) * GCV of Coal (kcal/kg)) + (Type of Fuel – 2 (Tonne) * GCV of Fuel – 2 (kcal/kg)) + (Type of Fuel – 3 (Tonne) * GCV of Fuel – 3 (kcal/kg)) + (Type of Fuel – 4 (Tonne) * GCV of Fuel – 4 (kcal/kg))] / [(Total Steam Generation (Tonne))]
= [(13540*4230)]/ [(13540*4230) + (487*3200)]
= 0.974

Sr No.	Description	Units	Baseline Year [BY]	Assessment Year [AY]
1	Boiler Efficiency	%	80.56	79.48
2	Steam Generation at Boiler 1-2 (Co-Gen Boiler)*	Tonne	673358.0	623682.0
3	Steam Generation at Boiler 3-4 (Process Boiler)**	Tonne	71623.0	74260.0
4	Specific Energy Consumption for Steam Generation Boiler 1-2 (Co-Gen Boiler)	Kcal/ kg of Steam	969.137	1100.17
5	Specific Energy Consumption for Steam Generation Boiler 3-4 (Process Boiler)	Kcal/ kg of Steam	1084.22	1054.47
6	Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler)	Factor	0.565	0.561
7	Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler)	Factor	0.899	0.891

**: The above example stands for 2 Cogen Boiler 1-2, the calculation could be repeated for 1-5 nos of boiler*

***: The above example stands for 2 Process Boiler 1-2, the calculation could be repeated for 6-10 nos of boiler*

❖ **Steam Generation at Boiler (1-2) in BY**
= Steam Generation by Co-Gen Boiler – 1 (Tonne) (BY) + Steam Generation by Co-Gen Boiler – 2 (Tonne) (BY)
= 321669.0 + 351689.0
= 673358.0 Tonne

❖ **Steam Generation at Boiler (1-2) in AY**
= Steam Generation by Co-Gen Boiler – 1 (AY) (Tonne) + Steam Generation by Co-Gen Boiler – 2 (Tonne) (AY)
= 291836.0+ 331846.0
= 623682.0 Tonne

❖ **Steam Generation at Boiler (3-4) in BY**
= Steam Generation by Co-Gen Boiler – 1 (BY) (Tonne) + Steam Generation by Co-Gen Boiler – 2 (Tonne) (BY)
= 15968.0 + 55655.0
= 71623 Tonne

❖ **Steam Generation at Boiler (1-2) in AY**
= Steam Generation by Co-Gen Boiler – 1 (Tonne) (AY) + Steam Generation by Co-Gen Boiler – 2 (Tonne) (AY)
= 16274.0 + 57986.0
= 74260.0 Tonne

❖ **Specific Energy Consumption for Steam Generation Boiler 1-2 (Co-Gen Boiler) in BY**

= (Specific Energy Consumption form Steam Generation Co-Gen Boiler-1 (kcal/ kg steam) (BY)* Operating TPH of Co-Gen Boiler-1 (BY)) + (Specific Energy Consumption form Steam Generation Co-Gen Boiler-2 (kcal/kg steam) (BY) * Operating TPH of Co-Gen Boiler-2 (BY)) / [(Operating TPH of Co-Gen Boiler-1(BY)) + (Operating TPH of Co-Gen Boiler-2 (BY)]

= [(1008.2*38.2 + 933.45*41.812)]/ [(38.2+41.812)]

= 969.137 kcal/ kg of Steam

- **Specific Energy Consumption for Steam Generation Boiler 1-2 (Co-Gen Boiler) in AY**

  = [(Specific Energy Consumption form Steam Generation Co-Gen Boiler-1 (kcal/ kg steam) (AY) * Operating TPH of Co-Gen Boiler-1 (AY)) + (Specific Energy Consumption form Steam Generation Co-Gen Boiler-2 (kcal/kg steam) (AY) * Operating TPH of Co-Gen Boiler-2 (AY)) / [(Operating TPH of Co-Gen Boiler-1 (AY))] + (Operating TPH of Co-Gen Boiler-2 (AY)]

  = [(1217.6 *37 + 1035.2 *46.55)]/ [(38.2+46.55)]

  = 1100.17 kcal/ kg of Steam

- **Specific Energy Consumption for Steam Generation Boiler 3-4 (Process Boiler) in BY**

  = [(Specific Energy Consumption form Steam Generation Process Boiler-1 (BY) (kcal/kg steam) * Operating TPH of Process Boiler-1 (BY)) + (Specific Energy Consumption form Steam Generation Process Boiler-2 (kcal/kg steam) (BY) * Operating TPH of Process Boiler-2 (BY))]/ [(Operating TPH of Process Boiler-1 (BY)) + (Operating TPH of Process Boiler-2 (BY)]

  = [(1168.1*3.2+8.2*1051.5)]/[(8.2+3.2)]

  = 1084.22 kcal/ kg of Steam

- **Specific Energy Consumption for Steam Generation Boiler 3-4 (Process Boiler) in AY**

  = (Specific Energy Consumption form Steam Generation Process Boiler-1 (kcal/ kg steam) (AY) * Operating TPH of Process Boiler-1 (AY)) + (Specific Energy Consumption form Steam Generation Process Boiler-2 (kcal/kg steam) (AY) * Operating TPH of Process Boiler-2 (AY))/ [(Operating TPH of Process Boiler-1 (AY)) + (Operating TPH of Process Boiler-2 (AY)]

  = [(1156.1*3.1 + 1014.6 *7.9)]/[(3.1+7.9)]

  = 1054.47 kcal/ kg of Steam

- **Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler) BY**

  = [(Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler-1) (kcal/kg steam) (BY) * Operating TPH of Co-Gen Boiler-1 (BY)) + **(**Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler-2) (kcal/kg steam) (BY) * Operating TPH of Co-Gen Boiler-2 (BY)] / [(Operating TPH of Co-Gen Boiler-1 (BY) + Operating TPH of Co-Gen Boiler-2 (BY)]

  = [(0.56*38.2) + (0.571*41.812)]/ [(38.2+41.812)]

  = 0.565

- **Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler) AY**

  = [(Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler-1) (kcal/kg steam) (AY)

* Operating TPH of Co-Gen Boiler-1 (AY)) + (Weighted Percentage of Coal Energy Used in steam Generation (Co-Gen Boiler-2) (kcal/kg steam) (AY) * Operating TPH of Co-Gen Boiler-2 (AY)] / [(Operating TPH of Co-Gen Boiler-1 (AY) + Operating TPH of Co-Gen Boiler-2 (AY)]
= [(0.61*37) + (0.523*46.55)]/ [(37+46.55)]
= 0.561

❖ **Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler) BY**
= [(Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler-1) (kcal/kg steam) (BY) * Operating TPH of Process Boiler-1 (BY)) + **(**Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler-2) (kcal/kg steam) (BY) * Operating TPH of Process Boiler-2 (BY))] / [(Operating TPH of Process Boiler-1 (BY) + Operating TPH of Process Boiler-2 (BY)]
= [(0.69*3.2) + (0.981*8.2)]/ [(3.2+8.2)]
= 0.899

❖ **Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler) AY**
= [(Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler-1) (kcal/kg steam) (AY) * Operating TPH of Process Boiler-1 (AY)) + **(**Weighted Percentage of Coal Energy Used in steam Generation (Process Boiler-2) (kcal/kg steam) (AY) * Operating TPH of Process Boiler-2 (AY))] / [(Operating TPH of Process Boiler-1 (AY) + Operating TPH of Process Boiler-2 (AY)]
= [(0.68*3.1) + (0.974*7.9)]/ [(3.1+7.9)]
= 0.891

❖ **Weighted Specific Energy Consumption for Steam Generation (BY)**
= [(Steam Generation at Boiler 1-2 (Tonne) (BY) x Specific Energy Consumption for Steam Generation in Cogen Boiler 1-2 (kcal/kg steam) (BY)) + (Steam Generation at Boiler 3-4 (Tonne) (BY) x Specific Energy Consumption for Steam Generation in Process Boiler 3-4 (kcal/kg steam) (BY))]/ (Steam Generation at Boiler 1-2 (Tonne) (BY) + Steam Generation at Boiler 3-4 (Tonne) (BY))
= [(673358*969.137) + (71623.0*1084.22)]/ [(673358+71623.0)]
= 980.20 kcal/kg of Steam

❖ **Weighted Specific Energy Consumption for Steam Generation (AY)**
= [(Steam Generation at Boiler 1-2 (Tonne) (AY) x Specific Energy Consumption for Steam Generation in Cogen Boiler 1-2 (kcal/kg steam) (AY)) + (Steam Generation at Boiler 3-4 (Tonne) (AY) x Specific Energy Consumption for Steam Generation in Process Boiler 3-4 (kcal/kg) (AY))]/ [(Steam Generation at Boiler 1-2 (Tonne) (AY) + Steam Generation at Boiler 3-4 (Tonne) (AY)]
= [(623682*1100.17) + (74260*1054.47)]/ [(623682+74260)]
= 1095.3 kcal/kg of Steam

❖ **Normalized Specific Energy Consumption for Steam Generation (AY) (kcal/kg of Steam)**