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Report on Developing Baseline Specific Energy Consumption in Petrochemicals Industry in India

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Executive Summary

The primary objective of the Energy Conservation Act (EC Act), 2001,(later amended in 2010) is to promote efficient use of energy and its conservation through certain statutory measures in various sectors of economy. Under this act, 15 industry types were identified as Energy Intensive Industries depending on their annual energy consumption.

In 2008, Government of India announced the 'National Action Plan on Climate Change (NAPCC), identifying eight missions to promote inclusive growth in the country. The National Mission on Enhanced Energy Efficiency (NMEEE) is one of the eight identified mission under NAPCC. One of the initiatives under NMEEE is Perform Achieve and Trade (PAT) scheme which is a market based mechanism having the objective to enhance energy efficiency by providing specific energy consumption targets with an option to trade the additional energy savings, in the form of energy saving certificates. Bureau of Energy Efficiency (BEE) under Ministry of Power (MoP) is implementing this scheme in 8 industrial sectors in the first phase, which are Thermal Power Plants, Aluminum, Pulp & Paper, Chlor- Alkali, Cement, Iron & Steel, Textile and Fertilizer. During the first phase of PAT,(2012-13 to 2015-16), about 460 designated consumers (DCs) are expected to participate in the scheme who would be required to reduce the Specific Energy Consumption (SEC) from their baseline values.

BEE further plans to include few new sub-sectors from the already identified 15 Energy Intensive Industries under the EC Act, during the next PAT cycle, depending on their energy consumption. Similarly, the remaining 8 industrial sectors need to be studied in detail to work out the baseline specific energy consumption (SEC) based on the production quantity and all type of energy usage. In this baseline study the petrochemicals sector was analyzed to develop the SEC and to identify the potential of energy conservation and to arrive at the energy saving targets.

The petrochemicals sector is highly energy intensive and plays an important role in the Indian economy. The various products in the Indian petrochemical sector falls under 9 Categories and 39 products and 55 plants were identified for this study. The chemical and petrochemical sector in India presently contributes about 3% in the GDP and constitutes 14% of the domestic industrial activity. The polymer industry alone annually contributes over Rs 8,000 crores by way of taxes and duties.

Energy consumption in the Indian Petrochemical sector was estimated for the year 2011-12 and was worked out on the basis of actual production and the design specific energy consumption for a specific petrochemical product provided by the technology supplier . The gross primary energy consumption is estimated to be 120 million GJ or 2.85 MTOE for the year 2011-12.,Production of Propylene and Ethylene consumes maximum energy with almost 63% of the cumulative energy consumption for the entire sector.

Secondary data analysis of the sector indicates that three products account for 75% of the total energy consumption, the remaining energy is consumed by remaining 14 major products . As such specifying a minimum energy consumption level for demarking the Designated Consumers (DC) was a challenging task for the sector. Having reviewed thevarious international benchmarking practices and their respective pros and cons of each method, and keeping in mind the complexity of the petrochemical sector we propose that the following two methods may be considered for arriving at the SEC for each of the products. These methods are robust and can help in setting targets for the designated consumers.

a) A Statistical Approach, which helps in setting specific energy consumption and also arriving at normalization factors. The factors (independent variables) that affect energy consumption (dependent varaible) in a petrochemical plant are used to arrive at a regression equation, which could be used for each of the petrochemical product. The same has been demonstrated in this report with examples. However, these equation developed will have to be further refined after collecting product specific actual plant data. The theortical concepts of the statistical method are discussed in the "Review of International benchmarking practices" chapter and examples of statitical models are provided in Annexure 7.
b) A Energy Efficieny Index (EEI) approach, is fundamentally a Ratio of Reaction Heat to Total Energy Consumed. This is based on the first principles of reaction engineering, the ratio indicates the energy consumed (or generated depending on whether the reaction is exothermic or endothermic) to that actually consumed. However, this also need to consider various operational parameters such as capacity of the plant, hours of continuous operation, etc. The EEI method has also been demonstrated in the report. This method is discussed in detail in "Roadmap for Implementing PAT in Petrochemical Sector" chapter.

A questionnaire for collecting precise data from petrochemical plants has also been provided in the report for facilitating unifrorm and comprehensive data collection and recording. A sample filled questionnaire for an actual Polypropylene, Olefins and Polyethylene Plant has also been attached in Annexure 3 of the report .

The Government Policies and Regulations relevant to the petrochemical sector, mainly focusing on Policy on Petroleum, Chemicals & Petrochemicals Investment Regions (PCPIR) and also National Policy on Petrochemicals, Technology Up-gradation Fund (TUF) Scheme, etc. Highlights of these policies are also mentioned in this report in "Government Policies and Regulations" chapter.

Having reviewed the current scheme proposed under PAT-I where targets have been provided to the designated consumers, except for the power sector the other sectors lack scientific rationale and the desired robustness for arriving at the threshold limits for individual sectors.

Based on the secondary data the threshold value of 30000 tonnes of oil equivalent is a good representation of the petrochemical sector in terms of energy usage in a plant, however it scores low on the sector representation as such. The threshold level of 12000 tonnes of oil equivalent seems to be a more reasonable representative of the sector, as it would cover over 50% of the plants. This topic is discussed in detail under the "Roadmap for Implementing PAT in Petrochemical Sector" chapter.

Within the limited data availability, we also have attempted to conclude that a SEC reduction in the range 5% to 6%, over a 3-year PAT cycle, may be a reasonable target.

We sincerely express here that the level of accuracy and analytical depth of the research conducted under the study could have increased multiple times if the petrochemical plant's first hand energy consumption, manufacturing technology / licensor, process details, etc were available rather than the secondary data that was used for this study.

A stakeholder discussion was held to brainstrom the findings of the study and the summary of the discussion is documented in this report under "Summary of Stakeholder Deliberations on proposed methodology and Way Ahead" chapter.

Overview of global petrochemicals industry

Petrochemical industry owes its origin to growing demand of synthetic materials for household, automotive, manufacturing and other sectors, especially post-World War II. The earliest petrochemical experiments date back to early 1900s when synthetic rubber was invented, plastics in 1907 by Bakelite, petrochemical solvents in 1920s, polystyrene in 1930 and so on. Ever since its origin the petrochemical industry has been a true manifestation of existing state of economy, due to its strong co-relation with demand. From its initial stage till late 1980s, developed countries like US, Western Europe and Japan, played a great role in growth of petrochemical sector. However, the current petrochemical sector is significantly dependent on the expected demand surge from emerging countries, especially China and India, and on low-cost producing countries from Mid-east.

The petrochemical industry is quite cyclical and has some defined stages as shown in the pictorial representation below. The cycle is dependent on regional and global demand imbalances (demand exceeding supply), level of investment, regional dynamics, global economic situation etc. Though no fixed time-frame for completion of one complete cycle can be ascertained, it can be safely assumed that the present year 2012 could be end of the current recessionary cycle and herald a beginning of a fresh cycle with slew of new investments planned in China, Mid –East and other regions.

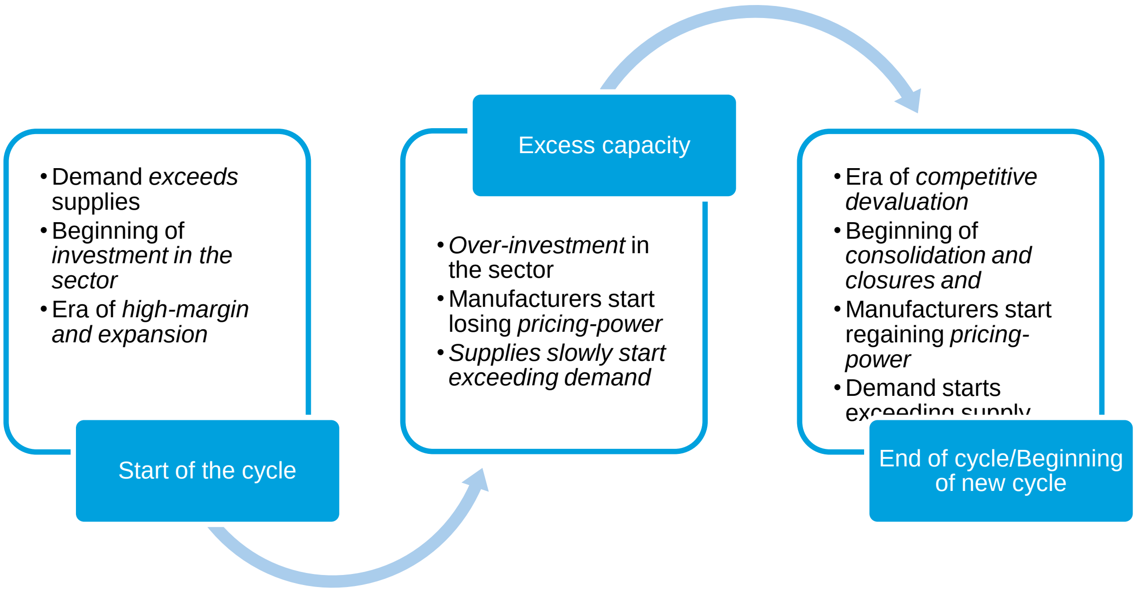


Figure 1: Dynamics of a Petrochemical Cycle

Trends of Global Petrochemical Industry

Shift from 'technology-push' to 'demand-push': The petrochemical industry has changed drastically in last few decades. Since it is quite cost-intensive technology, prior to 1980s, US, Western Europe, and Japan played a prominent role, both as production and demand centres. However post-2000, with emerging economies, like China and India, there is a definitive shift to these new demand centres. Share of China in global petrochemical demand has increased from 24 per cent in 2006 to 32 per cent in 2010, during which the global demand has itself grown by 15 per cent. Demand share from the old guards like, Western Europe and US are set to decrease, and Asia is emerging in petrochemical production. In addition to China, India, and Mid-east, production has also increased in other Asian countries like Singapore, South Korea, Taiwan, Thailand, Malaysia, and Indonesia due to domestic demand and/or available export market.

Feedstock cost being a significant part of total cost, a shift in petrochemical production to oil and gas rich Mid-east is noticed. Globally most of the regions are facing declining oil and gas production and highly volatile feedstock cost. This has led Mid-east countries looking for refinery-petrochemical integration in a big way. Availability of cheap feedstock like naphtha and natural gas, growing regional demand, availability of cheap labour, and proximity to emerging demand centres (China and India) have led to surge of new petrochemical complexes in different Mid-east countries. Most of the products from Mid-east countries find its way to export market. However due to higher dependence on one type of feedstock (ethane-based), issues related to project-execution, and increased capacity-addition in China (a major export market), Mid-east countries may witness growth-constraints.

Growth of petrochemical industries is highly dependent on the growth of user-industries like automotive, packaging industry etc. Despite the global economic slowdown, these industries are expected to grow, especially in emerging economies, where recent increase of higher income has been a key factor. Automotive owes its growth to transportation and infrastructure sectors, whereas, packaging industry will continue growing due to the convenience, protection and cost-effectiveness it offers, especially to food and beverage sector.

Due to shortage of oil and gas in large emerging economies, especially China, coal may see increase in use as petrochemical feed-stock. This is expected since China has access to coal and for all its planned petrochemical projects, it can be utilized as feedstock. This will necessarily have detrimental impact on environment. It is, however, expected, that coal-gasification process will get boost to check the environment concerns that coal may pose.

Environment has been a key concern for petrochemical industry. Regions like Western Europe and US have imposed strict emission norms, thus, restricting growth in these regions. This is likely to continue in these regions and is expected to extend to other regions as well.

Energy Consumption Trends in Petrochemical Industry

Petrochemical industry is an energy-intensive industry. The chemical and petrochemical sectors contribute to approximately 10 per cent of total energy demand and if we add the energy use of the feedstock, this share may go upto 30 per cent. Within chemical sector, petrochemical sector consumes 70 per cent of total energy.

Top ten chemicals consisting - ethylene, propylene, m-xylene, methanol, p-xylene, methyl tert-butyl ether, butylene, tere-phthalic acid, propylene oxide, caprolactam – form 70% of total CO_2 emitted, but constitute only 38% of total petrochemical production. Methanol is expected to witness highest growth in total CO_2 emission by 2018. Caprolactam is the highest CO_2 emitter on per unit of weight, followed by toluene di-isocyanate and Poly butadiene rubber.

With the expected growth story discussed above, total CO_2 emission may increase by approximately 50 per cent by 2018 from 2008 levels. Asian region alone will contribute to 70 per cent of this increase. Regionally, Asia leads the total CO_2 emission list and will continue this trend in the foreseeable future. Other regions, North America, Western and Central Europe, may see marginal growth. In ethylene production, Mid-east may outpace Asia (minus mid-east) in total CO_2 emission, whereas, for methanol production Asia (minus mid-east) is way ahead.

Table 1: Electricity Usage by Demand Source[1]

Energy Demand Source	Process electricity use (EJ/year)	Share of total electricity use (%)
Electrolysis	0.5	13
Motors	~2.4	~65
Lighting	0.25	7
Others	~0.55	15

According to IEA Report on Chemical and Petrochemical Sector 2009, the biggest source of electricity consumption in chemical and petrochemical sector is motors, contributing to 65 per cent of total energy consumed. With worldwide alarming and constraining trends on energy efficiency and CO_2 emissions, the global petrochemical industry can expect emphasis on higher energy-efficiency and better feedstock-utilization. The same report emphasizes that the expected energy saving potential will be maximum in process heat (>4 EJ per year) followed by recycling and energy recovery (>2EJ per year).

[1] Source : IEA, Report on Chemical and Petrochemical sector , 2009

The working paper on “Global Industrial Energy Efficiency Benchmarking - An Energy Policy Tool” by UNIDO talks about the sectoral energy benchmarking based on the benchmark curves. In benchmark curves the energy use of individual plants is plotted as a dependent variable from the most efficient to the least efficient plant, either as function of cumulative production or of the number of plants. The information from benchmark curves can be used to assess the relative performance of individual plants. It can also, where sufficient specific information is available and the coverage of the benchmark curve is fairly comprehensive, be used to estimate the aggregate savings potential. The benchmark curve contains valuable information about best practice technologies (BPT), i.e. technologies that are energy efficient and already applied in practice. This helps in projecting the potential effect of implementing BPT and other best available energy saving technologies.

The “Energy Efficiency Benchmarking Covenant” by the Flemish Government also commands to realize the best international standards of energy efficiency based on the international benchmarking principle. This comparison provides the basis for participating businesses to draw up an energy plan which determines which measures they will use to ensure that they achieve the world top level with regard to energy efficiency.

Technology Trends in Petrochemical Industry

Development of petrochemical industry is a journey of technical innovation. In the past, the countries with technical edge were the major players of the sector. With surge of urban growth, the industry grew despite constraints, in these countries. Post-1980s or more decisively post-2000, the base started shifting to Asia, not necessarily the centre of technological excellence. In the changing scenario, role of technology is no less important. In short, the present state of industry needs to handle issues related to feedstock availability, sustainability, long-term profitability of manufacturers (in light of cyclicality of industry) and refinery-petrochemical integration.

Currently majority of feedstock used worldwide is hydrocarbon based. Hence the technologies are evolving around this and even the industry has shifted to Mid-east, the largest oil and gas producing region. Since hydrocarbon reserves are depleting and their prices are volatile, China, a prominently growing player, has shown keen interest in using coal as feedstock. Coal as feedstock for olefin production, is gaining prominence in China, and so are the concerns related to global environment due to coal-usage. This necessitates an urgent technological issue of clean coal. Scientists worldwide are working on coal-to-gas and other technologies, which can reduce the environmental burden.

Another feedstock related trend is related to efficiency of feedstock-usage. Feedstock cost is a significant cost in petrochemical industry, hence there is constant effort to optimize feedstock-consumption and remain competitive through economies of scale and feedstock-efficiency improvements.

Petrochemical is an energy-intensive industry. Basic petrochemicals account for more process energy use and CO_2 emissions than any other type of chemical. This industry is facing the challenges of emission (due to environment concerns) and energy-supply security (due to depleting energy sources).

The table below provides a summary of energy consumption and energy efficiency index in global chemical and petrochemical industry. The energy efficiency index shows the potential of further energy saving- lower the index, higher the potential for energy savings.

Table 2: Energy Consumption and Energy Efficiency Index in Global Chemical and Petrochemical Industry[2]

Country	Reported Energy use (PJ)	Energy efficiency Index
US	6862	0.70
Japan	2130	0.90
China	3740	0.80
Saudi Arabia	1115	0.82
Germany	1157	0.90
Netherlands	618	0.82
France	654	0.88
Brazil	577	0.83
UK	490	0.94
India	1091	0.84
Chinese Taipei	741	0.81
Italy	389	0.94
World	***28819***	***0.82***

In light of growing concern about emission norms, technologies involving sustainability hold the key to the future of industry. The current technology is handling this by developing more energy-efficient processes and innovating processes using sustainable feed-stocks like bio-mass.

Global Demand Supply and Capacity

Globally petrochemical market is a USD 1.3 trillion market, forming the single largest segment of chemicals market. Demand of petrochemical is entwined with growth and hence has great correlation with global,

[2] Source: IEA

regional and national economic growth. The global petrochemical demand in 2010 was approximately 314 million tonnes, which had grown at CAGR of 3.6 per cent from demand of approximately 273 MT in 2006. Major part of this demand, approximately 80 per cent, comes from five products- polyethylene (23 per cent), polypropylene (16 per cent), methanol (15 per cent), purified terephthalic acid (14 per cent), and polyvinyl chloride (11 per cent).

The table below shows the status of demand and capacity in 2010 and estimated demand and capacity in 2015. It is interesting to note that in all product categories, the demand and capacity are expected to show a healthy and positive CAGR.

Table 3: Capacity and Demand of Major Petrochemical Products in 2010-15[3]

Product	Capacity	Demand	Expected Capacity	Expected Demand	Capacity CAGR	Demand CAGR
	2010	**2010**	**2015***	**2015***	**2010-15**	**2010-1015**
	MTA	*MTA*	*MTA*	*MTA*	*(%)*	*(%)*
Ethylene	143	120	165	151	2.9	4.7
Propylene	94	75	113	94	3.75	4.6
PET	19	15.3	27	20.6	7.28	6.13
Benzene	56	41	62	47	2.06	2.77
Butadiene	14	9.6	15	11.6	2	3.9
p-Xylene	35	28	45	37	5.15	5.73
PTA	49	41	68	55	6.77	6.05
PVC	46	35	55	44	3.64	4.7
HDPE	41	33	50	44	4.05	5.92
LLDPE	28	21	34	29	3.96	6.7
LDPE	22	19	25	22	2.6	3

Ethylene production is a key indicator of petrochemical production. Globally there has been steady rise of ethylene production capacity. The global ethylene production capacity in 2010 (end 2010) was approximately 143 MTA (million tonnes annum) , compared to 130 MTA in 2009, 126.7 MTA in 2008, and 119.6 MTA in 2007, maintaining a healthy CAGR of approximately 5.4 per cent.

[3] Source: CMAI

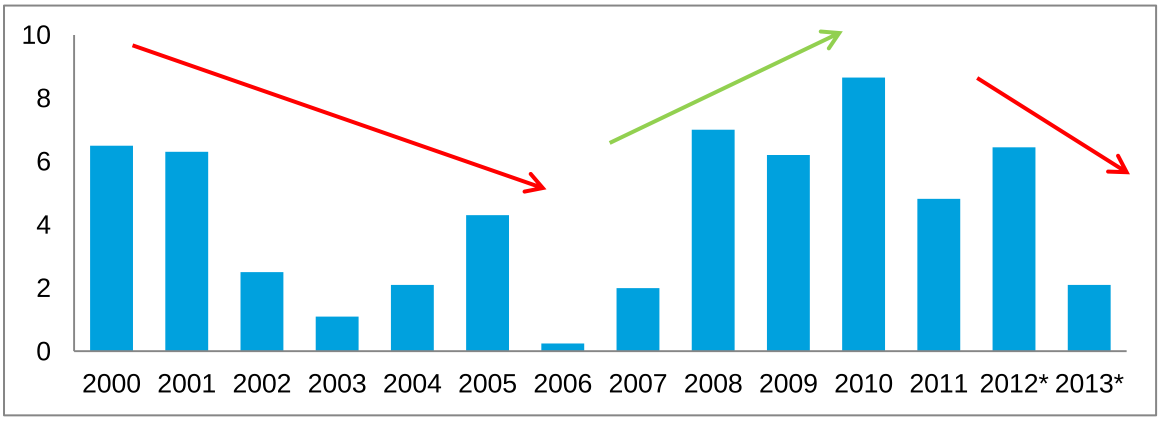
On a regional basis, Asia-Pacific region has the largest ethylene capacity followed by North America, Western Europe and Mid-East. However, at present US has the largest capacity, followed by China and Saudi Arabia. But with the capacity addition planned, China may surpass US by 2015-16.

Table 4: Global Ethylene Production Capacity[4]

Region	Ethylene capacity, MTA	Major countries	Ethylene capacity, MTA
Asia Pacific	42.63	China (Excluding Taiwan)	12.98
		Japan	7.26
		Taiwan	4.00
		India	3.30
		Malaysia	1.72
		Singapore	2.78
		South Korea	5.63
		Thailand	3.17
Eastern Europe	7.97	Russia	3.49
Mid-east/Africa	23.36	Saudi Arabia	11.95
		Iran	4.73
		Kuwait	1.65
		Qatar	2.52
N. America	34.50	US	27.59
		Canada	5.53
		Mexico	1.38
South America	5.08	Brazil	3.50
Western Europe	24.90	Germany	5.74
		France	3.37
		Netherlands	3.96
		UK	2.85
		Italy	2.17
		Belgium	2.46
		Spain	1.43

[4] Source: Oil Gas Journal

The period of 2007-10 was booming period for global petrochemical capacity addition worldwide, following a disastrous year for industry in 2006. Keeping in line with the expected demand, year 2010 alone saw capacity addition of 8.65 MTA- highest annual addition ever- out of which 3.95 MTA was in Mid-east and balance 4.7 MTA was in Asia-Pacific. The ethylene capacity addition trend post-2000 is charted below, with two obvious trend lines denoting decelerating (red line) and accelerating (green) growth rates.



* Estimates

Figure 2: Capacity additions 2000-2011, MTA[5]

Most of the major ethylene capacity additions are expected in China and Mid-east, as detailed above, with exception of Algeria and Venezuela. Emergence of China is witnessed not only in ethylene capacity addition. According to an estimate, during 2008-11, China has added capacities in propylene (5.3 MTA, 57 per cent growth), benzene (4.6 MTA, 80 per cent growth) and p-xylene (4.4 MTA, 109 per cent growth) as well. With all these additions, it looks to reduce its imports from Mid-East, and shift towards self-reliance.

Mid-east, which is mainly an export market, plans to add capacities in propylene (5 MTA, 80 per cent growth), benzene (0.9 MTA, 30 per cent growth) and p-xylene (1.6 MTA, 79 per cent growth). As discussed above, due to feedstock-advantage, this region has clear price advantage in ethylene production at USD 250-300 per MT, compared to its nearest competitor South East Asia at USD 850 and above.

[5] Source: Oil Gas Journal

Overview of Indian petrochemicals industry

The petrochemical industry is one of the fastest growing industries in India. With the growth in the economy, rising income levels and shifting of manufacturing base from US, Western Europe and Japan to Asia, it is expected that petrochemical sector in India will continue to grow during this decade. In India, the major petrochemical products comprise synthetic fibres, polymers, elastomers, synthetic detergent intermediates and performance plastics. India is the fifth largest consumer of polymers in the world after United States, China, Japan and Germany, although India has very low per capita consumption of polymers. Current per capita consumption of polymers in India is approximately 7 kg compared to global average of 28 kg. Similarly in the synthetic fibre segment, India's current per capita consumption is only 5 kg, whereas global average is 10 kg. India accounts for approximately 4% of the regional share in global polymer production in 2010, which constitutes about 70% of the end products of the petrochemicals market in India.

The Indian polymer market has tremendous growth potential and is equivalent to 1.2 to 1.4 times the GDP growth rate. The current PE, PP, PVC and PS capacity in India is around 3.3 million MT, 2.84 million MT, 1.27 million MT and 0.36 million MT respectively. Reliance is the market leader with HPL, GAIL and IOCL being the other major players in the Indian polymer market.

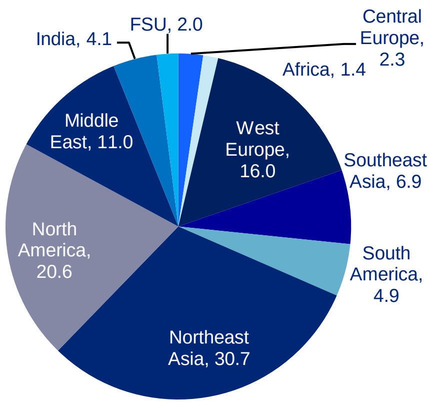


Figure 3: Worldwide Polymer per capita

The Indian petrochemical industry was established around mid-sixties when two private sector companies - Union Carbide and National Organic Chemical Industries Ltd., set up naphtha based crackers of 20 KTA and 60 KTA in Mumbai in 1966 and 1968 respectively. The first public sector naphtha based integrated petrochemical complex was set up by IPCL in 1978 at Vadodara of 130 KTA capacity. In 1989, IPCL commissioned its gas based petrochemical complex at Nagothane of 300 KTA capacity.

During 1990s, post liberalization and government reforms in this sector such as delicensing, deregulation, liberalization of trade policies and lowering of tariffs, huge investment was made by other players such as

RIL, GAIL, Haldia Petrochemicals Ltd. (HPL) to set up large integrated complexes in late 90s. In 1998, RIL completed phase-II expansion of Hazira petrochemicals complex including world's largest multi-feed cracker, PET plant, MEG plant, PTA plant and PE plant. In the same year, GAIL set up its first gas based petrochemical complex at Pata and IPCL commissioned its third petrochemical complex at Gandhar. In 1999, HPL commissioned naphtha based petrochemical complex at Haldia. During 1999-2000, RIL's refinery-cum-petrochemicals at Jamnagar was commissioned. Recently in 2010, IOCL commissioned petrochemical complex at Panipat. Currently, there are three naphtha based and an equal number of gas based cracker complexes in India with a combined annual ethylene capacity of 2.9 million MT. Also, there are four aromatic complexes also with a combined xylene capacity of 2.9 million MT.

The Indian petrochemical sector has come a long way. Now, majority of the players are integrating refinery and petrochemical complexes, which provides improved margins due to readily available feedstock and hence significant saving in transportation, sharing of utilities, support services and infrastructure etc. and most important aspect is flexibility to optimize products to capture the highest market value. The table below gives the details about major petrochemical complexes in India. Annexure 2 entails more details on Product-wise installed capacities, production and the major players in the sector.

Table 5: Major Petrochemical Complexes in India[6]

Petrochemical Complex	Plants/Facilities	Main Products and Capacity (`000 TPA)
RIL, Vadodara	Naphtha Cracker, LDPE Plant, Mono Ethylene Glycol/Ethylene Oxide Plant, Butadiene Extraction Unit, Polybutadiene Rubber Plant (2 plants), Benzene Extraction Unit, LAB plant, Acrylonitrile Plant, Acrylic Fibre Monocompo-nent Plant, Acrylates Plant, VCM Plant, PVC Unit, Polypropylene Copolymer Pant, Acrylic Fibre Bi-component Plant, Polypropylene Plant	Ethyelene (130), Propylene (107), Butadiene (37), Benzene (23), O-xylene (454), P-xylene (486), DMT (30), EO/EG (20), Acrylonitrile (30), LAB (43.5), LDPE (80), PP (55), PVC (55), PBR (20), Acrylic Fibre (24)
RIL Hazira	Naphtha Cracker, Mono Ethylene Glycol Plant (3 plants), PVC Plant, VCM Plant, HDPE Plant, POY Plant, PP Plant, PSF Plant, PTA (2 plants), Aromatics Plant, PET Plant, PFF Plant, Combined Cycle	PP (360), Propylene, Ethylene, 1-Butene, VCM (160), EDC, EO/MEG (340), DEG, TEG, HDPE (360), LDPE, PVC (160) Naphtha Cracker capacity- 750 KTA

[6] Source: Company Websites & Petrochemical Process Technology Book by I.D. Mall

	Power Plant (2 plants)	Aromatics Plant capacity- 350 KTA
RIL Dahej	Gas Cracker, Ethane Propane Recovery Unit, HDPE Plant, Mono Ethylene Glycol/Ethylene Oxide Plant, PVC Plant, VCM Plant, Chlor Alkali Unit	Ethane/propane (450), Ethylene (300), Butadiene (10), PVC (150), Propylene (380, EO (20), Ethylene dichloride (240), VCM (158), EG (10), Alpha olefins (100), Alcohols, Chlor Alkali, Chlorine (115), Caustic (130), Ethoxylates (100)
RIL Patalganga	Naphtha Cracker, Polyester Filament Yarn Unit, Polyester Staple Fiber Unit, PTA Unit, Paraxylene Plant, LAB Plant	P-xylene (400), Terephalic acid, LAB (100), Polyester
RIL Nagothane	Gas Cracker, LDPE Plant, Butene-1 Plant, LLDPE/HDPE Plant, PP Plant, Mono Ethylene Glycol/Ethylene Oxide Plant	Ethylene (400), LDPE (80), LLDPE (80), HDPE (55), Propylene (63), Butene (15), Polypropylene (60), Acetylene
RIL, Jamnagar	Aromatics Complex, Polypropylene plant	2.1 MMTPA (PX+ OX) capacity, PP ((1030 KTA and a new PP line of 900 KTA)
HPL, Haldia	Naphtha Cracker, HDPE Plant, LLDPE Plant, PP Plant, C4 Hydrogenation Unit, Butadiene Extraction Unit, Benzene Extraction Unit, Pyrolysis Gasoline Hydrogenation Unit	Ethylene (300), HDPE and LLDPE (200), Polypropylene
GAIL, Pata	Gas Cracker, HDPE Plant, HDPE/LLDPE Plant, Gas Sweetening Unit, C2-C3 Extraction Unit, Butene-1 Plant, LPG Plant	Ethylene (300), HDPE (80), PP(100), PVC (100)
IOCL, Panipat	Naphtha Cracker, Paraxylene/Purified Terephthalic Acid (PX/PTA) plant, PP Plant, HDPE Plant, HDPE/LLDPE Plant, MEG Plant	P-Xylene (360), TPA (550), Ethylene (575), Propylene (350), MEG (250)
BRPL, Bongaigaon, Assam	Aromatic Complex, DMT Plant, Polyester Fibre Plant	P-xylene (40), DMT (40), Polyester Fibre (10)
MRPL, Mangalore	Aromatics Complex, Mixed Xylene Unit	P-xylene, Mixed xylene Aromatics Complex capacity is 100 KTA

Trends in Indian Petrochemical Sector

According to production figures from Ministry of Chemicals and Fertilizers Annual report 2012, Performance plastics, fibre intermediates, aromatics and synthetic fibre/yarn production grew by 6% or more in last seven years i.e during 2003-04 to 2010-11. The Ministry of Chemical and Fertiliser has categorised number of products for the petrochemical sector. This section provides an insight to the product-wise installed capacity and production of the major petrochemicals in the country as categorised by the Ministry of Chemical and Fertiliser.

Building Blocks (Ethylene, Propylene, Butadiene, Benzene, Toulene, P-Xylene, O Xylene and M-Xylene)

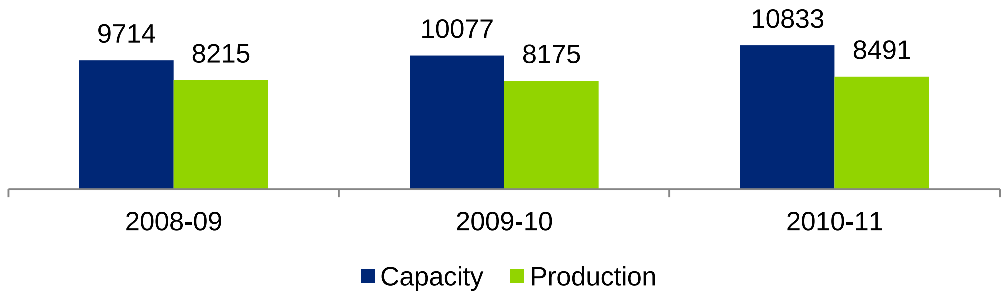


Figure 4: Building Blocks – Capacity v/s Production, kTA

- Basic petrochemicals fall in two major categories – Olefins and Aromatics. Olefins are the major building blocks of the petrochemical industry.
- In 2010-11, ethylene and propylene constituted more than 90% of the total production and capacities in olefins category. During the same period, P-xylene and benzene constitute more than 80% of the total production and capacities in aromatics category.
- Installed capacity of aromatics has remained steady during 2008-11, however olefins capacity during the same period has increased by ~21%.
- Ethylene capacity increased by ~34%, however production grew merely by ~1% during 2008-09 to 10-11.
- O-xylene capacity decreased by ~11%, however production increased by ~40% during 2008-09 to 10-11.
- Benzene production has shown positive growth, however toluene and mixed xylene production growth was negative during 2008-09 to 10-11.

Fibre Intermediates (Caprolactum, Acrylonitrile, MEG, DMT and PTA)

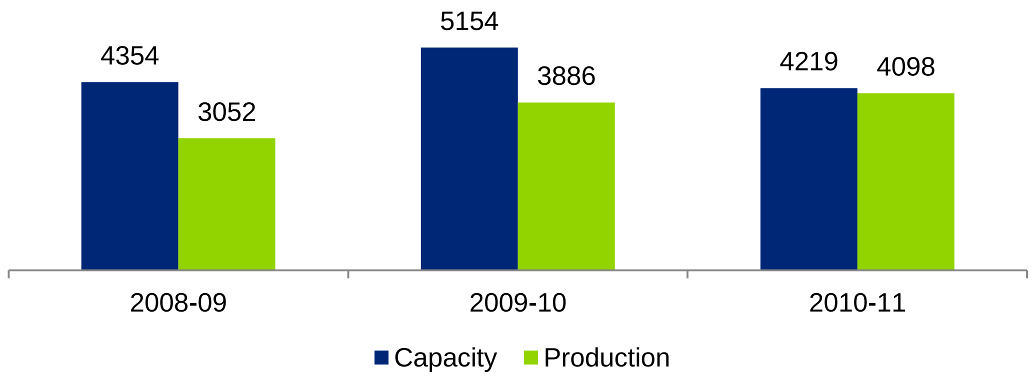


Figure 5: Fibre Intermediates – Capacity v/s Production, kTA

- In 2010-11, PTA and MEG constituted around 90% of the total production and capacities in fibre intermediates category.
- Production maintained CAGR of ~10% during 2008-11. However, installed capacity for fibre intermediates was inconsistent. It grew in 2009-10, but decreased by 18% in 2010-11.
- MEG capacity increased by ~27%. However PTA capacity which increased by 26% during 2008-09 to 09-10, decreased by ~30% in the consecutive year, 2010-11.
- There was no production of DMT during 2008-09 to 10-11.
- Caprolactum and PTA production grew by 46% and 48% respectively, however MEG had shown negative growth of ~5% during 2008-09 to 10-11.

Polymers (HDPE, LDPE, LLDPE, Polystyrene, Polypropylene, Polyvinyl Chloride and Expandable Polystyrene)

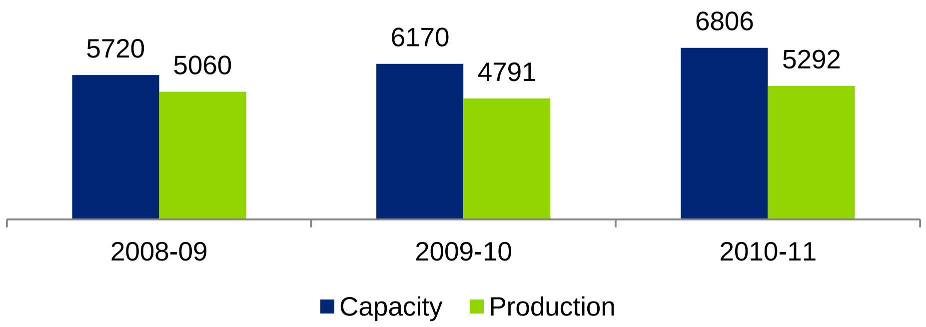


Figure 6: Polymers – Capacity v/s Production, kTA

- Polymers are the major products that account for bulk of the petrochemical industry. India has significant production capacity of polymers which is growing at significant pace.
- In 2010-11, HDPE/LLDPE, PP and PVC capacities constituted around 40%, 31% and 19% of the total capacities in polymer category. During the same period, production of HDPE/LLDPE, PP and PVC production constitute around 34%, 32% and 24% of the total production in this Category.
- Installed capacity of polymers increased by 19% from 5720 to 6806 KTA during 2008-09 to 2010-11, %, however production grew merely by ~4% during 2008-11.
- LLDPE/HDPE capacity increased by ~47% , however LDPE capacity and production decreased by 20% & 6% respectively during 2008-11.
- PVC capacity grew by 16% during 2008-11.

Synthetic Fibres/Yarn (PFY, Nylon Filament Yarn, Polypropylene Filament Yarn, Acrylic Fibre, PSF, Polypropylene Staple Fibre, Polyester Staple Fibrefil)

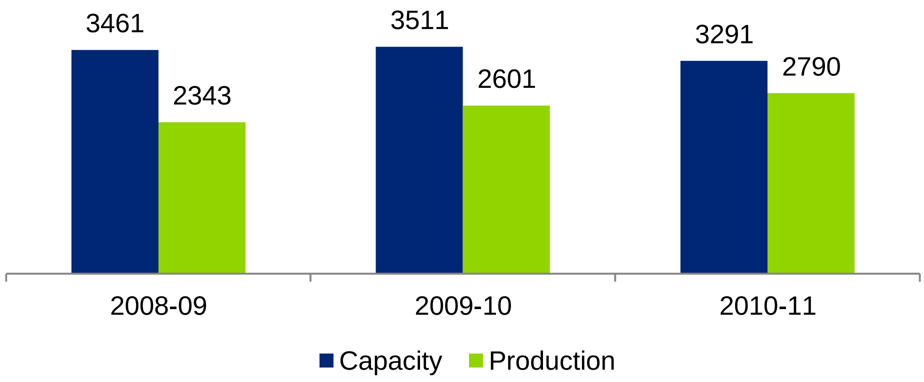


Figure 7: Synthetic Fibres/Yarn – Capacity v/s Production, kTA

- In 2010-11, PFY and PSF capacities constituted around 34% and 25% of the total capacities in synthetic fibre/yarn category. During the same period, production of PFY and PSF constitute around 34% and 23% of total production in this category.
- In the last three years, the total installed capacity of synthetic fibre /yarn had decreased from 3461 to 3291 KTA.
- Polyester fiber capacity decreased by 6%, however production increased by ~19% during 2008-11.
- Acrylic fibre capacity decreased by ~34% and PSF increased by ~23% during 2008-11.

Synthetic Rubber/Elastomers (SBR, PBR, NBR, EPDM and EVA)

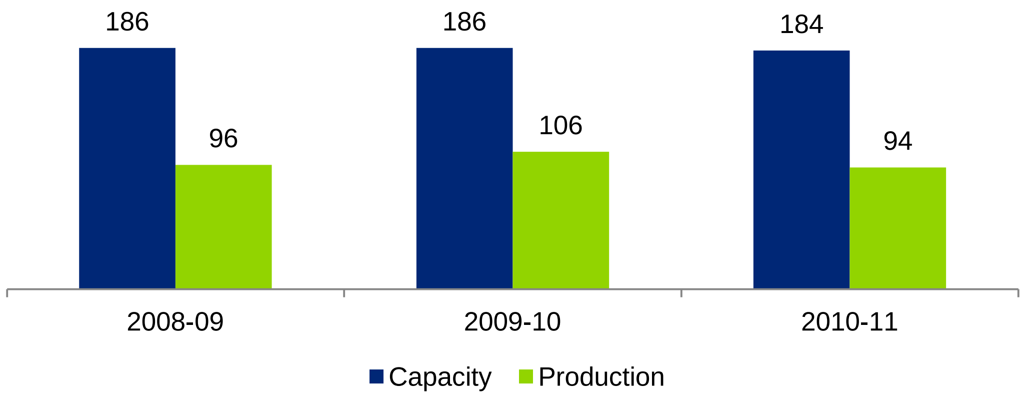


Figure 8: Synthetic Rubber/Elastomers – Capacity v/s Production, kTA

- In 2010-11, PBR and SBR capacities constituted around 40% and 34% of the total capacities in Synthetic rubber/elastomers category. During the same period, production of PBR and SBR constitute around 81% and 13% of total production in this category.
- Installed capacity for this category remained steady and production merely grew at CAGR of 1.05%.
- Production of EPDM and EVA almost stopped since 2007-08.

Synthetic Detergent Intermediates (LAB and EO)

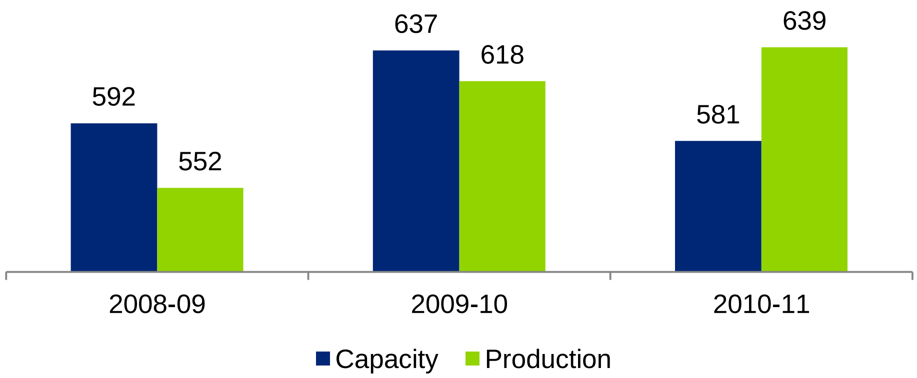
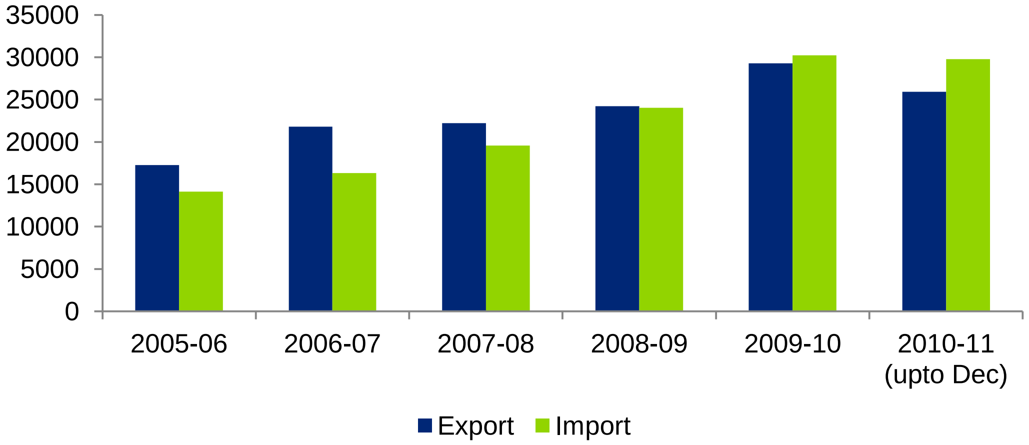


Figure 9: Synthetic Detergent Intermediates – Capacity v/s Production, kTA

- In 2010-11, LAB and EO capacities constituted around 86% and 14% of the total capacities in synthetic detergent intermediates category. During the same period, production of LAB and EO constitute around 74% and 26% of total production in this category.
- Installed capacity for this category decreased from 637 to 581 KTA; EO capacity decreased significantly by 40% in last two years.
- LAB capacity and production grew by 5% and 9% respectively during 2008-09 to 10-11
- Demand for EO is mainly coming from ethoxylates, glycol ether and dyes intermediates

Trends in Import-Export of Petrochemical Products

Indian petrochemical imports have gone up significantly in the last few years due to growth of demand fuelled by a robust economic growth.



[7]

Figure 10: Exports and Imports of Petrochemicals (Figures in Rs. Crore)

Key trends in the Indian Petrochemical Sector

- Ethylene imports increased by ~225 percent during FY2009-11 in value terms**.** UAE, Qatar and Iran were the major exporters to India.
- Styrene import was more than US$500 million during FY2009-11 as India is entirely dependent on imports for this product.
- Benzene exports increased by ~35 percent during FY2009-11 in value terms. Major importing country includes Saudi Arab, USA, Singapore and Belgium.
- India imported ~US$170 million of toluene in FY2009-10 and FY2010-11. Singapore, Korea Republic and Iran were the major exporters.
- O-xylene exports increased by more than 200 percent during FY2009-11 in value terms. Major importers include China, Indonesia and Pakistan.
- India exported as well as imported significant value of p-xylene during FY2009-11. Imports increased by almost 50% and exports decreased by ~15 percent in value terms over the previous year.
- Indian exports of m-xylene increased significantly to Malaysia, Indonesia and Pakistan in 2010-11.
- PTA and MEG imports by India increased significantly by ~87 percent and ~47 percent in value terms during FY2009-11.
- LAB export increased by ~170 percent during FY2009-11 in value terms. Major importers include Indonesia and Vietnam.
- India's PE import was US$1645 million in 2010-11 an increase of over 40% over the previous year.
- India exported as well as imported significant value of PP during FY2009-11. Exports increased by ~20 percent and imports increased by ~6 percent in value terms over the previous year.

[7] Source: Ministry of Chemicals and Fertilizers, Government of India

- India’s SBR and ABS imports increased by ~50% during FY2009-11.

Demand Supply situation in India

As per report of sub-group on chemicals & petrochemicals for the 12th five year plan, Department of Chemicals & Petrochemicals, GoI; India’s petrochemicals consumption is estimated to grow at CAGR of 10.7%, whereas capacity is estimated to grow by 10.2% during 12th plan period. Robust consumption growth is expected in fibre intermediates, commodity plastics, building blocks, synthetic fibres and synthetic rubber category in next five years in India. The table in Annexure 2 shows the product-wise demand-supply actuals and projections as per this report.

Category-wise demand-supply scenario in India

Building Blocks

- Currently, India is entirely dependent on imports for styrene and in the absence of any capacity addition plan; it is likely to remain import dependent.
- The major contribution to the ethylene capacity during the 11th five year plan was made by partial de-bottlenecking of capacity by GAIL and HPL and the start-up of IOC complex at Panipat. During the same period, extraction of Propylene by RIL at its Refinery Complex augmented the supply of Propylene.
- Ethylene and propylene capacity in India is expected to increase when supplies from OPal and BCPL are likely to come on stream by 2014.
- Butadiene capacity in India is expected to increase when supplies from new steam crackers planned by IOC and OPaL are likely to come on stream. IOC has planned to commission 138 KTA butadiene extraction unit at Panipat by 2013-14. Also a butadiene extraction unit of 95 KTA capacity at Dahej is likely to come on stream by 2014-15.
- Due to low capacity addition planned in toulene during the 12th plan period, demand-supply gap would widen to 380 KTA in FY 2016-17 against 170 KTA in FY 2011-12
- Benzene demand is expected to grow at CAGR of 9.65% during 12th five year plan period, however due to huge capacity addition planned during the same period; benzene export is likely to be more than domestic demand. Major demand is expected to come for production of from cyclohexane and cumene/phenol.

Polymers

- PE is the largest polymer in the polymer category. Amongst the polymers, PP is the fastest growing polymer. LLDPE is the fastest growing polymer in the PE category.
- Currently, excess demand of LDPE is met by imports.
- Due to low capacity addition plans in PVC during the 12th plan period, demand-supply gap would widen to 1467 KTA in FY 2016-17 against 757 KTA in FY 2011-12.

- PE and PP capacities in India are expected to increase when supplies from Opal and BCPL are likely to come on stream by 2014. Also GAIL Pata expansion from 5 to 8 MMTPA is likely to increase PE capacities in India.

Synthetic Rubbers

- Currently, only 25% of the synthetic rubber demand in India is met through domestic production.
- During FY2005-11, demand for synthetic rubber grew at CAGR of 11.5%.
- PBR, butyl and NBR would remain in deficit in 2016-17, although substantial capacity addition is planned during 12th plan period
- Substantial capacity addition during 12th five year plan in SBR (from 20 to 370 KTA) and EPDM (from 10 to 90 KTA) would be sufficient to overcome the deficit. IOCL and RIL have capacity addition plans in SBR and butyl rubber segments.

Fibre Intermediates

- Polyester fibre is forecasted to account for around 70% of the incremental fibre demand in the next decade.
- PET demand is expected to grow at CAGR of 19.5% during 12th plan period.
- During 12th five year plan period, significant capacity addition is planned in polyester as a result demand for PX and PTA which are used to produce polyester is expected to grow at CAGR of ~15% and 13% respectively.
- PTA and MEG deficit would continue and it is expected to increase during 12th plan period.
- To meet the growing demand of polyester, new capacity additions are planned by IOC, RIL and MRPL in polyester feedstock chain.

Synthetic Fibres

- In polyester segment including PFY and PSF, strong capacity addition plans ahead of domestic demand would keep India a substantial exporter of polyester fibre. Capacity of PFY would be doubled by 2016-17, whereas demand is expected to grow by 1.8 times.
- No capacity addition plans for Nylon yarn during 12th plan would increase the deficit in this category (both NFY and NIY)

Surfactants

- Demand for the LAB and EO grew by 8% and 13% during the 11th plan period.
- During 12th plan period, it is expected that there would be deficit of ~ 100 KTAs of LAB in the absence of any capacity addition plans.

Key Petrochemicals Trade Movements

According to the exports & imports data from Ministry of Commerce & Industry, GoI, the products which contribute largely to the petrochemical exports are benzene, o-xylene, p-xylene, m-xylene, mixed xylene, LAB and PP and the products which contributed largely to the imports are ethylene, styrene, toluene, p-xylene, MEG, PTA, LAB, PE, PP, SBR, PVC and ABS. The table below gives the export-import statistics of petrochemical products.

Table 6: Export-Import Statistics of Petrochemical Products

Product/HS Code	Exports		Imports		Major Importers	Major Exporters
Figures in million US$	**2009-10**	**2010-11**	**2009-10**	**2010-11**		
Unsaturated Ethylene (HS Code: 290121)	0.08	0.06	34.59	113.69	Netherland, Singapore	UAE, Qatar, Iran
Unsaturated Propylene (HS Code: 290122)	24.68	22.96	0.59	0.79	Indonesia	China
Styrene (HS Code: 290250)	1.1	2.67	500.49	555.38	Iran	Saudi Arab, Singapore, Kuwait
Benzene (HS Code: 290220)	365.28	492.3	97.34	49.95	Saudi Arab, USA, Singapore, Belgium	Iran, Indonesia
Toulene (HS Code: 290230)	1.76	4.73	167.26	170.06	UAE, Sri Lanka, Saudi Arab	Singapore, Korea, Republic, Iran
Ortho-Xylene (HS Code: 290241)	166.06	520.86	42.1	44.67	China, Indonesia, Pakistan	Taiwan, Iran, Israel
Para-Xylene (HS Code: 290243)	503.58	429.01	304.04	450.06	Indonesia, Pakistan, Malaysia	Kuwait, Singapore, Oman, Indonesia, Iran

Meta-Xylene (HS Code: 290242)	0.04	156.79	0.64	2.17	Malaysia, Indonesia, Pakistan	Korea Republic
Mixed Xylene (HS Code: 290244)	42.7	85.39	2.41	0.05	Korea Republic, Singapore, China	Italy
MEG (HS Code: 290531)	3.57	30.88	477.95	701.04	Belgium, Qatar	Saudi Arab, Kuwait, Iran
DEG (HS Code: 290941)	3.7	15.68	2.01	0.72	China, UAE, Argentina	Iran, Taiwan
TEG (HS Code: 290949)	18.87	23.64	11.66	16.68	USA, China, Qatar	USA, China
PTA (HS Code: 291736)	0.51	0.55	439.27	824.35	China, USA	Korea Republic, Thailand, Iran, Taiwan
DMT (HS Code: 291737)	0	0.04	4.04	5.62	Canada	Korea Republic, Turkey
LAB (HS Code: 381700)	128.47	345.05	118.07	132.72	Indonesia, Vietnam, SOC Republic	Qatar, Saudi Arab, Iran
PE (density < 0.94; HS Code: 390110)	9.54	40.76	686.25	1101.01	Turkey, Kenya	Saudi Arab, USA, Thailand, Qatar, Korea Republic, Singapore
PE (density >=0.94; HS Code: 390120)	18.19	149.18	478.38	544.24	China, Turkey	Saudi Arab, Qatar, UAE, Iran
PP (HS Code: 390210)	624.77	748.22	442.22	468.33	China, Turkey, Indonesia	Saudi Arab, Korea Republic, Singapore, USA,

						Thailand
SBR (HS Code: 400219)	1.95	4.39	218.33	404.2	Italy, Sri Lanka DSR	Korea Republic, Taiwan, Russia
PVC (HS Code: 390410)	0.32	0.62	88.14	112.32	Nigeria	Korea Republic, Taiwan, USA
PS (HS Code: 390319)	70.71	86.89	10.29	20.3	Egypt, Turkey, UAE	Singapore
SAN (HS Code: 390320)	0.02	0.04	4.39	9.86		Korea Republic
ABS (HS Code: 390330)	0.08	10.25	56.53	111.6	Taiwan, Korea Republic	Korea Republic, Malaysia
Polyethylene terephthalate slices or chips (HS Code: 39076010)	30.51	63.74	5.42	32.29	UAE, Morocco, Bangladesh PR	UAE
Polyester or contract resins (HS Code: 39079120)	5.66	9.38	13.73	28.46	Spain	Singapore, Korea Republic
Total	**2022.15**	**3244.08**	**4206.14**	**5900.56**		

Petrochemicals uses and applications in India

Almost every item used on a daily basis is composed of a petrochemical product. It finds its application in almost every sphere of life like packaging, clothing, automobiles, housing, construction, irrigation, medical appliances, furniture, household items, agriculture, electronics and electrical appliances etc.

India represents a significant growth opportunity for petrochemical products with the growth on the economy. Sectors including automotive, infrastructure electronics, textile, construction, micro-irrigation, healthcare and packaging segments are expected to be the major contributors in the growth of petrochemicals in India.

The major inputs to various sectors and applications are mentioned below. There are many other uses; the list only contains few major uses and applications.

Table 7: Sector wise Petrochemical Product Uses

Sector	Petrochemical Product	Uses & Applications	Benefits
Transportation/Automotive (including railways , roads and airplanes)	Plastics	Body parts	Light weight enhances fuel efficiency, cost-effective, flexible and durable, reduced maintenance, corrosion & chemical resistance, splendid designing, aerodynamic looks etc.
	Synthetic rubber, nylon tyre cord fabric	Tyres	Cost effective over radial tyres, better grip
Textile	Synthetic fibre (Polyester, Polyamide-Nylon, Acrylic and Polypropylene fibre)	Cloths	Substituted limited availability of cotton and other natural fibre, easy to wash etc.
Agriculture	Plastic pipes	Irrigation	Saves water and enhances production, lightweight and non-corrodible (durable), reduced pumping hours due to micro irrigation will save electricity

	Polymer parts	Agro-machinery	Improves Productivity
	Plastic & Leno bags	Storage, handling	Easy to use Easy to wash and wear
Housing/offices	Plastic pipes	Sewer	Low cost, lightweight and non-corrodible (durable)
	PVC Polycarbonate	Windows Shatterproof windows, transparent roofs	Techno-commercial benefits over traditional aluminium windows Extremely clear cplastic that offers excellent visibility and actually transmits light better than alternative materials, durable
Electronic and electrical	ABS	Computers, radios, televisions and telephone handsets	Lightweight and non-corrodible (durable)
Healthcare	Plastic	Medical appliances, packaging, hygiene products, blood bags, syringes, masks and gloves and implants, medical and surgical gowns, inhalers etc.	Cost effective, lightweight and non-corrodible (durable)
Household	Plastic Polymer	Furniture Grocery bags, bottles for various uses, toothbrush,	Prevent deforestation, cost-effective, lightweight and non-corrodible (durable)

	carpets, curtains etc.

Table 8: Product-wise Uses and Applications in India

Product	Uses & applications
Polymers	• HDPE- It finds its major application in raffia, blow moulding, injection moulding, films, pipes etc. • LLDPE- It finds its major application in mono and multi-layered films (major being butane film followed by HAO and metallocene LL film), roto-moulding, wires & cables etc. • LDPE- It finds its application in general purpose film, extrusion coating, liquid packaging, heavy duty film, injection moulding, wires & cables and adhesive lamination. • EVA- Major application of EVA is footwear manufacturing, films etc. • PP- It finds its application in raffia, tubular quench films, IM HP, impact co-polymer, random co-polymer, BOPP, fibre & fialment • PVC- It is also called as ‘infrastructure plastic’ because of its applications in pipes, conduits, ducts, wires & cables, films & sheets, fittings, foot wear, flooring, windows & doors and roofing etc. • PS- It finds its major application in electronics appliances such as computer, thermocol, foam, refrigerator trays, CD/ DVD cases, structural insulation, bottles, disposable cups, smoke detectors, films, housings of electrical equipment like hairdryers, TVs and kitchen appliances etc.
PET	Its main application is in production of bottles, sheet, strapping and injection moulded products, fastening straps etc.
Polycarbonate	Polycarbonate finds its application in sheets/film, automotive (window and non-window), optical media, appliances, housewares, electronics/electrical, medical, ophthalmic, construction, sports, recreational, packaging etc.
ABS	It is mainly used in buildings /construction, transportation/ automobile industry, electronics/electrical appliances such as computers, radios, televisions and telephone handsets, alloys and other application like medical, toys and recreational.
SAN	It is mainly used in electrical/electronic, automotive, containers, household goods, acrylics, cosmetics and compounding with ABS.

Linear Alkyl Benzene (LAB) and Ethylene Oxide (EO)	LAB and EO are the major synthetic intermediates used in manufacture of detergents and surfactants. EO also finds its application in production of other derivatives such as ethoxylates, glycol ether, dye intermediates, ethanol amines, TEG and drug intermediates.
Butadiene	Butadiene is used in the production of a wide variety of synthetic rubbers (SBR, BR, and NBR etc.), ABS, polymer resins and few chemical intermediates. Other chemical intermediates manufactured from butadiene are adiponitrile and chloroprene.
SBR	It is used mainly in automobile tyres and also in adhesives, sealants, conveyor belts, auto components, coatings and rubber articles such as shoe soles.
PBR	It is used mainly in tyres, retread, auto components, conveyor belts etc.
Aromatics	• Benzene is used mainly in the production of ethyl benzene, cyclohexane/ caprolactum, LAB, cumene/phenol, chlorobenzene, alkylbenzene, nitrobenzene and other industrial chemicals. • Toluene is used as major solvent in the petrochemical industry. It is also used in the manufacture of toluene derivatives such as toluene di-isocynate (TDI), para-cresol, iso butyl benzene, chlorotoluene, nitrotoluene and pharmaceuticals. • Mixed Xylene is used as solvents in paints, resins, pharmaceuticals, printing inks, rubber, and leather industries. • O-xylene is used for a variety of applications. A majority (92%) of all the o-xylene produced globally is used for the manufacture of phthalic anhydride. It is also used for production of unsaturated polyester resins and as solvents in many applications.
Acrylonitrile (ACN)	It is used mainly as a monomer in the production of acrylic fibres. It is also used for pesticide & speciality purpose.
Para-xylene	It is mainly used in the manufacture of purified terephthalic acid) and DMT.

Processes and Technologies in use for manufacturing of petrochemicals products

Introduction

The major feedstocks for petrochemical industry are Naphtha & ethane/propane rich gas. The primary building blocks of petrochemical manufacturing are as follows.

- Ethylene
- Propylene
- Benzene
- Butene

- Toluene
- Xylene

Process flow diagram indicating the above primary building blocks, intermediates & products manufactured from each of these are represented below.

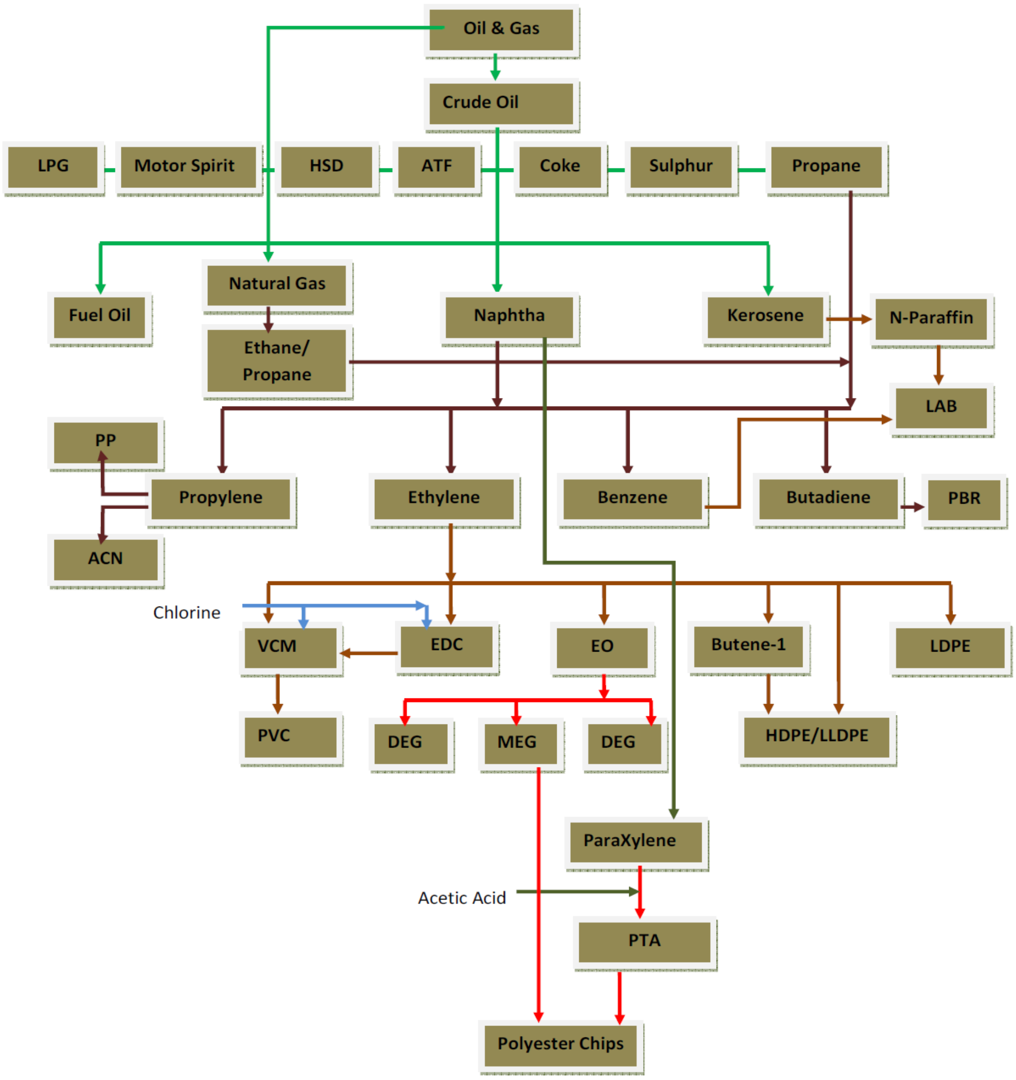


Figure 11: Process flow diagram indicating the above primary building blocks, intermediates & products manufactured

Naphtha from crude oil processing refineries is one of the major feed stocks used in Petrochemical complexes. Presence of C2+ hydrocarbons in Naphtha makes it suitable for cracking to all the primary building blocks, including olefins & aromatics. Benzene & Xylene are mostly manufactured in plants using Naphtha as feedstock.

Ethane/Propane mix gas is also being used in many plants. However, in India plants using this feed stock are not many, due to restricted supply and limited capability of manufacturing aromatics such as benzene & xylene.

The intermediates & Final products in petrochemical sectors fall into the following categories:

- Commodity Plastics (PP, LDPE, HDPE, LLDPE, PVC)
- Fibre Intermediates (PTA. MEG, PET)
- Elastomers (SBR,PBR)
- Surfactants (EO, LAB)
- Other Basic organic chemicals (Benzene, Toluene, ACN, PAN)

The major technologies for manufacturing of primary building blocks & Final products are discussed below.

Capacity & demand of various petrochemicals given in this report is taken from "Report Submitted to Working Group on Chemicals & Petrochemicals for the 12th Five Year Plan, Government of India, January 2012".

The specific energy consumption figures are taken from a publication 'Chemical & Petrochemical sector" published by IEA/OECD in 2009 as well as from industry sources. All specific energy figures are obtained during years 2004 to 2008.

Primary Building Blocks

Ethylene, Propylene, Butadiene & Styrene are the primary building blocks of petrochemical industry. Benzene & Toluene are also considered as building blocks and are described in basic organic chemicals. Xylene is considered as fibre intermediate. The following table summarises capacity & demand of these products in India

Table 9: Capacity and Demand of Primary Building Blocks

Products (In 1000 TPA)	Capacity (2011-12)	Demand (2011-12)
Ethylene	3867	3785
Propylene	4117	3700
Butadiene	295	124
Styrene	0	496

The available capacity of Ethylene, Propylene & Butadiene are sufficient for domestic use and there is a small amount of export also observed.

Styrene is not manufactured as a saleable product in India. Those plants which manufacture elastomers produce styrene as intermediate or import. There is no plan to add capacity of styrene in the country in the next 3 years.

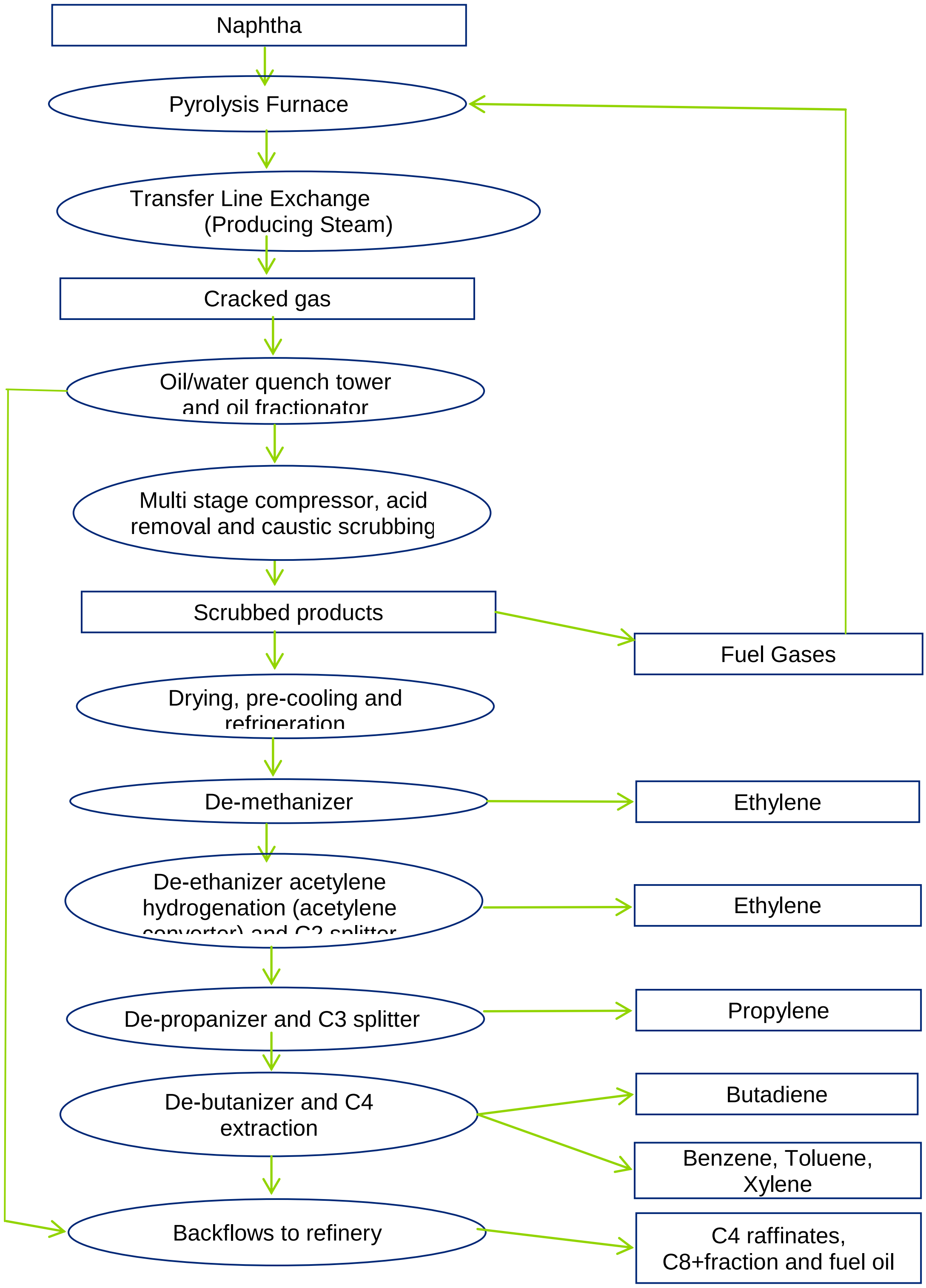


Figure 12: Primary Building Blocks Flow Diagram

Ethylene & Propylene

The Pyrolysis furnace cracks the feed in presence of dilution steam to ethylene, propylene & byproducts. Heat is recovered in 100 ata steam which is used for driving steam turbines of various drives. The cooled gas is compressed, dried and ethylene & propylene are separated through cryogenic processes.

The average specific energy consumption varies from 13.0 to 25 GJ/Ton of ethylene depending on feed type and battery limit conditions. When processing Ethane/propane gas, the specific energy consumption is on the lower side, and with Naphtha the figures are close to 25 GJ/Ton.

The major plants in India producing Ethylene & Propylene is listed below. Note that the production is given as total olefins capacity. The quantity of ethylene & propylene depends on market requirements and is manufactured by varying feedstock & operating conditions.

Table 10: Major Plants in India Producing Ethylene & Propylene

Producer	Location	Capacity	Technology
Reliance Industries	Hazira	900000	Stone & Webster
	Nagothane	400000	Stone & Webster
	Vadodara	190000	Lummus
	Dahej	400000	Stone & Webster
Indian Oil corporation	Panipat	800000	Lummus
Haldia Petrochemicals	Haldia	670000	Lummus
GAIL	Pata	500000	Stone & Webster

The breakup of ethylene & propylene production capacities by cracker plants and refineries is summarised below.

Table 11: Breakup of Ethylene & Propylene Production Capacities

Ethylene	Capacity, TPA
RIL	1883400
GAIL	400000
Haldia Petrochemicals	700000
IOCL, Panipat	857000
Propylene	**Capacity, TPA**
RIL	759800
IOCL, Panipat	650000

BPCL, Mumbai	50000
CPCL, Chennai	30000
HPCL, Vizag	41000
HOCL, Cochin	29000

Note that ethylene is not manufactured in refinery complexes, whereas propylene is manufactured in small quantities in refineries. IOCL Panipat has a cracker complex to produce ethylene.

Ethylene & Propylene production by steam cracking by Lummus accounts for 43% of installed capacity in India. The remaining 57% of production capacity is accounted by Stone & Webster.

Table 12: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.3	13.1	-1.4	45

As compared to Naptha cracking, where the fuel gases from Demethaniser & drying is sufficient to cater the need of energy for cracker; plants using ethane propane mix need external sources of energy for cracking.

The following schematic describes Lummus' technology for olefins

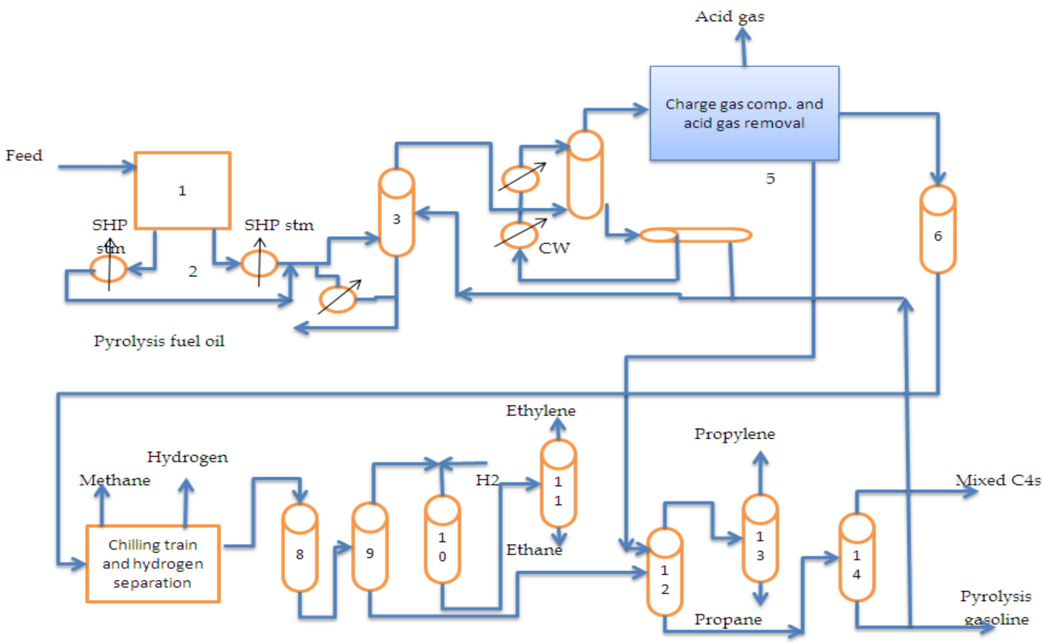


Figure 13: Lummus Technology for Olefins

Olefins produced in refineries using Axens technology is as per below steps.

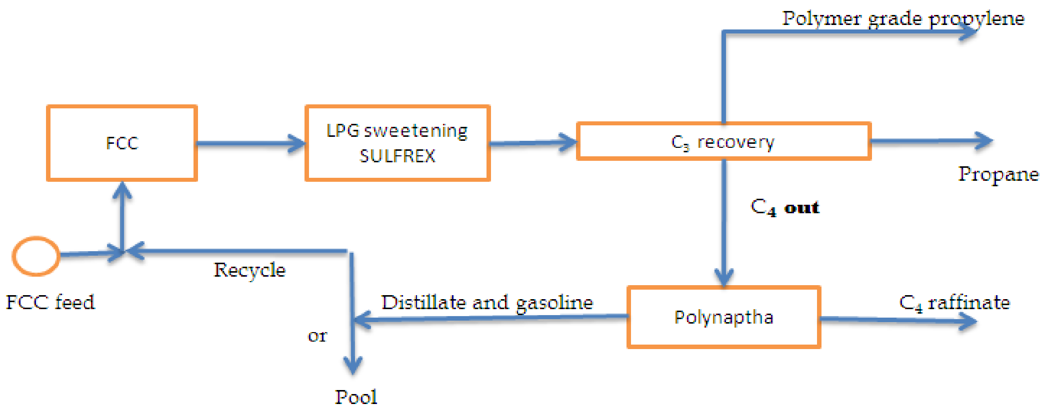


Figure 14: Axens Technology for Olefins

Lummus technology for producing propylene from ethylene & C4+ feeds is given below.

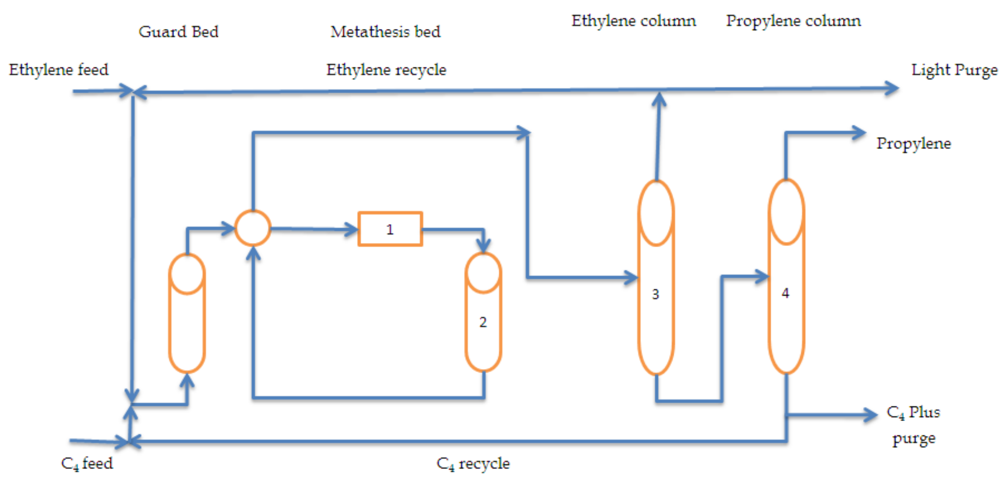


Figure 15: Lummus Technology for Propylene

This technology integrated with cracker plant gives flexibility to produce ethylene or propylene depending on market demands.

Butadiene

Butadiene is produced by solvent extraction or extractive distillation process wherein the butadiene is extracted by a solvent. The major Butadiene manufacturers in India are the following:

Table 13: Specific Energy Consumption

Butadiene	Capacity, TPA
RIL	200000

Haldia Petrochemicals	101000

The BASF technology for Butadiene production is given below.

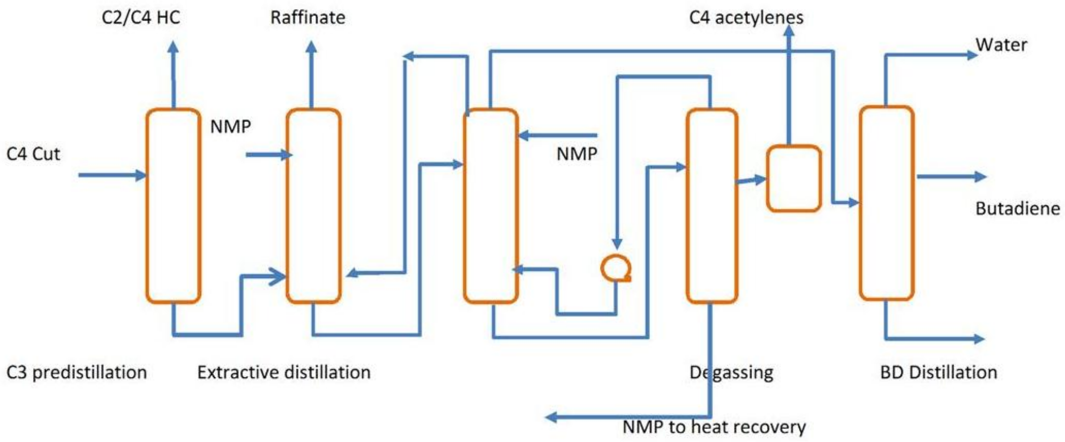


Figure 16: BASF Technology for Butadiene

The C4 cut enters the pre-distillation tower, in which methyl acetylene, propadiene and other light components are separated as gaseous overhead product. Its bottom product enters the bottom section of the main washer column while N-methylpyrrolidone (NMP) solvent enters at the column top. Overhead product C4 raffinate consisting of butanes and butenes is drawn off.

The crude butadiene withdrawn as overhead product from the rectifier is sent to the butadiene column. In its top section, mainly water and some remaining light components are separated, while heavy ends are drawn off as bottom product. The butadiene product is withdrawn as liquid side product.

Table 14: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.5	0	6.7	45

Commodity Plastics

Commodity plastics are the major products that account for bulk of the petrochemical industry. India has significant production capacity and demand for commodity plastics. The following table summarises capacity and demand of commodity plastics.

Table 15: Capacity and Demand of Commodity Plastics

Products (In 1000 TPA)	Capacity (2011-12)	Demand (2011-12)
LDPE	205	405
LLDPE	835	1198
HDPE	1825	1657
PP	4140	2993
PVC	1330	2087
PS+EPS	640	340

Amongst commodity plastics, PVC is one of the major products where capacity growth in past had been significantly lagging demand growth.

India has large capacity of PS and EPS between three major producers. However, all these facilities are based on imported monomer since there is no local production of Styrene.

Low Density Poly Ethylene (LDPE)

LDPE finds its application in general purpose film, heavy duty film, liquid packaging, injection moulding, extrusion coating, wire & cables, adhesive lamination. Due to its inherent strength, LD is extensively used as a blend with other polymers.

Total capacity of LDPE production in India is 205000 TPA, which is mostly manufactured at RIL Nagothane & Vadodara Plants having a total capacity of 175000 TPA. The flow diagram for manufacturing LDPE is given below.

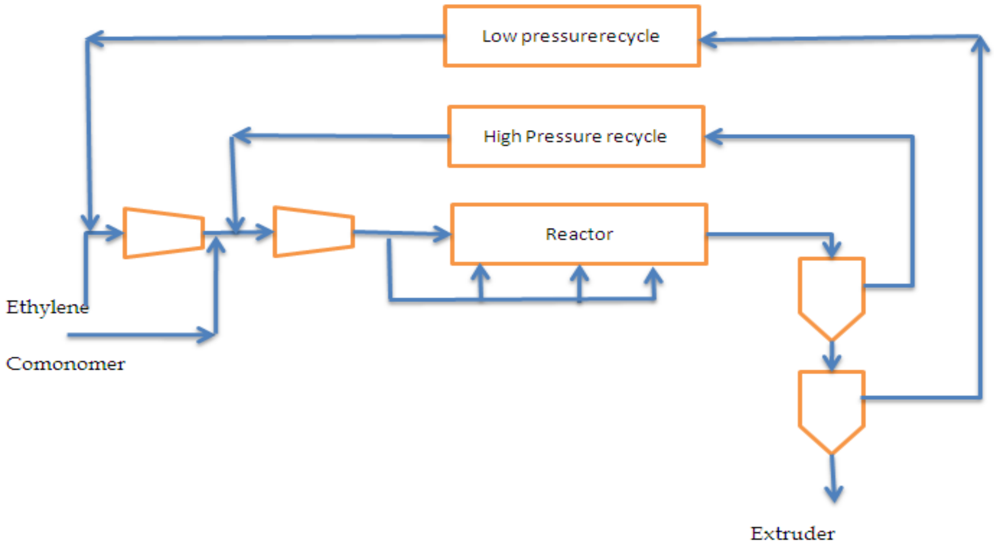


Figure 17: Flow Diagram for Manufacturing LDPE

Ethylene, initiator and comonomers are fed to the process and compressed to pressures up to 3,100 bar before entering the tubular reactor. The polymer properties (MI, density, MWD) are controlled by the initiator, pressure, temperature profile and comonomer content. After the reactor, excess ethylene is recovered and recycled to the reactor feed stream. The polymer melt is mixed with additives in an extruder to yield the final product.

Table 16: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
3.5	0	-2.1	0

High Density Poly Ethylene (HDPE)

The list of Plants manufacturing HDPE & LLDPE in India is as follows.

Table 17: List of Plants Manufacturing HDPE & LLDPE

HDPE/LLDPE plants	Capacity	Technology
RIL, Hazira	360000 HDPE	Dupont & Nova Chemicals
RIL, Gandhar	160000 HDPE	Basell
RIL, Nagothane	220000 HDPE/LLDPE	BP Chemicals

Haldia Petrochemicals	700000 HDPE/LLDPE	Mitsui CX & Basell
GAIL, Pata	210000 HDPE/LLDPE	Novacor
IOCL, Panipat	300000 HDPE 350000 HDPE/LDPE	Basell Nova Chemicals

The Bassell HDPE process is shown below. This is a 3 reactor- solution based polumerisation process.

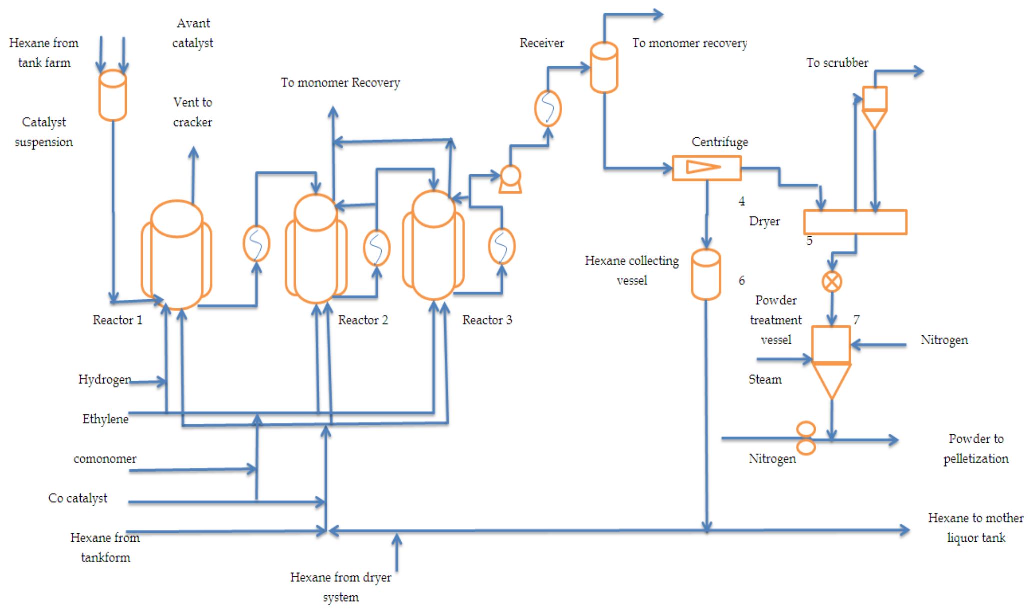


Figure 18: Bassell HDPE Process

Polymerization occurs in a dispersing medium, such as n-hexane, using a very high-activity Ziegler catalyst. No deactivation and catalyst removal is necessary because a very low level of catalyst residue remains in the polymer. For HDPE production the catalyst, the dispersing medium, monomer and hydrogen are fed to the reactor (1,) where the first polymerisation step occurs. The second and third step polymerization occurs under different reaction conditions with respect to each reactor. No further catalyst only ethylene, butene and further dispersing medium are fed to the second (2) and third reactor (3). Reactor conditions are controlled continuously, thus HDPE with very high properties is manufactured. Finally, the HDPE slurry from the third reactor is sent to the decanter (4) and the polymer is separated from the dispersing medium. The polymer containing the remaining hexane is dried in a fluidized bed dryer (5) and catalyst/cocatalyst residuals are removed in the powder treatment vessel (7). The powder is then pelletized in the extrusion section. The separated and collected dispersing medium of the fluid separation step (6) with the dissolved co-catalyst and comonomer is recycled to the polymerization reactors. A small part of the dispersing medium is distilled to maintain the composition of the diluent.

Table 18: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.9	0	1.0	0

Linear Low Density Poly Ethylene (LLDPE)

The gas phase technology of Basell sperilene process is given below.

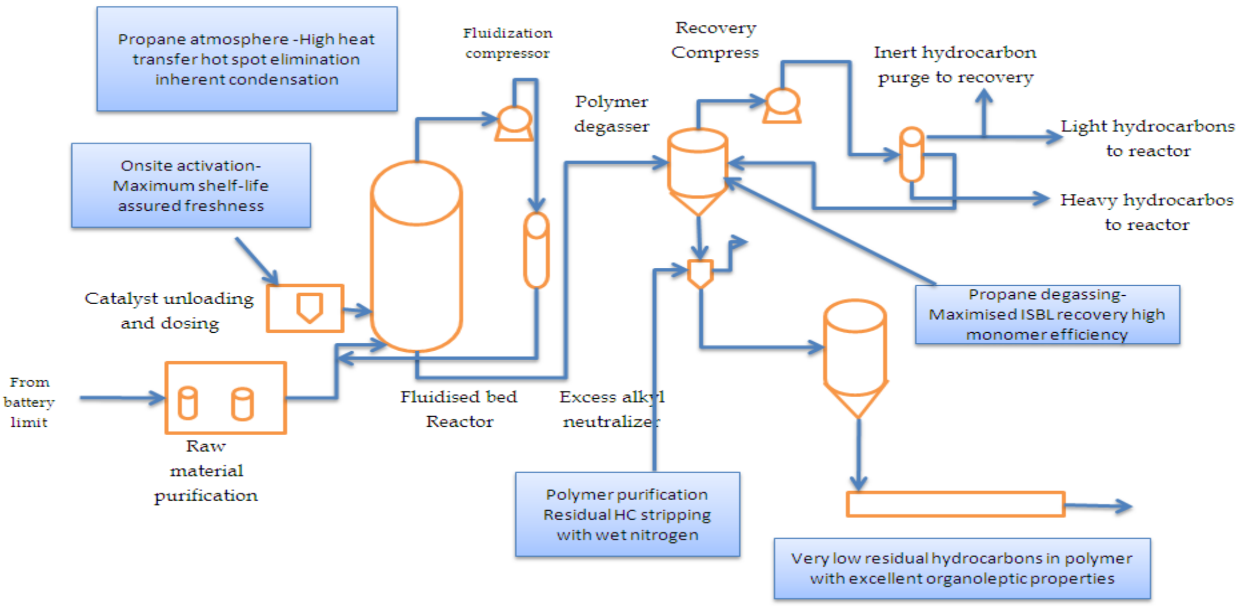


Figure 19: Basell Sperilene Process

Ethylene, comonomer and hydrogen are fed to the reactor according to the required production capacity and proportions needed for the target product. Propane is used as the inert medium of reaction and provides an independent means of controlling the reaction kinetics while providing a heat removal capability far superior to that of inorganicinerts (such as nitrogen). The heat of the reaction is removed from the fluidizing gas in a water cooled vertical heat exchanger.

The polymer is withdrawn continuously from a specially designed outlet at the bottom of the reactor and sent to a degassing vessel where monomer unreacted, comonomer and hydrogen are removed from the polymer with the help of a counter-current propane gas flow. Specific energy consumption for LLDPE is given below.

Table 19: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.4	0	1.6	0

PolyPropylene (PP)

The major plants manufacturing Polypropylene is provided in the table below.

Table 20: Major Plants Manufacturing Polypropylene

Poly Propylene plants	Capacity, TPA	Technology
RIL, Vadodara	100000	Basell
RIL, Nagothane	60000	Himont
RIL, Hazira	360000	UCC
Haldia Petrochemicals	320000	Basell-spheripol
IOCL, Panipat	600000	Basell-spheripol

KBR technology used for manufacturing polypropylene is described below.

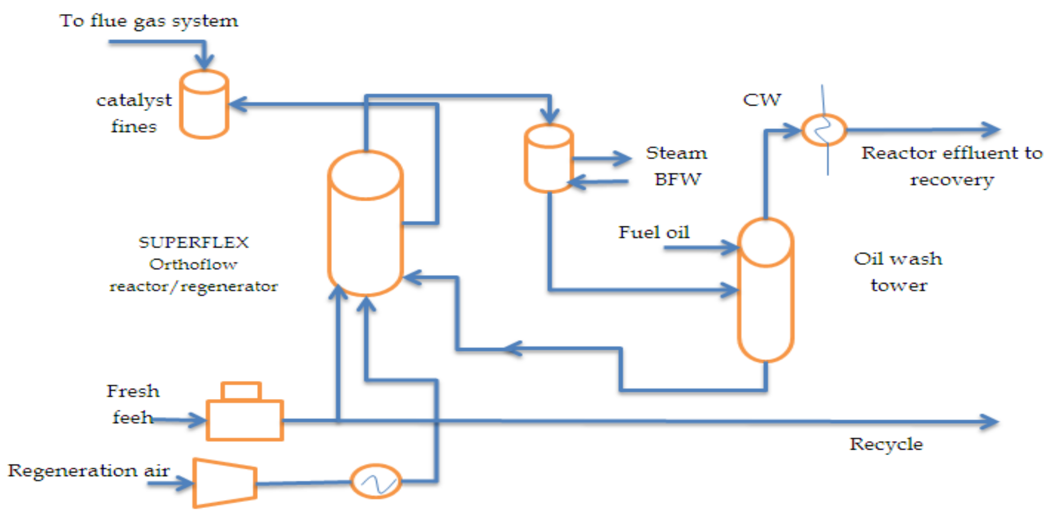


Figure 20: KBR Technology for Polypropylene

Inside the reactor (1) the growing polymeric granule is continuously recirculating between two interrelated zones, where two distinct and different fluodynamic regimes are realized. In the first zone (1a), the polymer is kept in a fast fluidization regime; when leaving this zone, the gas is separated and the polymer crosses the second zone (1b) in a packed-bed mode and is then reintroduced in the first zone.

Unreacted monomer is mostly recovered at intermediate pressure (3) and recycled back to the MZC reactor through a compressor, while polymer can be fed to a fluidized gas- phase reactor (4) operated in series (optional) where additional copolymer can be added to the product from the gas loop. From the intermediate separator/second reactor, the polymer is discharged to a receiver (5), the unreacted gas is recovered, while the polymer is sent to a proprietary unit for monomer steam stripping and catalyst deactivation (6). The removed residual hydrocarbons are recycled to the reaction. While the polymer is dried by a closed-loop nitrogen system (7) and, now free from volatile substances, the polymer is sent to additives incorporation step (8).

Table 21: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.9	0	1.0	0

Poly Vinyl Chloride (PVC)

The major plants in India manufacturing PVC are provided in table below.

Table 22: Major Plants Manufacturing PVC

PVC plants	Capacity, TPA	Technology
RIL, Vadodara	55000	Oxyvinyls
RIL, Gandhar	150000	Oxyvinyls
RIL, Hazira	160000	Geons
Chemplast Sanmar	235000	Basell-spheripol
Finolex , Ratnagiri	260000	Hoest AG
DSCL, Kota	70000	Chisso corporation

The PVC manufacturing process can be divided into 5 different steps from input of raw materials to the end products:

- Input Fresh VCM, additives and water into a stirring reactor (1), and maintaining temperature during the polymerization to control the grade of the PVC

- Discharge PVC powder after 85-90% VCM/PVC conversion to a blow down tank (2) to flush off VCM gas and recover VCM gas to VCM gas holder (6)
- PCV slurry containing VCM is fed into the stripping column (3) continuously, most of the residual VCM will be recovered from this column
- The slurry will be de-watered with a centrifuge device (4)
- The slurry will be dried by the proprietary dryer (5). It is then passed to storage silos.

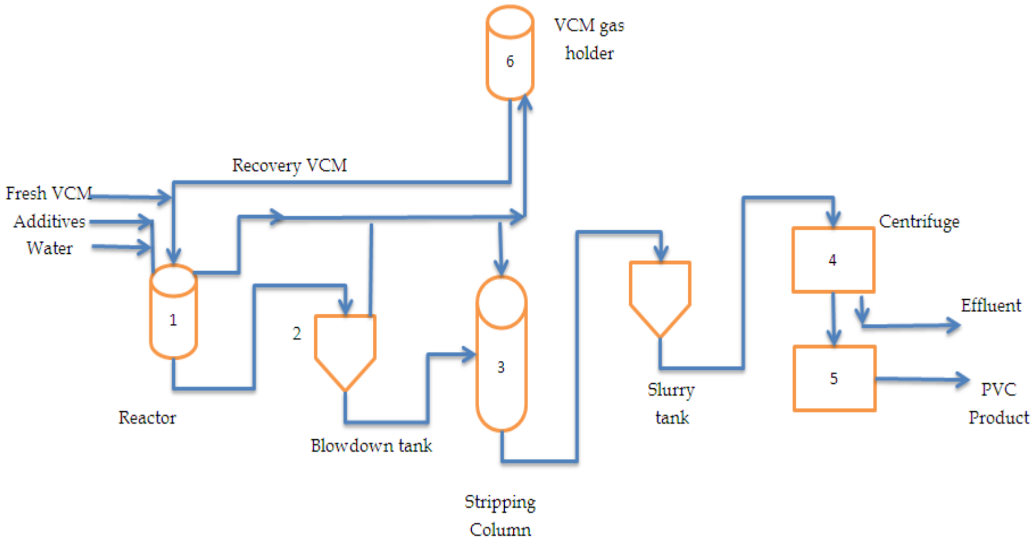


Figure 21: PVC Manufacturing Process

The specific energy consumption process is given below.

Table 23: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.6	0.5	1.2	0

Poly Styrene (PS)

The major Polystyrene manufacturers in India are given below.

Table 24: Major Polystyrene Manufacturers

Poly Styrene plants	Capacity, TPA
Supreme Petrochem	272000
LG Polymers, Vizag	100000
BASF, Dahej	100000

Styrene is obtained by reacting **ethylene** with **benzene** in the presence of **aluminum chloride** to yield ethylbenzene. The benzene group in this compound is then dehydrogenated to yield phenylethylene, or styrene, a clear liquid **hydrocarbon** with the chemical structure $CH_2{=}CHC_6H_5$. Styrene is polymerized by using free-radical initiators primarily in bulk and suspension processes, although solution and emulsion methods are also employed.

Various grades of polystyrene can be produced by a variety of batch processes. Batch processes generally have a high conversion efficiency, leaving only small amounts of unreacted styrene to be emitted should the reactor be purged or opened between batches. A typical plant will have multiple process trains, each usually capable of producing a variety of grades of polystyrene. The following figure is a schematic representation of the polystyrene batch bulk polymerization process.

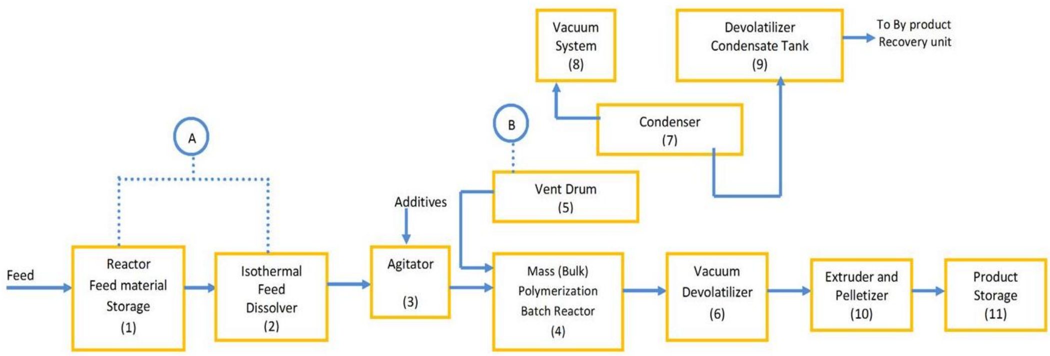


Figure 22: Polystyrene Batch Bulk Polymerization Process

The division of specific energy consumption has been represented in table below.

Table 25: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.4	0.5	0	0

Fibre intermediates

India has a strong synthetic fibre base integrated to large production capacity of fibre intermediates. The following table summarises capacity and demand of synthetic fibre intermediates in India.

Table 26: Capacity and Demand of Synthetic Fibre Intermediates

Products (In 1000 TPA)	Capacity (2011-12)	Demand (2011-12)
Para Xylene	2477	2306
PTA	3850	4350
MEG	1300	1836
PET	814	542

India remains a net importer of PTA & MEG which the basic raw materials for polyester chips/filament yarm industry. It is expected to add Para Xylene capacity of 2.4 Million TPA by year 2014, which will enahnce the capacity of downstream production of PTA.

The status of synthetic yarn production capacity & demand is as follows. Evidently, PSF and PFY are the most predominant synthetic fibres manufactured in the country.

Table 27: Synthetic Yarn Production Capacity & Demand

Products (In 1000 TPA)	Capacity (2011-12)	Demand (2011-12)
PSF	1334	1214
PFY	2582	1973
NFY	32	48
NIY	74	115
PIY	21	40

Xylene

Commercially important xylenes are of two kinds: Para xylene and Ortho xylene. Para xylene is used for the manufacture of DMT and PTA and this is the backbone of the synthetic fibre industry. Ortho xylene is mainly used in the production of phthalic anhydride. The following plants manufacture Xylene in India.

Table 28: Xylene Manufacturing Plants

P-Xylene	Capacity, TPA
RIL	1856000
IOCL, Panipat	360000
IOCL, Bongaigaon	29000
O-Xylene	**Capacity, TPA**
RIL	420000
IOCL, Bongaigaon	6000

The configuration of an aromatics complex depends upon the available feedstock, the desired product slate, and the balance between performance and capital investment. A fully integrated modern complex contains a number of UOP process technologies. The naphtha feed is first sent to a UOP naphtha hydrotreating unit (1) to remove sulfur and nitrogen compounds and then sent to a UOP CCR Platforming unit (2) to reform paraffins and naphthenes to aromatics. The following figure shows the process of UOP for manufacturing P-Xylene.

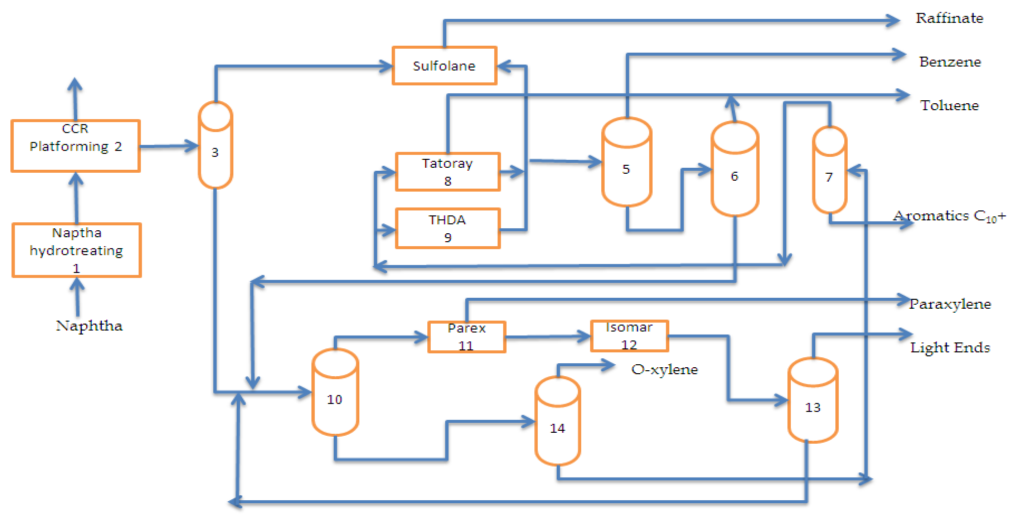


Figure 23: UOP Process for Manufacturing P-Xylene

The specific energy consumption of P-Xylene is given below.

Table 29: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.2	6.3	0.8	0

Purified Terephthalic Acid (PTA)

The important manufacturers of PTA in India are:

Table 30: Important Manufacturers of PTA

PTA plants	Capacity, TPA	Technology
RIL, Hazira	700000	Dupont
RIL, other locations	1350000	Dupont
Mitsubishi Chemical Corpn, Haldia	990000	MCC
IOCL, Panipat	553000	Dupont

Polymer grade PTA can be produced based on the liquid phase oxidation of p-xylene in the presence of a catalyst to produce crude terephthalic acid (C-TPA). Acetic acid and p-xylene are fed to a reactor with a cobalt acetate catalyst (Step 1). The reactor is fed with compressed air to supply oxygen for the reaction. Reactor pressure and temperature are maintained at 1,500 kPa - 3,000 kPa (220 psi - 435 psi) and 175°C - 230°C (347°F - 446°F) respectively. Products from the reactor are pumped to a centrifuge to separate the C-TPA (Step 2). The C-TPA produced is purified using the Amoco purification process.

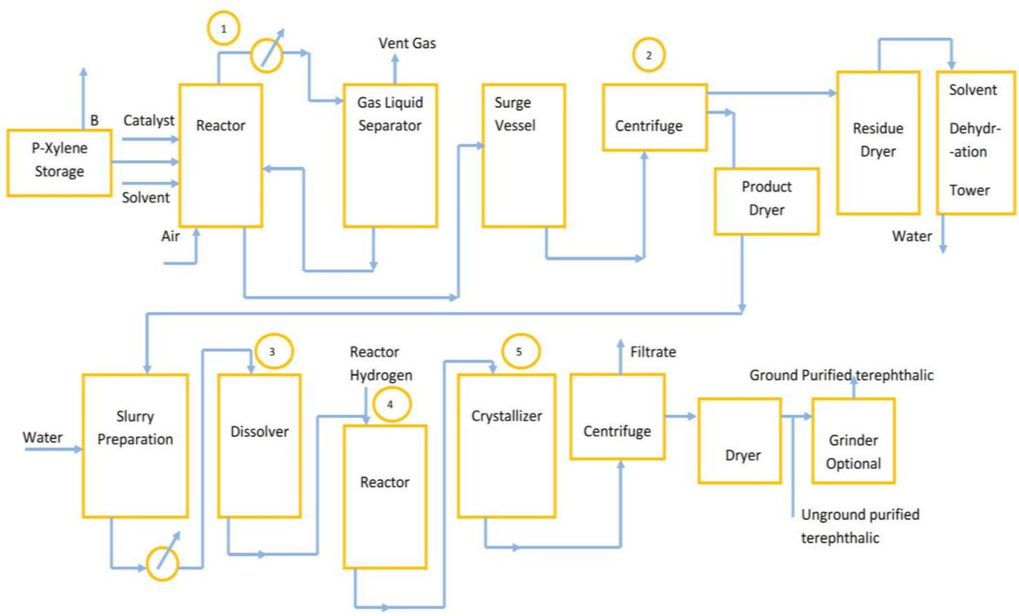


Figure 24: PTA Manufacturing Process

The specific energy consumption is 2.9 GJ/Ton.

Table 31: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.3	0	2.6	0

Mono Ethylene Glycol

EO in an aqueous solution is reacted with CO2 in the presence of a homogeneous catalyst to form ethylene carbonate (1). The ethylene carbonate subsequently is reacted with water to form MEG and CO2 (3).

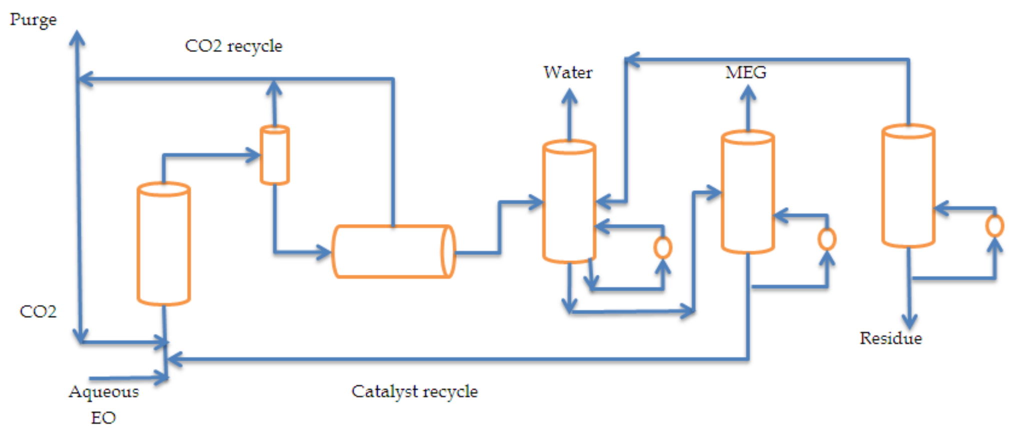


Figure 25: MEG Manufacturing Process

The specific energy consumption is 4.5 GJ/Ton (from Industry sources)

Table 32: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.2	0.8	3.5	0

Poly Ethylene Terephthalate (PET)

This is a thermoplastic polyester widely used for production of beverage bottles. It is also used for flexible packaging film. Reliance Industries at Hazira is the single manufactrurer of PET in India with a capacity of 290000 TPA.

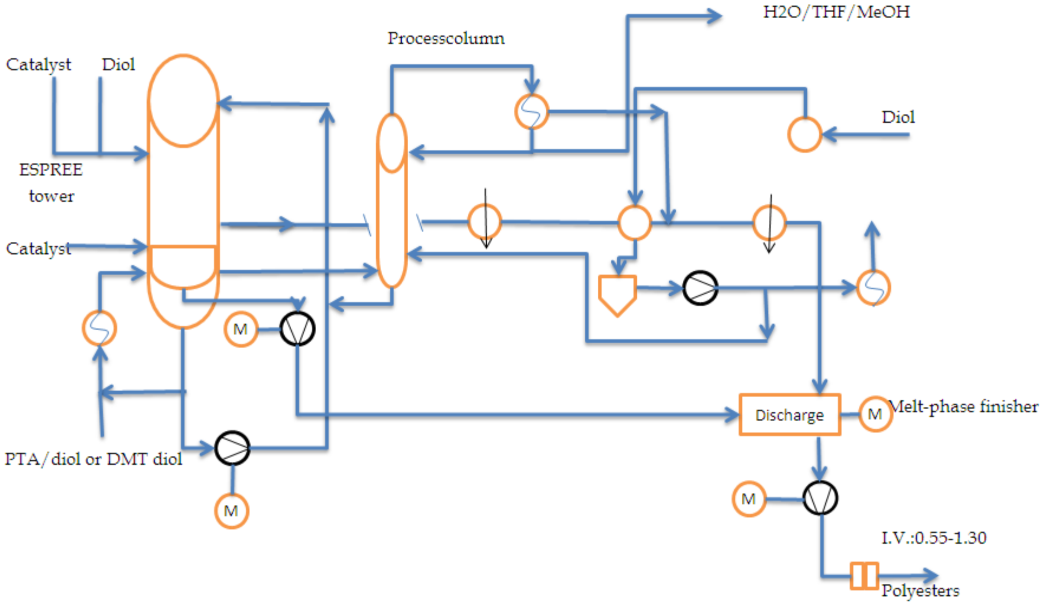


Figure 26: PET Manufacturing Process

The specific energy consumption is 4.8 GJ/Ton.

Table 33: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.7	4.1	0	0

Caprolactum

Major manufacturers of caprolactum in India are provided in the following table.

Table 34: Major Manufacturers of Caprolactum

Caprolactum plants	Capacity, TPA
GSFC, Vadodara	70000
FACT, Cochin	50000

Essentially, all of its production is consumed in the manufacture of nylon 6 which is used for fiber (clothing, carpets and industrial fibers) and for resin production. Caprolactam is produced by the Beckmann rearrangement of the oxime in the presence of oleum. Cyclohexanone oxime is formed by the reaction of Cyclohexanone and Hydroxilamine. The subsequent neutralisation step yields ammonium sulphate as co-product. The crude Caprolactum is purified by solvent extraction, ion-exchange, hydrogenation, evaporation and vacuum distillation to obtain products of extremely high purity and consistent quality.

The specific energy consumption is represented in the following table.

Table 35: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
1.1	0.2	-3.2	0

Polyester Chips

The basic raw materials are Pure Terephthalic Acid (PTA) and Ethylene Glycol (EG). The reaction involved is direct esterification in case of PTA followed by polycondensation. The reaction is carried out in one or more reactors above atmospheric pressure and at elevated temperature. Excess glycol is used for carrying out the reaction, which is recovered during polycondensation and recycled.

Polyester filament yarns are manufactured either from molten polymer or polyethylene terephthalic acid (PET) chips by melt spinning process. In this process molten polymer from a manifold is metered through various spinnerettes, having number of holes, to form filaments. These filaments are then solidified by air-quenching and wound on take-up winders after application of spin-finish. The yarns manufactured could be UDY (undrawnyarn), POY (partially oriented yarn) or FDY (fully drawn yarn) depending upon the winder speed and heatsetting methods.

Supplies of PFY technology are Zimmer, Inventa, Lurgi, Didier, Toray, Du-Pont, Teijin, Enka, Snia and Samsung. The major Indian manufacturers of Polyester chips (with raw materials PTA & EG) are as follows. Manufacturers who only buy chips and then melt –extrude are not considered here.

Table 36: Major Polyester Chips Manufacturers

Polyester fibre plants	Capacity, TPA
RIL, all locations	1606000
Indorama Synthetics, all locations	610050
South Asian Petrochemicals, Haldia	200000
Jindal Polyfilms	108000
Ester Industries	107000
Chiripal Industries, Ahmedabad	100000
Modern Petrofils	80000
Sanghi Polyester	75000
Century Enka	75000

The specific energy consumption for chips production is given below.

Table 37: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.2	0	2.0	0

Nylon-6 (Polycaproamide) chips

Currently tyre cord fabric made of Nylon is dominating. The other applications include fabric for conveyor belt, rubber hose reinforcement, tarpaulin, awnings, static covers and display fabric. The major manufacturers producing Nylon chips, which is subsequently used for yarn production is as follows.

Table 38: Major Nylon Manufacturers

Nylon plants	Capacity, TPA
Century Enka, Pune	180000
SRF, Chennai	110000
GSFC, Surat	9000
FACT, Cochin	3000
JCT Ltd., Phagwara	14000

The technology for Nylon-6 manufacturing is by Uhde Inventa-Fisher. The raw material for manufacturing Nylon 6 is coal. Cyclohexane oxime is produced by a series of chemical reactions on coal. Cyclo heaxaneoxime is then treated with sulphuric acid to form caprolactum. The caprolactum is a monomer with 6 carbon atoms that are polymerized to from chains of caprolactum. Polymerization is done by gently heating it in a steam – jacked stainless steel vessel. The solution is stabilised as a super polymer under constant steam and pressure. The chips containing 9% monomer and cyclic oligomers are treated with hot water in extraction column. Wet chips are sent to centrifuge, then dried with nitrogen.

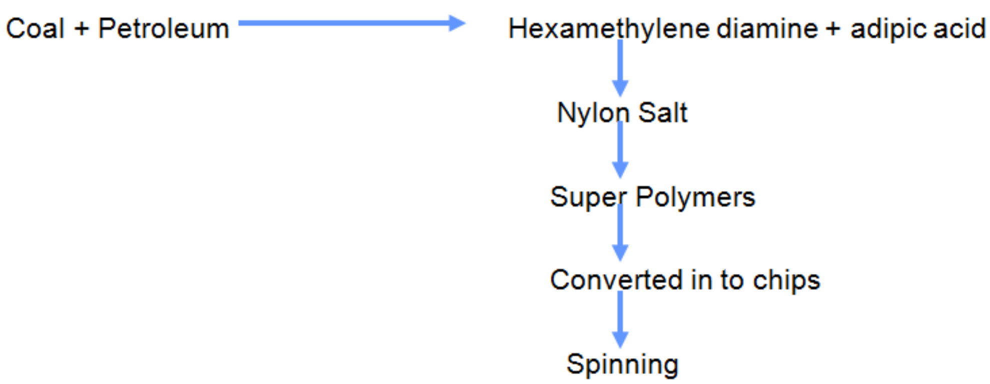


Figure 27: Nylon Manufacturing Process

Table 39: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.2	0	2.0	0

Surfactants

The production capacity & demand of surfactants (LAB & EO) in provided in the table below. The capacity of these surfactants is more than the demand. The last plant installed in India was in 2004 at IOCL.

Table 40: Production Capacity and demand of Surfactants in India

Products (In 1000 TPA)	Capacity (2011-12)	Demand (2011-12)
LAB	530	480
EO	209	173

Linear Alkyl Benzene (LAB)

The details of major plants in India manufacturing LAB is provided below.

Table 41: Major LAB Manufacturing Plants

LAB plants	Capacity, TPA	Technology
RIL, all locations	180000	UOP
Nirma, Vadodara	110000	UOP
Tamil Nadu Petroproducts	120000	NA
IOCL, Vadodara	120000	UOP

UOP accounts for more than 70% installed capacity of LAB. The process flow diagram is given below.

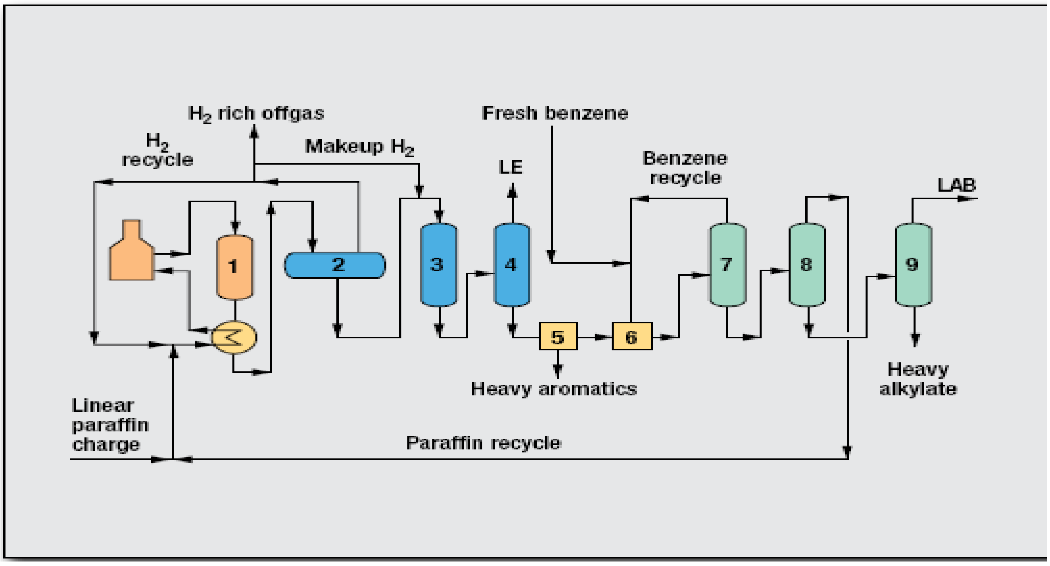


Figure 28: UOP Manufacturing Process for LAB

Linear paraffins are fed to a pacol reactor(1) to dehydrogenate the feed into corresponding linear olefins.Reactor effluent is separated into gas and liquid phases in a separator (2).Diolefins in the separator liquid are selectively converted to monoolefins in aDeFine reactor (3).Light ends are removed in a stripper (4) and the resulting olefin parafin mixture is sent to a PEP absorber (5) where heavy aromatics is removed prior to being sent to a Detal reactor(6) where the olefins are alkylated with benzene.The reactoreffluent is sent to fractionation section (7,8) for separation and recycle of unreacted benzene to the Detal reactor ,and separation and recycle of unreacted paraffins to the pacol reactor.Areturn column (9) separates the LAB product from the heavy alkylate bottoms stream. The specific energy consumption is about 4.0 GJ/Ton (from industry sources)

Ethylene Oxide (EO)

In India, EO is produced by Reliance Industries Ltd (RIL) and India Glycols Ltd. (IGL). RIL sells the entire EO produced for the Merchant Market while IGL captively consumes all EO produced for Surfactants & Glycol ethers production. The current effective capacity of EO is 209000 TPA. The predominant technology is by ABB Lummus.

Ethylene and oxygen in a diluent gas made up of a mixture of mainly methane or nitrogen along with carbon dioxide and argon are fed to a tubular catalytic reactor (1). The temperature of reaction is controlled by adjusting the pressure of the steam which is generated in the shell side of the reactor and removes the heat of reaction. The EO produced is removed from the reaction gas by scrubbing with water (2) after heat exchange with the circulating reactor feed gas.

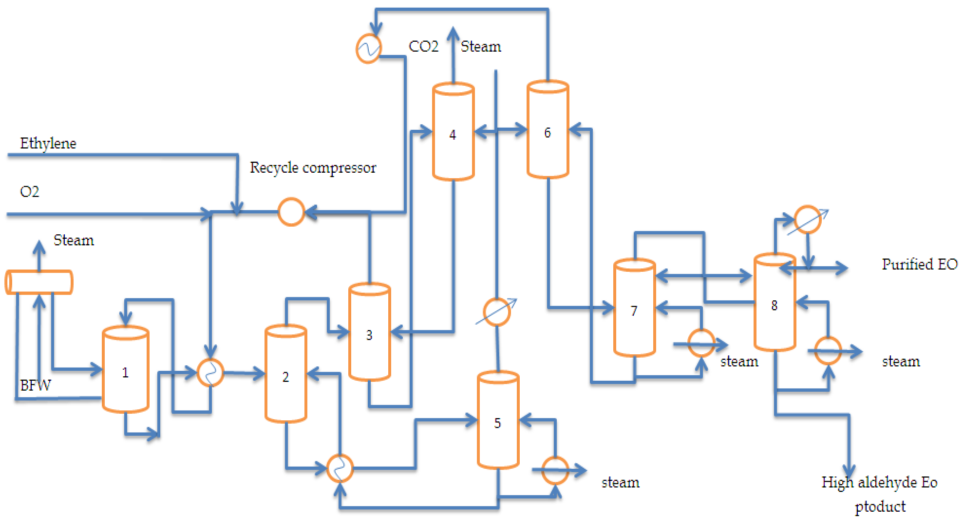


Figure 29: Ethylene Oxide Manufacturing Process

The specific energy consumption is 3.3 GJ/Ton of product (from industry sources).

Table 42: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.8	2.5	0	0

Other Basic Organic Chemicals

The other major petrochemicals are Benzene, Toluene and Acrylonitrile commonly known as the basic organic chemicals. The manufacturing capacity & demand for these products are given below.

Table 43: Manufacturing Capacity & Demand for Basic Organic Chemicals

Products (In 1000 TPA)	Capacity (2011-12)	Demand (2011-12)
Benzene	1235	590
Toluene	270	440
Acrilonitrile	40	125

Benzene

There are three categories of benzene producers in India:

- Cracker operators [RIL, IPCL (Baroda), HPL], who accounted for 39 percent of the domestic benzene production.

- Refineries (RIL, IOC, BPCL, and KRL), who accounted for 54 percent of the domestic benzene production.
- Steel producers (SAIL, which produces benzene as a by-product from coke oven gas), accounts for around 6 percent of domestic benzene production

The major manufacturers of benzene in India is represented in the following table.

Table 44: Major Benzene Manufacturing Plants

Company	Capacity, TPA
RIL	680000
IOC	200000
BPCL	80000
KRL	85000
HPL	125000
Steel Plants	60000

The main source of benzene supply comes from Steam cracking and Reformate/toluene hydro dealkylation based production units, each accounting for about 400,000 tonnes and 620,000 tonnes, respectively.

Benzene is produced by steam cracking as well as aromatic extraction processes. In the latter, the feed rich in C7+ aromatics is treated with hydrogen in a hydodealkylation process to produce benzene. Only the hydrodealkylation process produces benzene on-purpose.

Specific energy consumption in steam cracking method is about 12 GJ/Ton. Specific energy consumption of aromatic extraction method is given below.

Table 45: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.3	13.1	-1.4	0

Schematic of Lummus technology(aromatic extraction) is given Toluene section. In this process dealkylation of Toluene/Xylene is done to extract Benzene.

Toluene

At present the method used to produce Toluene is by separating the aromatic mixture. The plant consists essentially of an extractor, a water wash, a heater and a clay treater. The feed is contacted with the solvent counter currently. After extraction and treatment, the mixed aromatics are distilled in train of two towers for the separation of the three aromatics, benzene, toluene and xylene.

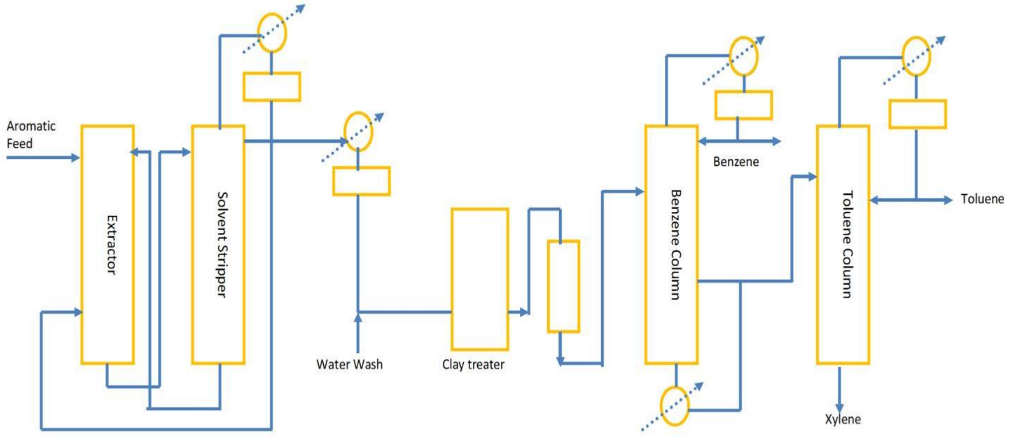


Figure 30: Benzene, Toluene and Xylene Manufacturing Process

The specific energy consumption is similar to that of Benzene, as given below.

Table 46: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.1	0	2.0	22.5

Acrylonitrile (ACN)

Reliance Industries, Vadodara is the only manufacturer of ACN in India, with a capacity of 40000 TPA.

Acrylonitrile is produced domestically by a single process i.e. Sohio process of propylene ammoxidation. A simplified flow diagram of the basic Sohio process is presented in Fig. Propylene, ammonia (NH3), and air are fed to the reactor in near stoichiometric ratios. The yield of acrylonitrile monomer from this reaction is typically 79 weight percent with approximately 2 and y molar percent yields of each of the by-products acetonitrile and hydrogen cyanide (HCN) respectively. The stream exiting the reactor contains acryonitrile and by-products but also un-reacted oxygen, carbon monoxide, carbon dioxide, and nitrogen. The acrylonitrile product obtained from the Sohio process has a purity of 99 + percent.

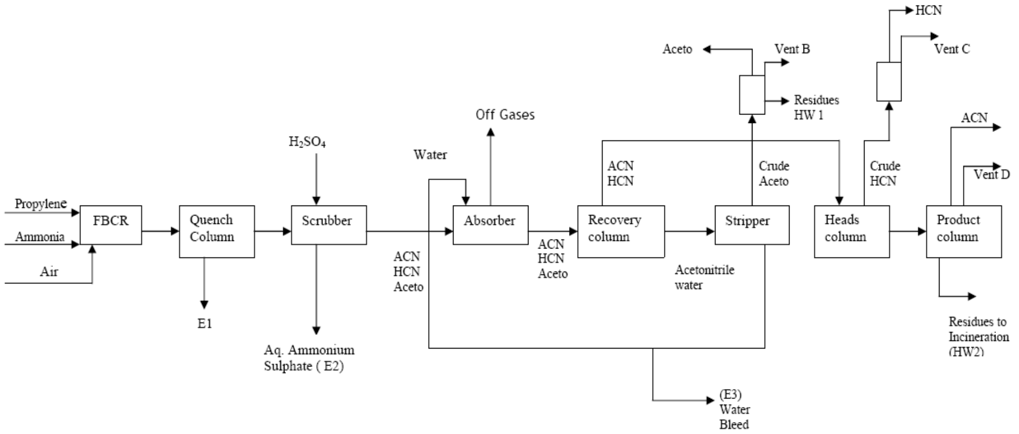


Figure 31: ACN Manufacturing Process

The specific electricity consumption is 1.1 GJ/Ton with a steam credit of 6.4 GJ/Ton.

Table 47: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.8	0.3	-6.4	0

Phthalic Anhydride (PAN)

The major manufacturers of PAN in India are as follows.

Table 48: Major Manufacturers of PAN

PAN – Plants	Capacity, TPA
IG Petrochemicals Ltd	116110
Thirumalai Chemicals Ltd	145000
Asian Paints Ltd.	29796

Fig below shows the process flow diagram for phthalic anhydride production using o-xylene as the basic feedstock. Filtered air is preheated, compressed, mixed with vaporized oxylene and fed into the fixed-bed tubular reactors (Step 1). The reactors contain vanadium pentoxide as the catalyst and are operated at 340°C to 385°C (644° to 725°F). In order to maintain catalyst activity, small amounts of sulfur dioxide are added to the reactor feed. Exothermic heat is removed by a molten salt bath circulated around the reactor tubes and produce PA (Step 4). The liquid then flows to the vacuum distillation column where the remaining water and impurities are removed (Step 5). In the final step, the pure product is pumped to molten storage (Step 6).

Typically this reaction produces more energy than it consumes & the plants manufacturing PAN is expected to be net exporter of energy.

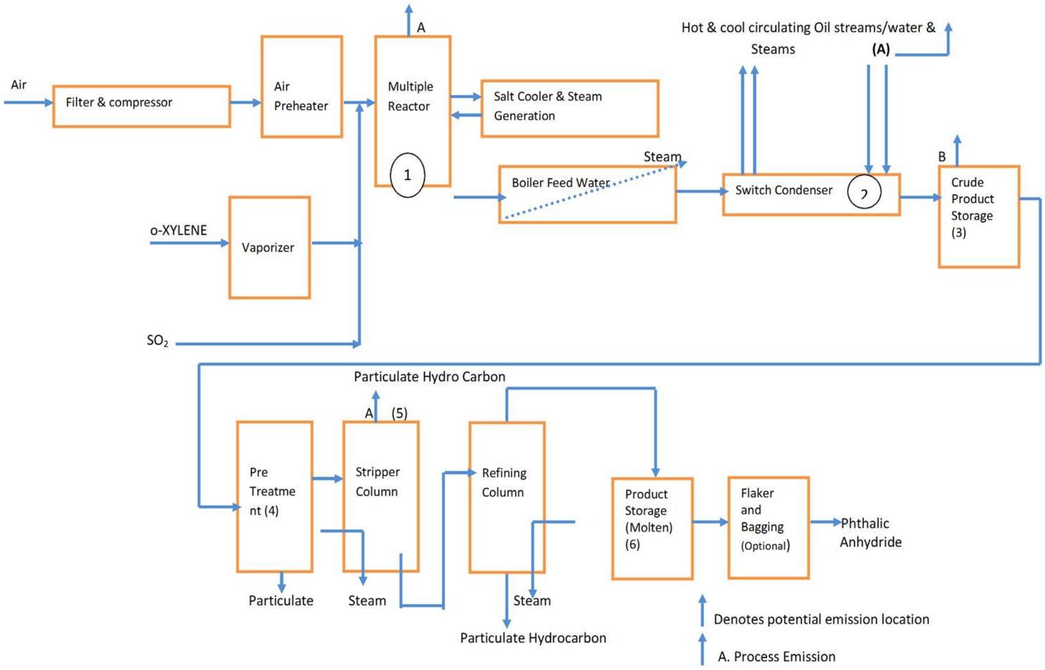


Figure 32: PAN Manufacturing Process

The specific energy consumption is 20.7 GJ/Ton of product

Table 49: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.7	20	0	0

Acrylonitrile Butadiene Styrene (ABS)

ABS resins are well-established, high volume, amorphous engineering thermoplastics, which offer an excellent balance of heat, chemical and impact resistance with superior processing versatility.

It is derived from Acrylonitrile, butadiene, and styrene either as such as graft polymer or SAN on Polybutadiene or as a blend of ABS plus SAN. Composition of the constituent monomers can be varied in order to alter the properties of the final resin.

Current capacity in India is 120 KT. The major producer of ABS in India is INEOS ABS (formerly Lanxess, Bayer) with 80,000 metric tonnes of capacity and Bhansali Polymer with current capacity of 40,000 metric tonnes.

ABS is produced by grafting styrene and acrylonitrile onto a polybutadiene matrix. The three basic steps in the suspension process are: prepolymerization, polymerization, and product separation. The processing steps for mass polymerization are: prepolymerization, polymerization, devolatilization, and extrusion. Mass polymerization generates a minimum of wastewater and eliminates the need for dewatering and drying. In both the suspension and mass processes the polybutadiene must be soluble in styrene. Polybutadiene resin may be added as a dry resin rather than a latex.

Table 50: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.2	0	2.0	0

Styrene Acrylonitrile (SAN)

Styrene and Acrylonitrile monomers can be copolymerized to form a random, amorphous copolymer that has improved weather ability, stress crack resistance, and barrier properties. The copolymer is called styrene Acrylonitrile or SAN. The SAN copolymer generally contains 70 to 80% styrene and 30 to 20% Acrylonitrile.

The manufacturers are the same as that of ABS, though in this case only two monomers are involved and they can manufacture both SAN and ABS. Current capacity in India is 120 KT .The major producer of ABS in India is INEOS ABS (formerly Lanxess, Bayer) with 80,000 metric tonnes of capacity, and Bhansali Polymer with current capacity
of 40,000 metric tonnes.

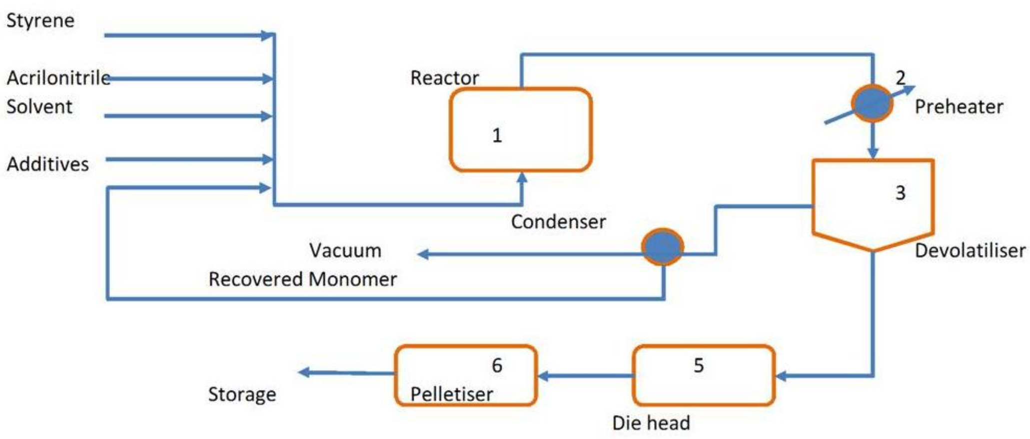


Figure 33: SAN Manufacturing Process

Table 51: Specific Energy Consumption

Specific energy consumption, GJ/Ton			
Electricity	Fuel	Steam	Feedstock
0.2	0	2.0	0

Elastomers (Synthetic rubber)

Since India has a large production base for natural rubber, demand for synthetic rubber had been structurally very different. The share of synthetic rubber consumption in India is only 30%.

Reliance is the sole manufacturer of PBR which account for ~60% of total domestic synthetic rubber capacity of 124 KT (2010-11). This is the only major synthetic rubber operating unit in India. The capacity and production of synthetic rubber in India is given below.

Table 52: Capacity and Production of Synthetic Rubber

Products (In 1000 TPA)	Capacity (2011-12)	Demand (2011-12)
PBR	74	131
SBR	20	186

Poly Butadiene Rubber (PBR)

Reliance Industries, Vadodara is the only manufacturer of PBR in India with a capacity of 95000 TPA. There are 2 nos plants at this location, with technology from Polystar and JSR.

Polybutadiene rubber is prepared by either emulsion or solution polymerisation. In general these processes are based on organo-lithium compounds or co-ordination catalysts. Polymerization is carried out using pure dry butadiene and a solvent. When the desired conversion is achieved, the catalyst is deactivated and polybutadiene is recovered from the unreacted butadiene and solvent, washed to remove the catalyst residue, and dried.

Styrene Butadiene Rubber (SBR)

The only manufacturer in India producing SBR is Apcotex Lattices, Thane with a capacity of 30000 TPA.

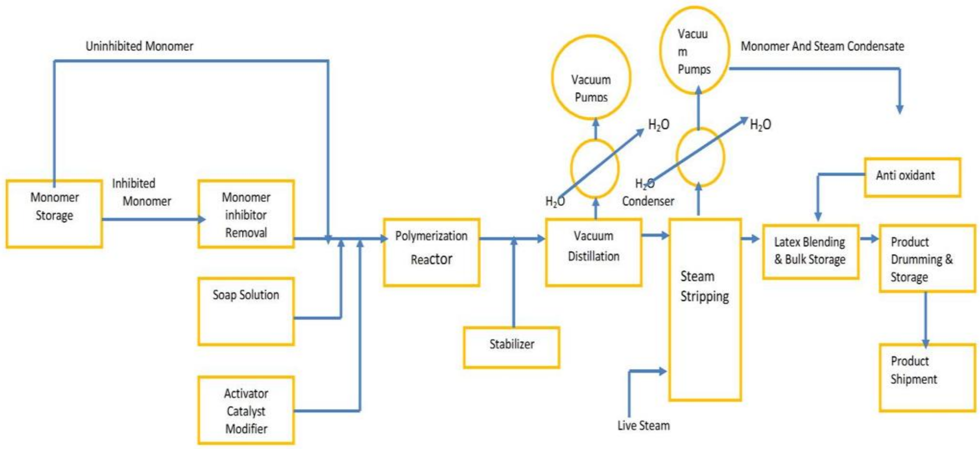


Figure 34: SBR Manufacturing Process

Fresh butadiene and styrene are received, stored, and blended with recovered butadiene and styrene. The two chemicals, along with a catalyst and soap solution, are pumped to the reactors where polymerization takes place. After the short-stop stage, in which an agent is added to the mixture in order to stop the reaction, unreacted butadiene and styrene are recovered for recycling and pumped back to the storage tanks. In the next stage, stripped latex is accumulated for blending, if required. The latex is then coagulated and converted into crumb and screened, washed, and filtered. Excess water is removed, and the crumb is dried in a hot-air dryer. It is then weighed out in 77-pound (35-kilogram) bales and wrapped in polyethylene bags for shipment.

Energy Consumption in Indian Petrochemical Industry

Energy consumption in the Indian Petrochemical Industry has been estimated for the year 2011-12. In the absence of actual energy consumption figures it has been worked out on the basis of actual production and the design/benchmark specific energy consumption for a specific petrochemical product[8].

[8] Source: Chemical and Petrochemical Sector, IEA 2009; Ministry of Chemicals and Fertilisers; CMIE

Based on the above computation the gross primary energy consumption is estimated to be 120 mn GJ or 2.85 mn MTOE for the year 2011-12[9]. Production of Propylene and Ethylene consumes maximum energy with almost 63% of the cumulative energy consumption for the entire sector. The graph plotted below

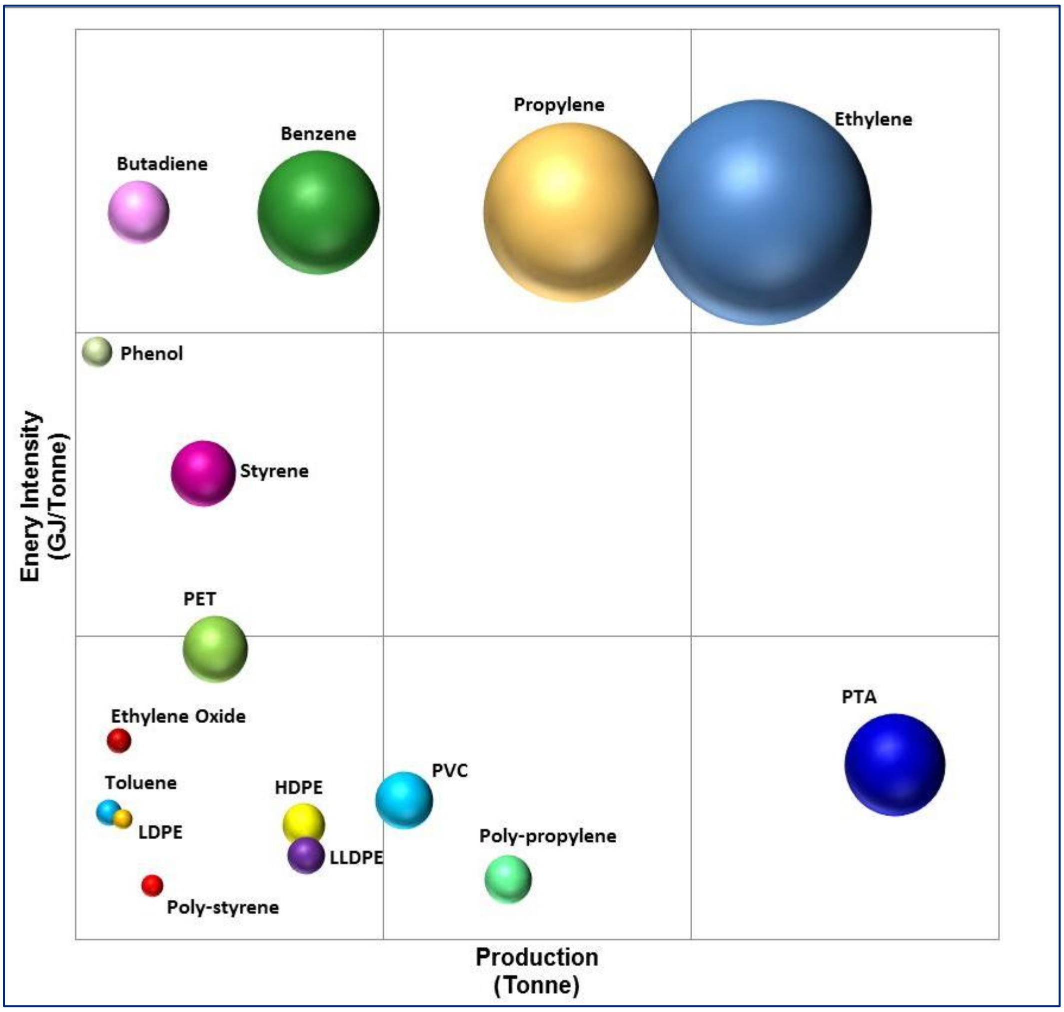


Figure 35: Estimated Product Wise Energy Consumption for Indian Petrochemical Sector

brings more insight on product wise energy consumption as estimated for the sector. The graph plots the petrochemical products based on their energy intensity (GJ/T) versus the total production. The size of the bubble indicates the total estimated energy consumption of the product.

While three products account for 75% of the total energy consumption, the remaining energy is consumed by remaining 14 major products as indicated in the graph above[10]. As such specifying a minimum energy consumption level for demarking the Designated Consumers (DC) would be challenging task for the sector. As such laying down of such energy consumption level would be very important so as to address a uniform penetration across the sector and not just restrict the DC to the top three products viz. Ethylene, Propylene and Benzene, in the energy consumption list. While most of the units manufacturing these products would be large integrated complexes producing other products as well, it would be appropriate to have separate

[9] This is determined in terms of final energy terms. Conversion to primary energy will involve use of generation efficiencies.
[10] Acrylonitrile (ACN) being a net negative energy intensive product is not represented in the chart

benchmarking levels for integrated and other units. The approach to creating benchmarks for determining DC will be recommended further during the course of this project once the actual data will be available and interaction with the stakeholders will be made.

Energy efficiency improvement initiatives across petrochemical sector in India

Bureau of Energy Efficiency is leading the national movement toward the implementation of Energy Conservation Act 2001. The Bureau is assisting industry and commercial establishments to meet the mandatory provision of the Act through voluntary approach. In order to implement the energy efficiency projects in industrial sectors and commercial sector and build awareness and capacity of key stakeholders in the sector for replicating/implementing similar projects across the country, BEE initiated Energy Conservation Awards. Every year BEE felicitates the award winning industrial units for making commendable efforts in energy conservation in their respective fields. Some of the progressive industrial units in petrochemical sector have already realized the cost effectiveness of energy conservation measures.

Major areas for energy-efficiency improvement are utilities (around 30%), fired heaters (around 20%), process optimization (around 15%), heat exchangers (around 15%), motor and motor applications (around 10%), and other areas (around 10%). Of these areas, optimization of utilities, heat exchangers and fired heaters offer the most low investment opportunities, whereas in other areas low-cost opportunities also exist. Some process related EE opportunities needs investments.

The table below summarizes the cross cutting energy efficiency measures implemented by leading petrochemical industries in last 9 years in India

Table 53: Energy Efficiency Measures Implemented by Leading Petrochemical Industries

Energy Management Programs (dedicate energy efficiency team)	
Energy Monitoring and control system	
Steam Supply	
Flue gas heat recovery	Blow down steam recovery
Combined heat and power	Steam expansion turbines
High temperature CHP	Fuel substitutions in boilers
Boiler process controls	Reduction in Flue gas temperatures
Steam Distribution System and Steam End-use	
Improved distribution system insulation	Leak repair
Insulation maintenance Flash steam recovery	Steam trap improvement Return condensate
Steam trap maintenance and monitoring	Improve efficiency at steam

	end use
Process Heaters and Furnaces	
Control air-to-fuel ratio	Improve control
Improve heat containment	Switch electric heaters to fuelled heaters
Improve heat transfer	Maintenance
Heating, Cooling and Process Integration	
Reduce fouling in heat transfer equipment	Process integration
Regular checks of cooling water systems	Pinch analysis
Heat recovery	Total site pinch analysis
Motor Systems	
Properly sized motors	Reduce voltage unbalance
High efficiency motors	Adjustable-speed drives
Improve power factor	Variable voltage controls
Pumps	
Pump system maintenance	Avoiding throttling valves
Pump system monitoring	Pump demand reduction/Proper pipe sizing
Controls Adjustable-speed drives	High-efficiency pumps
Precision castings, surface coatings or polishing	Properly sized pumps
Multiple pumps for variable loads	Impeller trimming Use dry vacuum pumps
Fans and Blowers	
Properly sized fans	Adjustable speed drives
Improved controls	High efficiency belts
Compressors and compressed air systems	
System improvements (pressure reduction)	Controls
Maintenance	Properly sized regulators
Monitoring	Properly size piping
Leak reduction	Heat recovery
Reducing the inlet air temperature	Adjustable speed drives
Maximize allowable pressure dew point	High efficiency motors
Improved load management	
HVAC systems	
Converting vapour compression system to vapour absorption systems	Energy efficient system design

Variable-air-volume systems	Adjustable-speed drives
Distillation	
Optimization of reflux ratio/Enhanced distillation control	Feed conditioning
Check required product purity	Upgrading column internals
Seasonal operating pressure adjustments	Stripper optimization
Reducing reboiler duty	Insulation
Process Specific measures	
Recover exothermic heat	Recuperative incinerators
More selective furnace coils	Improved transfer line exchangers/Secondary transfer line exchangers
Additional expander on de-methanizer	Increased efficiency cracking furnaces
Pre-coupled gas turbine to cracker furnace	Higher gasoline fractionator bottom temperature
Improved heat recovery quench water	Reduced pressure drop in compressor interstages
Additional re-boilers (cold recuperation)	Extended heat exchanger surface
Optimization steam and power balance	Improved compressors
Improved product recovery systems	Low pressure steam recovery
Optimal design EO/EG-sections	Multi-effect evaporators (Glycol)
Optimize recycle loops	Gas-phase direct chlorination of ethylene
Catalytic cracking EDC	Condensate recovery and process integration

Review of International benchmarking practices

Specific Energy Consumption per ton of Ethylene (SECe)[1]

Description:

Ethylene as the most important product from steam cracking in the past, the specific energy consumption per ton of ethylene (SECe) is a common measure of energy consumption for cracking. Modern plant values for SECe are 14 GJ/ton of ethylene for ethane cracking (13 MBtu/ton, HHV) and 20-27 GJ/ton of ethylene for naphtha/gas oil cracking (19-26 MBtu/ton, HHV) (Phylipsen et al., 1998a).

Benefits:

- Single product Benchmark
- Simple method for implementation
- Usually data is readily available with manufacturing plants

Constraints:

- The cracker product mix is influenced by feedstock and processing conditions (or severity which includes parameters such as temperature, pressure and furnace residence time).
- Using the specific energy consumption per ton of ethylene (SECe) as a measure of energy efficiency would mean that all energy consumption is allocated to ethylene, and none to the other products.
- The benchmarking is limited to only to petrochemical plants manufacturing ethylene

Remarks:

Using another feedstock or severity will affect the SECe, even if total energy consumption does not change. In order to be able to compare different processes and feedstock (with different yields for the various products) another allocation has to be used. In order to exclude effects from changing product yields, energy consumption should be allocated over all products formed in a particular process (on a mass basis).

Ratio of the actual SEC to the reference SEC[1]

Description:

Specific energy consumption is defined as the net energy consumption per unit of high value chemicals (including hydrogen, ethylene, propylene, a mixed butane fraction and a BTX fraction5). The energy efficiency is presented as the ratio of the actual SEC to the reference SEC. The reference SEC can be global best practice technology SEC, best achieved technology SEC, best SEC in that sector in that country or Solomon's Index.

Benefits:

- Comparison within industries in sector implies achievability of the set targets
- Uniform index for comparison
- Greater possibility of Industry participation as the benchmarks are not theoretical but practically achievable

Constraints:

- Reference SEC may not be readily available, for e.g. Solomon Associates have a proprietary methodology for deriving Solomon Index which may not be opted by all petrochemical plants
- Arriving at Reference SEC for all major petrochemical products for different feedstock, production technologies, plant vinatges, might be difficult.

Remarks:

A thorough analysis of globally available of energy indexes, SECs, energy consumption pattern has to be undertaken in purview of its applicability to domestic industry. The resource requirement for deriving a reference SEC that takes into consideration the technology, feedstock, vintage, etc may turn out to be impractical.

Individual plant Specific Energy Consumption (SEC)[2]

Description:

SEC is calculated from the energy that a plant consumes during a cycle of operation, for example, one month, per product of that same period. Based on the present SEC, a target for reducing SEC is given to industry, which can be in percentage of present SEC. For e.g a petrochemical plant with SEC of 17 GJ/ton is given a target reduction of 5% of present SEC. This cycle is continued year on year till the plant meets the best in class SEC.

Benefits:

- Simple and plant specific method

- Accounts for all the variables present within the plant that affect SEC
- The SEC reduction targets can be given after discussion and solicitation with each plant to increase participation

Constraints:

- Plant specific target may create disagreement among industries in that sector
- Uniformity and justification of targets set for each industry may be difficult for implementing agency
- Arriving at best in class SEC accounting for all variables may require complex modelling

Energy Intensity[2]

Description:

Energy Intensity is defined as the proportion between the energy consumed in the production process the country's gross domestic product (GDP) or other unit such as ton of product, production value, transport value, etc. The energy consumed being analyzed differently depending on its source, for example, heat, electricity energy, or total energy.

Benefits:

- Uniform Index methodology
- Can be related to value of product or GDP extending its use to accounting at national level

Constraints:

- May not be suitable for industry level comparison
- The problem of accounting for various other factors affecting energy consumption may not be captured by this method

$$\boldsymbol{Specific\ Energy\ Consumption\ (SEC)} = \frac{\boldsymbol{Energy\ Consumption\ (MJ)}}{\boldsymbol{Primary\ Products\ (Ton)}}$$

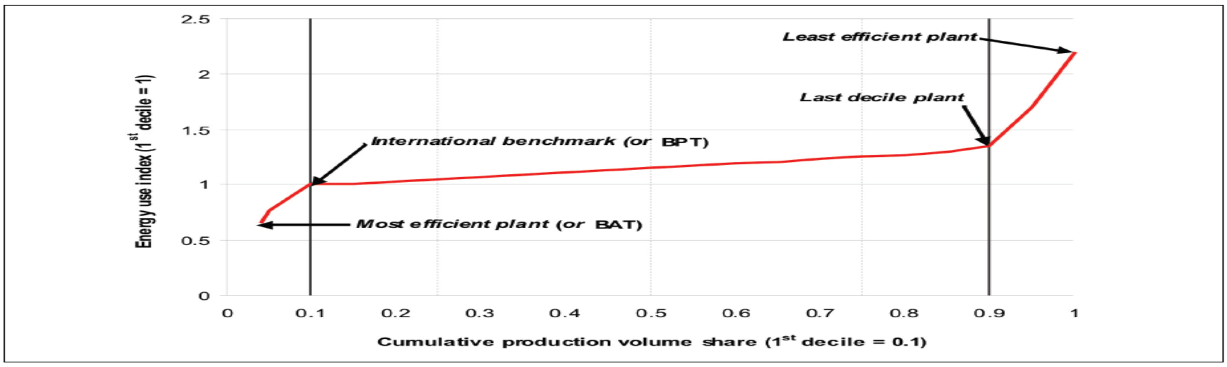
$$\boldsymbol{Energy\ Intensity\ (EI)} = \frac{\boldsymbol{Energy\ Consumption\ (TOE)}}{\boldsymbol{Value\ of\ Primary\ Products\ (million\ \$\ )}}$$

Benchmarking Curves[3]

Description:

Benchmarking is used to compare the performance of individual plants with the most energy efficient plant(s) on a sector-by-sector basis. Energy benchmarking is part of a much wider use of benchmarking as a management tool. The results of sectoral benchmark studies can be summarised in benchmark curves in which the energy use of individual plants is plotted as a dependent variable from the most efficient to the least efficient plant, either as function of cumulative production or of the number of plants. The information from benchmark curves can be used to assess the relative performance of individual plants.

Illustrative energy benchmark curve for the manufacturing industry



Energy Efficiency Improvement and Cost Saving Opportunities for the Petrochemical Industry - An ENERGY STAR® Guide for Energy and Plant Managers

The most efficient plants are represented to the left and lower part of the curve, and the least efficient plants to the right and higher part of the curve. The shape of benchmark curves would vary for different sectors and regions. However, typically a few plants are very efficient and a few plants are very inefficient. This is generally represented by the steep slopes of the benchmark curve before the 1st decile and after the last decile respectively. Between these two deciles, benchmark curves tend to display a broadly linear relationship between energy efficiency and the share of cumulative production. This relationship can be used to support a rough assessment of the energy efficiency potential for an industrial process, which is defined as 50% of the difference between the efficiencies observed at the first and last deciles.

Benefits:

- It sufficient specific information is available and the coverage of the benchmark curve is fairly comprehensive, be used to estimate the aggregate savings potential at the level of an individual country, a region, or worldwide.

Constraints:

- The most energy efficient plants in the benchmark curves are not, however, necessarily users of the most efficient technologies.

- They may be plants that benefit from exceptionally favorable feedstock quality or other non-technology-related factors.
- For some industries and countries, benchmark curves are readily available. But data is often much less readily available, and often less reliable.
- Even where benchmark curves are publicly available, it is often impossible to identify individual plants based on the information given.
- Plant data are often confidential because of antitrust regulations and market sensitivities.

Remarks:

It is not therefore possible to develop detailed efficiency investment programmes based on a benchmark curve because it remains unknown which plants exactly are the ones with the high savings potential. Information from additional sources is needed to complement benchmark curves if governments or other organisations are seeking to target investments in energy efficiency.

Benchmark data supplemented by Efficiency Indicator data[3]

Description:

If energy use data cannot be identified at plant level, it is sometimes possible to quantify energy efficiency improvement potentials by comparing the average energy use within a country or region with the comparable best practice plant in the world. Average energy use can be derived from publicly available information such as energy statistics and production data. But the resulting energy efficiency indicators are generally less sensitive than benchmarking data.

Plant benchmark data are complemented by two further types of analysis based on (i) the average current specific energy consumption (SEC) by world region or country, and (ii) the Energy Efficiency Index (EEI) as developed by Phylipsen et al (2002) and Neelis et al (2007) for the Netherlands.

The SEC analysis uses the average current SEC at country or regional level depending on data availability8. If SEC data are not available, energy statistics provide the only basis for assessing energy efficiency. Energy statistics provide information on energy use at sectoral level, thereby including all production processes within the sector.

The EEI approach estimates the EEI of country j for sector x with i production processes as follows:

$$EEI_{j,x} = \frac{TFEU_{j,x}}{\sum_{i=1}^{n} P_{i,j}\ X\ BPT_{i,x}}$$

TFEU is the actual energy use of sector x as reported in Energy Balances prepared by International Energy Agency (IEA) (in petajoules (PJ) per year), P is the production volume of product i in country j (in mega tons (Mt) per year), BPT is best practice technology energy use for the production of product i (in GJ per ton of output) and n is the number of products to be aggregated. On this basis, a country is the most efficient worldwide when all its processes for a given sector have adopted BPT. In that case, the

Country or region has an EEI of 1.

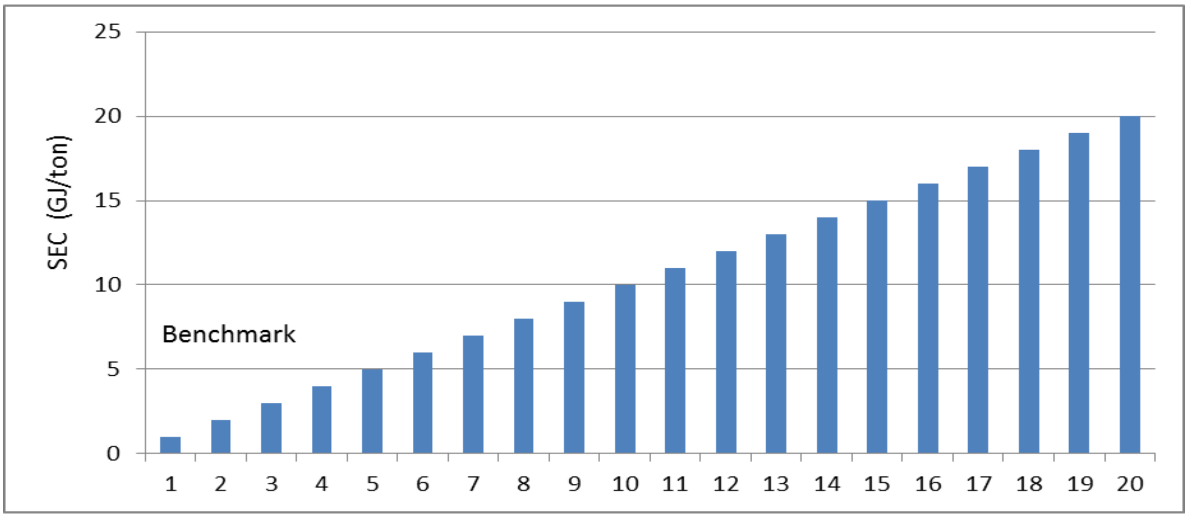
Remarks:

This method finds in applicability at state or national level where the IEA or similar agency has reliable data available for comparison.

Hypothetical Benchmarking[4]

Description:

Benchmarks need not be set at the average energy intensity; however, a benchmarking curve can also be used to develop applicable specific benchmarks. The figure below shows that the plants at the extreme left are the ones with low SEC and the SEC increase towards the right. The hypothetical benchmark may not be essentially the lowest but can be a more industry acceptable benchmark like the one marked on the graph. Setting the ambition of a benchmark – whether average, better-than-average, or top-performing – becomes particularly important in regulatory systems for reducing energy consumption, including both cap-and-trade and performance standards approaches.



Reference: White Paper - Issues and Options for Benchmarking Industrial GHG Emissions

Remarks:

Since this is a hypothetical benchmark, industry may not agree with the benchmarking targets. Also the benchmarking do not account for variables that affect the energy consumption like feedstock, vintage of plant, process parameters, etc.

Voluntary Performance Goals[4]

Voluntary programs may take one of several forms (Lyon 2003):

- initiatives undertaken by industry alone (e.g., self-regulation), such as the goals announced by the Cement Sustainability Initiative and the PFC reduction goals of the International Aluminum Institute;
- negotiated agreements between government and industry, such as the US EPA's Climate Leaders program; or
- public voluntary programs (e.g., ENERGY STAR) in which governments provide technical assistance and publicity to companies that adopt and meet certain goals.

Voluntary approaches have generally been perceived as being more acceptable to industry actors than regulatory or even market-based approaches to reducing greenhouse gases. Analyses of the success of voluntary environmental programs, however, have found that in general they have not and cannot attain levels of emissions reduction comparable to market-based or regulatory approaches (Lyon 2003; Morgenstern and Pizer 2007). When voluntary efforts have failed to meet their goals, some governments have pursued other policy approaches. For example, in the German voluntary program described above, when GHG reduction targets were not met in 2003 and 2004, Germany introduced a more ambitious cap into its cap-and-trade program in 2006 (German Federal Ministry of the Environment 2006). Despite their limitations, voluntary programs can help build technical capacity and early action towards eventual transition to a more comprehensive policy approach.

Remarks:

As discussed above the success of the program lies at the discretion of industries on which the voluntary targets are applicable, there is a conflict of interest. However, to encourage the industry to take first step towards energy efficiency this mechanism seems to be a good initiative.

Market-Based Approaches[4]

Description:

A cap-and-trade program is a market-based program to limit energy usage or greenhouse gas emissions. These types of programs are being implemented in the U.S. East Coast and Mid-Atlantic states through the Regional Greenhouse Gas Initiative (RGGI), in Europe, through the EU Emission Trading System (EU

ETS), and in the state of New South Wales, Australia through its Greenhouse Gas Abatement Scheme. The Western Climate Initiative, which comprises four Canadian provinces and seven U.S. states including Washington, is currently developing the detailed design for a regional cap-and-trade system, as are the states involved in the Midwest Greenhouse Gas Reduction Accord (MGGRA).

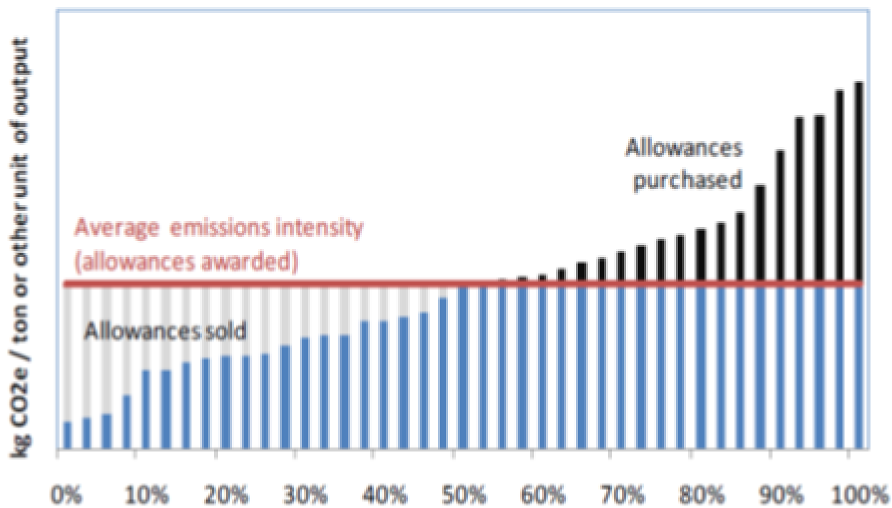
Constraints:

- **Production cost advantages**: differences among countries in terms of access to inexpensive raw materials, highly skilled or low-cost labor, or advanced technologies that may provide cost advantages greater than any increased cost of production resulting from the cap-and-trade program;
- **Large, fixed, capital investments:** the extent to which increased production costs in the US might influence where new manufacturing facilities are located; and
- **Transportation costs:** the degree to which transportation costs for inputs and outputs influence the competitive position of the industry.

Benchmark-based Allowance Allocation[4]

Description:

To help address concerns regarding industrial competitiveness, some observers have suggested that emissions allowances, the tradable commodity in a cap-and-trade system, be freely allocated to emissions-intensive, trade-exposed (EITE) industries. The American Clean Energy and Security Act, which passed out of the U.S. House of Representatives as H.R. 2454 in June 2009, provides for allowances to EITE industries on the basis of a benchmark emissions level defined as the sector's average direct emissions per unit of production output. Allowances are also rebated for indirect emissions (i.e., emissions released to produce purchased electricity or heat) based on a similar sector-average calculation. Each individual facility in an EITE sector would receive free allowances based on the facility's output times the average emissions intensity of the sector (the benchmark). Facilities with an emissions intensity below the average (more efficient or lower emitting facilities) would receive more allowances than they would need to cover their emissions and would therefore have extra allowances to sell.



Despite the apparent benefits of free allocation of allowances via output-based benchmarks, tradeoffs do exist. In particular, freely allocating allowances to industry can substantially diminish the price signal to firms to reduce GHG emissions, the central goal of the cap-and-trade program (Schneck et al. 2009; Matthes et al. 2008). Freely allocating allowances also foregoes the opportunity to use that allowance value for other uses, such as support for low income consumers, investments in clean energy technology, deficit reduction, or workforce training (US EPA, US EIA, and US Treasury 2009; Zabin, Buffa, and School 2009)25.

Remarks:

Free allocation of allowances is definitely not a long term strategy but can be implemented at the first stage of the program and then gradually pulled back year after year.

Emissions Performance Standards[4]

While EPA and many stakeholders have expressed a preference for a market-based approach to reducing greenhouse gases (e.g., cap-and-trade), regulatory emissions performance standards continue to be considered and advanced as a "backstop" policy, should market-based approaches fail to be implemented (Alsalam 2009; Richardson, Fraas, and Burtraw 2010).

Broadly speaking, regulations on GHG emissions from stationary, industrial facilities could be developed using one of two approaches. The first approach is to identify particular, sector-specific emissions benchmarks in terms, such as of tons CO2e per unit of output, that must not be exceeded. The second approach is to define a particular set of technological controls – such as best available control technology (BACT) – that must be implemented by a specific facility. These approaches are not mutually exclusive. For example, a BACT may be defined as a specific technology based on that technology's ability to meet a particular emissions benchmark.

Remarks:

As discussed above, to avoid a complete failure of voluntary or allowance based mechanism, a minimum energy reduction target is helpful. This minimum target may not need a technical clarification if it is below the Voluntary target set by industry.

Statistical Approach

Regression is a statistical technique that estimates the dependence of a variable of interest (such as energy consumption) on one or more independent variables, such as ambient temperature, reaction temperature and pressure, chemical constituents of products, etc. It can be used to estimate the effects on the dependent variable of a given independent variable while controlling for the influence of other variables at the same time. It is a powerful and flexible technique that can be used in a variety of ways when measuring and verifying the impact of energy efficiency projects.

Energy usage is typically the dependent variable (taken as specific energy consumption), whether energy usage is measured monthly through bills or measured more frequently through meter monitoring. The regression model attempts to predict the value of the dependent variable based on the values of independent, or explanatory, variables such as weather data.

Dependent Variable – the outcome or endogenous variable; the variable described by the model; for M&V, the dependent variable is typically energy use
Independent Variable – an explanatory or exogenous variable; a variable whose variation explains variation in the outcome variable; for M&V, weather characteristics are often among the independent variables

- Simple Regression – a regression with a single independent variable
- Multiple Regression – a regression with two or more independent variables

Advantages of Regression

Regression is a very flexible technique that can be used in conjunction with other M&V methods to help provide a deeper understanding of how and when energy is used. Regression can also be used to extrapolate short-term measurements to annual energy. If the relationship between the independent and dependent variables is not expected to change over the range of operating conditions, then short-term measurements can be extrapolated to annual energy use, even if the measurement period does not capture the full annual variation.

A particular advantage of regression is that it not only facilitates an estimate of energy savings, but it also can provide an estimate of the uncertainty in savings calculations.

Regression is conceptually simple, have at least a basic familiarity with it.

Disadvantages of Regression

Although simple in concept, proper use of regression requires a clear understanding of statistical methods and application guidance; situations can occur that require a more detailed understanding of statistical methods and to relate them with process engineering parameters. While the basic technique is fairly straightforward, complications to the site or the data can easily require more advanced techniques and a more thorough understanding of regression methods.

Regression models require multiple observations on the dependent and independent variables. There are times, however, when explanatory variables are not readily available or we only have access to proxies. Independent variables that are not included in the regression model often introduce added error. If energy use is not a strong function of the independent variable(s) in the equation, or if there is large variability in energy use ("scatter" in the x-y chart) relative to strength of the predictive relationship, regression analysis generates estimates that have high uncertainty.

It is important to note that regression is often performed without an estimate of the degree of uncertainty involved, so the validity of the resulting savings estimates is unknown.

The Regression Process[5]

The regression process can be summarized in six steps:

1. Identify all independent variables to be included in the regression model
2. Collect data
3. Synchronize data into appropriate time intervals (if necessary)
4. Graph the data
5. Select and develop the regression model
6. Validate the model

Step 1 - Identify All Independent Variables

To properly identify all independent variables, the entire facility should be considered and the different factors that play into its energy use should be identified. A model should only use the variables that explain the relationship and not include additional, extraneous information. ASHRAE Guideline 14, Appendix D, provides additional information on regression estimation with two or more independent variables (multiple regressions).

Some independent variables commonly used in energy regressions are:

- Ambient dry bulb temperature (actual or averaged over a time-period)
- Heating degree-days
- Cooling degree-days
- Plant output

Step 2 - Collect Data

Prior to installation of the measure, identify and collect data for a monitoring period that is representative of the facility, operation, or equipment. This is the baseline period, sometimes referred to as the tuning or pre period. The baseline monitoring period should be long enough to represent the full range of operating conditions.

It is vital that the collected baseline data accurately represent the operation of the system before improvements were made. Anomalies in these data can have a large effect on the outcome of the study. Examine data outliers – data points that do not conform to the typical distribution – and seek an explanation for their occurrence. A typical events that result in outliers include equipment failure, any situations resulting in abnormal closures of the facility, and a malfunctioning of the metering equipment.

Step 3 - Synchronize the Data

To accurately represent each independent variable, the intervals of observation must be consistent across all variables. For example, a regression model using monthly utility bills as the outcome variable requires that all other variables originally collected as hourly, daily, or weekly data be converted into monthly data points. In such a case, it is common practice to average points of daily data over the course of a month, yielding synchronized monthly data. There are problems with this approach because varying data lengths can cause net bias in the model. Net bias means that the total predicted energy use over the period being analyzed will differ from the actual energy use over that period.

Step 4 - Graph the Data

Create one or more scatter plots to begin to visualize the relationships between the dependent and independent variables. Most commonly, one graphs the independent variables on the X axis and the dependent variable on the Y axis.

Step 5 - Select and Develop Model

To create a baseline equation, perform a regression analysis on the measured variables. The analysis is typically called an ordinary least squares regression, because the mathematics generates a model that minimizes the sum of squared deviations between the actual and predicted values.

The equation calculated from the regression analysis represents the baseline relationship between the variables of interest. Frequently, more than one independent variable influences the outcome variable. For example, the electricity used by a chiller system might be affected by variations in outside temperature, relative humidity, hours of facility use, and number of occupants. To accurately model cooling energy consumption, we need to include additional independent variables, creating a multiple regression model.

Step 6 - Validate Regression Model

Once we have created a baseline model, we can generate the following statistical measures or tests to help validate that your estimated model relationships provide a good description of the data. At a minimum, use the following three measures to determine if the baseline equation is appropriate:

- R^2 (or R-squared),
- Net Determination Bias, and
- t-statistic.

R-Squared (Coefficient of Determination)

The coefficient of determination (R^2) is the measure of how well future outcomes are likely to be predicted by the model. It illustrates how well the independent variables explain variation in the dependent variable. R^2 values range from 0 (indicating none of the variation in the dependent variable is associated with variation in any of the independent variables) to 1 (indicating all of the variation in the dependent variable is associated with variation in the independent variables, a “perfect fit” of the regression line to the data). The rule-of-thumb for an acceptable model using monthly billing data is an $R^2 > 0.75$.

If the R^2 is low, we may wish to return to Step 5 in the regressions process and select additional independent variables that make sense to add to your model; then use the adjusted R^2 as a goodness-of-fit test for a multiple regression.

The R^2 value can be thought of as a goodness-of-fit test; but a high R^2 value is not enough to say the selected model fits the data well, nor that a low R^2 indicates a poor model. Fit criteria in addition to R^2 should be assessed.

For example, a model with a low R^2 is acceptable when there is a clear relationship between the dependent and independent variables.

Standard Error of the Coefficient (Intercept or Slope)

The standard error of the coefficient is similar to the standard error of the estimate, but is calculated for a single coefficient rather than the complete model. The standard error is an estimate of the standard deviation of the coefficient. For simple linear regression, it is calculated separately for the slope and intercept: there is a standard error of the intercept and standard error of the slope. These are necessary to get the t-statistic for each.

t-Statistic

The t-statistic is the coefficient (βi) divided by its standard error. Within regression, the t-statistic is a measure of the significance for each coefficient (and, therefore, of each independent variable) in the model. The larger the t-statistic, the more significant the coefficient is to estimating the dependent variable. The coefficient’s t-statistic is compared with the critical t-statistic associated with the required confidence level and degrees of freedom. For a 95% confidence level and a large number for degrees of freedom (associated with a lot of data), the comparison t-statistic is 1.96. Measure the t-statistic for every independent variable used, and if the t-statistic is lower than the critical value (such as 1.96) for any variable, reconsider the model. Go back to Step 5) and consider if a different model specification is more appropriate. Note that the more variables used in a regression, the lower will be the significance of each variable.

p-value

The p-value is the probability that a coefficient or dependent variable is not related to the independent variable. Small p-values, then, indicate that the independent variable or coefficient is a significant (important) predictor of the dependent variable in the model. The p-value is an alternate way of evaluating the t-statistic for the significance of a regression coefficient. Rather than requiring an input confidence level as you would to compare the t-statistic, the p-value provides probability as an output.

Analysis of Residuals

Analysis of residuals can provide a relatively easy way to confirm the assumptions required for a valid linear regression are met and to help validate the model's predictions. Plotting the predicted y-values against the actual y-values provides a quick way to validate the model's predictions; the slope should be close to 1.

Establishment of Baseline SEC under PAT-1

The specific energy consumption of any industries under PAT – I was calculated using the Gate-to-Gate concept with the following formula**.**

$$\textbf{SEC} = \frac{\textbf{Total energy input to the plant boundary}}{\textbf{Quantity of the Product}}$$

While calculating the total energy input to the plant, all energy sources are be converted to a single unit i.e. MTOE (metric ton of oil equivalent) using standard engineering conversion formula. In this calculation, the following factors were considered:

(a) All forms of energy (Electricity, Solid fuel, Liquid fuel, Gaseous fuel, by products used as fuel etc.) which are actually consumed for production of output should be considered.

(b) Energy consumed in colony and for outside transportation system is not be accounted.

(c) Energy used through renewable energy sources should not be accounted.

(d) The 'Product' is the key parameter. The definition of product for various sectors has been shown below for the purpose of calculating SEC. This has been arrived at considering the typical practice of defining SEC and consistency in product output.

The basis for baseline SEC and base year under PAT-1

The base line SEC was calculated based on the following procedure:

- All DCs were asked to submit the details of production and annual energy consumption since 2005-6 to 2009-10 through a notified form which was mandatory as per EC Act, 2001.
- A few additional sector specific factors like process technology, process flow, raw materials, product mix etc. were also collected.

- The SEC calculated from step (a) was considered as ‘Reported SEC’ by the DC. As there were various variable factors that affected the energy consumption significantly, some ‘Normalization Factors’ were also considered. It was proposed to consider the ‘capacity utilization’ as one of the most important parameter contributing to the normalization factor. However, the rationale for developing the ‘normalization factors’ was done only for a few sectors like the power, cement etc. In other sectors this exercise was not factored in successfully due to various uncertainties and the exercise still requires considerable research for arriving appropriate factors in a scientific manner.
- Now the reported SEC was normalized after incorporating the normalization factor.
- Normalized SEC = f (Reported SEC , Normalization factors)
- The base line SEC was estimated by taking the average normalized SEC of last 3 years i.e. 2007-8, 2008-9, 2009-10.
- The base year was defined as 2009-10.

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Government Policies and Regulations

PCPIRs

Overall Concept

The draft manufacturing policy recently approved by the Cabinet targets increasing the share of manufacturing in GDP to at least 25% by 2025 (from current 16%). The chemical and petrochemical sector in India presently contributes about 3% in the GDP and constitutes 14% of the domestic industrial activity. The polymer industry alone annually contributes over Rs 8,000 crores by way of taxes and duties.

In preview of the current scenario and policy initiatives, two distinct future growth scenarios have been considered in the XII five year plan for the sector. In the base case scenario considering the present initiatives, the Indian chemical industry could grow at 11% p.a. to reach size of $224 billion by 2017. However in an optimistic scenario, high end–use demand, improved export competitiveness and resultant growth impact for each sub-sector could lead to an overall growth rate of over 15% p.a. and a size of $290 billion by 2017 (~6% of global industry). The following growth targets have been set for the various segments of the chemical industry for the XIIth five year plan.

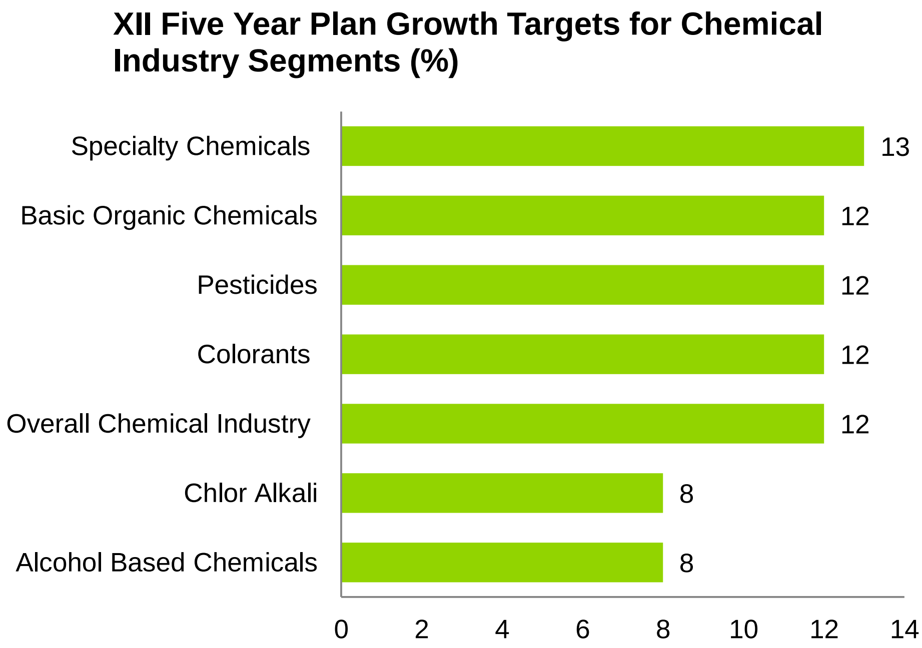

Figure 36: Twelfth Five Year Plan Growth Targets for Chemical Industry Segments

To enhance competitiveness of the industry both for the domestic and international market, Infrastructure and PCPIR has long been recognized as a catalyst for the sector growth. In this regard, Govt. constituted a high-level Task Force to explore ways to facilitate investments in petroleum, chemicals & petrochemicals sector. Based on the Task Force's recommendations, Govt. announced ***Policy on Petroleum, Chemicals & Petrochemicals Investment Regions (PCPIR)*** in 2007. Under the facility regime, setting up of integrated Petroleum, Chemicals & Petrochemical Investment Regions (PCPIRs) was envisaged for providing a conducive environment for setting up businesses, which would reap the benefits of co-siting, networking and enhanced efficiency through common services and also boosting manufacturing, exports and employment in the region.

PCPIRs is a specifically delineated investment region having an area of about 250 sq. kms of which at least 40% is earmarked for processing activities. These PCPIRs duly notified under the central or state legislation or policy may include Special Economic Zone/s (SEZs), Industrial Parks, Free Trade & Warehousing Zones, Export Oriented Units, or Growth Centres,. All the benefits available under the relevant legislation or policy will continue to remain available for the respective zones and parks forming part of the PCPIR. There is also a provision wherein the existing settlements could be covered under the PCPIR and the concerned government may not acquire the entire area comprising the PCPIR, but it will notify the same under the relevant Act for proper planning and zoning to ensure coordinated development.

Role of Key Stakeholders

- Government of India has constituted a High Powered committee (Cabinet Committee on Economic Affairs- CCEA) to ensure necessary approvals, ensuring necessary coordination among respective central ministries and state government and also monitoring all the planned activities, requisite environment and other related clearances for the development of the PCPIRs.

- In each of the PCPIR, a refinery/ petrochemical feedstock company would act as an anchor tenant, wherein the external linkages will be provided by Government of India and the concerned state government. The internal infrastructure of the PCPIR will be built and managed by a Developer, or a group of Co-developers. The users of external as well as internal infrastructure will pay for its use, except to the extent that the government supports the service through budgetary resources.
- As per the PCPIR Policy, Government of India is to ensure availability of external physical infrastructure linkages (Rail, Road (National Highways), Ports, Airports and Telecom) to the PCPIR in a time bound manner. To the extent possible, the infrastructure linkages created/ upgraded shall be through Public Private Partnerships (PPPs) and the Central Government to provide necessary viability gap funding (VGF) through existing schemes. It would also requisite budgetary provisions through public sector for creation of these linkages, as the case may be.
- The Government of India will also support the respective state governments and all the related agencies to disseminate information in view of promoting PCPIR, both at domestic and international arena to attract further investment.
- The policy also stipulates the role of state government in the development of the PCPIR, there role involves to identify the site, proposal preparation and seek approval from the CCEA. The state government will ensure to notify the PCPIR under the relevant act and acquire or assist in acquiring the land (Avoiding Agricultural Land) in accordance with the laws and ensuring rehabilitation during the course of planning and development.
- State government to notify a nodal department to coordinate all the respective linkages and to ensure that after notifying the area for PCPIR, all physical infrastructure and utility linkages under its jurisdiction are provided within stipulated time frame. It will also facilitate all the requisite clearances from the state government.
- The state government would also responsible for facilitating infrastructure including power connectivity and ensuring reliable power, bulk water requirement, road connectivity, sewage and effluent treatment linkages and addressing other environment and social aspects. The units may also seek open access as per the state electricity regulations.
- The state government may also notify additional package of incentive for the development of PCPIR. It would also constitute a management board for development and management of PCPIR under the relevant state acts.

Current Status - PCPIRs

Initially six proposals for PCPIR were submitted to Cabinet Committee on Economic Affairs (CCEA) for approval, out of which three got approved. This included Dahej in Gujarat, Haldia in West Bengal and Visakhapatnam in Andhra Pradesh, while in the second phase the proposal of Govt of Orissa was approved. These PCPIRs are expected to create infrastructure worth Rs. 57385.7 crore. The industrial investment in these regions is expected to be to the tune of Rs. 7, 63,914 crore while employment generation for about 36 lakh persons is expected over a period of a time.

In lieu of the policy framework, Memorandums of Agreement have been signed between the Government of India represented by Department of Chemicals and Petrochemicals and the Governments of AP, Gujarat and West Bengal. Notification of these three PCPIRs has been completed and Development Boards have been set up. The State Governments are in the process of finalising the Master Plans and obtaining Environmental Clearances. Investments amounting to Rs. 99412 crore have been made in these three PCPIRs since their approval. Memorandum of Agreement with Govt of Orissa was signed in November, 2011. A committee headed by Secretary (C&PC) has been constituted to monitor the progress of implementation of the approved PCPIRs.

Other Policy and Schemes

National Policy on Petrochemicals (2007)

The Government approved National Policy on Petrochemicals in April 2007

- The main objectives of the Policy are to increase investments and competitiveness both in the upstream and downstream sectors, encourage modernization of downstream processing units, promote research and development, development of adequate skilled manpower, etc. with an overall objective to achieve an environmentally sustainable and healthy growth in the petrochemical sector which will also increase the exports in the sector.
- The petrochemical sector is considerably deregulated, the items which require compulsory licenses are Hydrocyanic acid and its derivatives, Isocyanates and Di-isocyanates and Phosgene and its derivatives.
- 100% Foreign Direct Investment (FDI) is generally permitted through the automatic route without any sectoral cap. Specific approvals are required only in case of proposals requiring compulsory license, foreign investment of more than 25% in equity capital of a company manufacturing items reserved for the small scale sector and proposals relating to the acquisition of existing shares in an Indian company.
- In the Foreign Trade Policy announced by Ministry of Commerce and Industry for the period 2009-14, the various schemes like Duty Exemption Scheme (DES) which enables duty free import of inputs required for export production, Duty Entitlement Pass Book (DEPB) Scheme to neutralize incidence of Customs Duty on import content of export product, Zero Duty Export Promotion Capital Goods Scheme (EPCG) for import of capital goods for export production etc. are available to the industrial sector which also includes Petrochemicals.
- In pursuance of National Policy on Petrochemicals the Department of Chemicals & Petrochemicals envisaged following three schemes, formulated in the year 2010-11:
- National award for Technology Innovation – The scheme aims to incentivize meritorious innovations and inventions in the petrochemical Sector through National Awards. Central Institute of Plastic

Engineering Technology (CIPET) was entrusted with the task of seeking and short listing nominations for the scheme.

- Setting up of Centre of Excellence – The Scheme aims at improving the existing petrochemical technology and research in the country and to promote the development of new applications of polymers and plastics. CIPET and National Chemical Laboratory, Pune have already started research activities in their respective fields.
- Setting up of Plastic Parks – The Scheme aims at setting up need based Plastic Parks and ecosystems with requisite state of the art infrastructure and enabling common facilities to assist the sector to move up the value chain and contribute to the economy more effectively. The Scheme Steering Committee in its first meeting held on 24.02.2012 granted “in principle” approval for setting up of four plastic parks in the states of Tamil Nadu, Madhya Pradesh, Assam and Odisha

Technology Up-gradation Fund (TUF) Scheme

To compete with the global market and show improved performance, the Indian chemical industry needs to transform itself and upgrade rather operating at uneconomic scales of production with obsolete technologies. There is challenge in particular for the SME sector to invest such a huge capital upfront to upgrade technology. To address this challenge, it is envisaged in the XIIth five year plan, that the government could establish a technology up-gradation fund (TUF) that addresses specific technology issues faced by the industry. Other than consumer safety and employment, the specific qualifying technologies for funding should also support adoption of environment friendly, greener technologies and setting up of common chemicals infrastructure (E.g. effluent treatment plants) which would benefit SMEs and the environment.

The technology up gradation fund (TUF) for the textile industry is one of such a good precedent for the industry. Since its inception in the year1999 to 2010, more than 28,000 projects worth $ 46 billion benefited from the fund (with a total sanction of $ 16.5 billion).
A technology up-gradation fund (similar to textiles) outlay of Rs. 500 Crore (USD 111 million) or yearly outlay of Rs 100 crore (USD 22 million) for the XIIth plan period has been proposed for the Indian chemical industry.

The technology up-gradation fund (TUF) scheme will aim at modernization and technology up-gradation in the Indian chemicals sector. If the scheme is successfully implemented and receives a positive response from the industry, it could be further extended or the outlay increased as was observed in the case of the TUF scheme for textiles.

India’s Trade Agreements and its impact on the Petrochemical Sector

The multilateral arrangement under the WTO and Free Trade Agreements (FTAs) has resulted in rapid expansion of global trade and reduction in tariff rates. Over the past two decade, developed countries are opting for Non-Tariff Measures (NTMs) to protect their local industries, which include trade related procedures, technical regulations, standards, import or export licensing systems etc. The other most frequently used instrument across globe for the economic integration across countries or group of countries is the Regional Trade Agreements (RTAs).

In keeping an aggressive approach for a liberal global trade regime, India considers Regional Trading Arrangements (RTA's) as building block to achieve the objective of trade liberalization. India is party to number of such agreements which include Free Trade Agreements (FTA's); Preferential Trade Agreements (PTA's); Comprehensive Economic Cooperation Agreements (CECA's); etc.

The regional free trade agreements are intended to stimulate domestic economic growth through enhancing the nation’s market access to other countries and subsequently attracting more foreign direct investment. The RTAs will not only bring in more investment but will also facilitate technology transfer while stimulating increased productivity and competitiveness both at the domestic and foreign level.

To increase India’s market access abroad while addressing the trading concerns, India has adopted a multi-pronged strategy to deal with issues arising due to NTMs. On the import side, efforts are on to create suitable Sanitary and Phytosanitary (SPS) measures/ technical regulations on Indian imports over a period of time depending on the capability of the domestic sector to comply with the same. Also, such a regulatory environment would encourage a regime of quality production and thereby indirectly promote exports.

The Sub-group report on Chemicals & Petrochemicals for the 12th Five Year Plan Department of Chemicals & Petrochemicals has identified the key impact of the various trade agreements on the sector. The key highlights of same are as following:

- The FTA varies from one to other and hence has wide range of influence or impact on Industry to Industry and agreement to agreement. However, irrespective of the partner country, the two broad issues involved is assessment of the impact of any RTA/FTA are improved market access to the domestic market of the partner country which can boost India’s exports and the likelihood of imports coming from the partner country through preferential route to India’s domestic market.
- While some of India’s RTAs like SAFTA, India-MERCOSUR PTA, India-Chile PTA, etc have significant potential to provide a boost to India’s petrochemicals exports, certain other RTAs can be potential threats to the domestic petrochemical industry. FTAs like those with ASEAN, GCC, Thailand, Japan, Singapore, etc can have an adverse impact on the Indian petrochemical manufacturers by flooding the market with cheap imports. Some of India’s partner countries like Singapore and GCC are major international trade hubs with easy access to ports and act as transit a point, which increases the potential threat of preferential imports disrupting the Indian market with the added risk of rerouting of merchandise from other countries who are not party to the RTA.
- Petrochemical industry in several of India’s RTA partner countries like ASEAN and GCC have come up on the back of huge incentives/ benefits/ concessions provided by their respective governments, which

give them cost advantage vis-à-vis Indian manufacturers. India needs to take a cautious approach to trade agreements keeping in view the higher transaction costs in the country and needs to evaluate each RTA on a case-by-case basis to safeguard the domestic industry's interest, especially for sectors like petrochemicals which are extremely capital-intensive.

- To ensure that the primary objective of FTAs i.e. increasing trade, is met, it is important that India enters in to negotiations only with those countries and groups where there is complementarity between the two sides.
- In order to address the issue of trade diversion and abuse of preferential benefits, it is imperative that the rules of origin for the FTAs are stringent with dual criteria of both changes in tariff classification as well as minimum local content.

Roadmap for Implementing PAT in Petrochemical Sector

Challenges in Defining Specific Energy Consumption, Target Setting & Verification

Implementation of the PAT scheme demands that the methodologies used for Specific Energy Consumption (SEC) calculation uses measured quantities that are easily verifiable. A typical PAT cycle is for three years from the announcement of SEC reduction target to verification of achievement of the target. As such it is necessary that the methodology of calculation remains valid till the end of the PAT cycle. It is also desirable that the methodologies involve reasonably simple calculations so that the baseline SEC calculation can be done easily from historical monthly statistical data of production and energy consumption collected from plants by the Bureau of Energy Efficiency (BEE).

Once the baseline SEC is fixed, the next challenge is fixing the SEC reduction targets. In industrial sectors wherein SEC targets have already been announced, BEE has followed the principle of having separate, individual targets for each Designated Consumer (DC). Considering the fact that industries may use different process routes, differing vintages of technologies and other location specific issues, especially those related to quality of feedstock and energy, the premise of having separate, individual targets for each designated consumer is in itself sound only if the basis for the SEC calculation and targeted reduction are technically justifiable.

In the Petrochemical sector, technology licensees may have declared the expected energy consumption at various levels of capacity utilization; however, some of the older plants may have gone through renovation, revamps and de-bottlenecking exercises that may make the original specifications irrelevant; revised values may not have been clearly documented. Modeling of processes for establishing the energy consumption for varying production throughputs and operating process parameters is a theoretical possibility, however, this requires huge amount of process design and operating data that are unlikely to be shared by plants, as technology licensors may treat it as proprietary information. Even if all information is accessed, ensuring validity of the model for all operating conditions, process variations and varying feedstock quality is extremely difficult; such models evolved by external agencies can be easily challenged by Designated Consumers and may generate controversy during PAT implementation.

The third issue is verification of achievement of SEC reduction targets at the end of the PAT cycle; while it may be relatively simple for “single product” plants, it can be extremely complicated for “multi-product plants with shared processes” and “multi-product, multi-plant petrochemical complexes with shared processes”. Most large petrochemical complexes have cogeneration plants that supply heat and power to various plants in the complex. Depending on the “*Heat to Power”* ratio of the cogeneration plant, allocation of energy in primary fuel input to Heat and Electrical Power may differ depending on whether calculation methods give primacy to heat or electrical power. In addition, part of the heat energy may be from separate fired equipment and part of the electricity may be from the grid or other captive sources; these issues will further complicate the assigning of energy values. Most of these plants also have large utilities like compressed air systems, refrigeration plants, cooling water systems etc. that may be centralized. In most large complexes, accounting and allocation of the entire energy consumption in central services to individual operating plants and accounting all inter-plant energy transfers within the complex by sub-metering may also be difficult and impractical. In some cases, the feedstock may also provide part of the energy through waste streams, which may lead to situation wherein the sum total of the energy consumption of all plants in the complex may be greater than the energy imports of the complex.

For achievement of SEC targets, large complexes should be provided the freedom to implement the energy saving schemes anywhere in the complex, may be in process plants, offsite utilities, centralized cogeneration plants etc. Methodologies are required to capture and verify the impact of these measures on the SEC; it may even call for “out of the box” definitions for SEC.

An added complication is that, in large complexes, some the plants may not operate continuously, may be due to issues related to feedstock quality and/or market demand. It is also likely that some products and/or operations may be discontinued due to market conditions or obsolescence of the products or process technologies. The objective of PAT is to finally achieve measurable reduction in SEC in any plant or large complex, with reference to net energy imports (usually fuels & electricity) into the plant or complex boundary.

Keeping in view these, a few SEC calculation methodologies have been proposed for both individual plants and large complexes. Most petrochemical plants and complexes may have internal methodologies for monitoring SEC; however, data collection for PAT would have to be done in a uniform manner to facilitate inter-plant comparisons and also possibly help evolve benchmarks; a common questionnaire has been developed to facilitate data collection from plants and large complexes (please refer Annexure 3) and calculation of SEC. The questionnaire has been tested using available data from some petrochemical plants; the data collected and the proposed methodologies for SEC calculations are discussed herewith.

Specific Energy Consumption in “Single Product” Individual Plants

Specific Energy Consumption (SEC) or energy consumption per unit production can be calculated relatively easily in “single product” petrochemical plants (not part of a large petrochemical complex). In plants with multiple products or a mix of intermediates and final products, SEC is difficult to calculate as sub-metering of energy and utilities is never complete at a micro-level; a combination of measurements, approximate allocations and assumptions are used in such plants for SEC calculations.

For “single product” or “single major product” individual plants, the SEC is the ratio of the net total energy consumption within the defined plant boundary divided by the production.

$$\boldsymbol{SEC} = \frac{(\boldsymbol{Energy\ Imports} - \boldsymbol{Energy\ Exports})}{\boldsymbol{Production}}$$

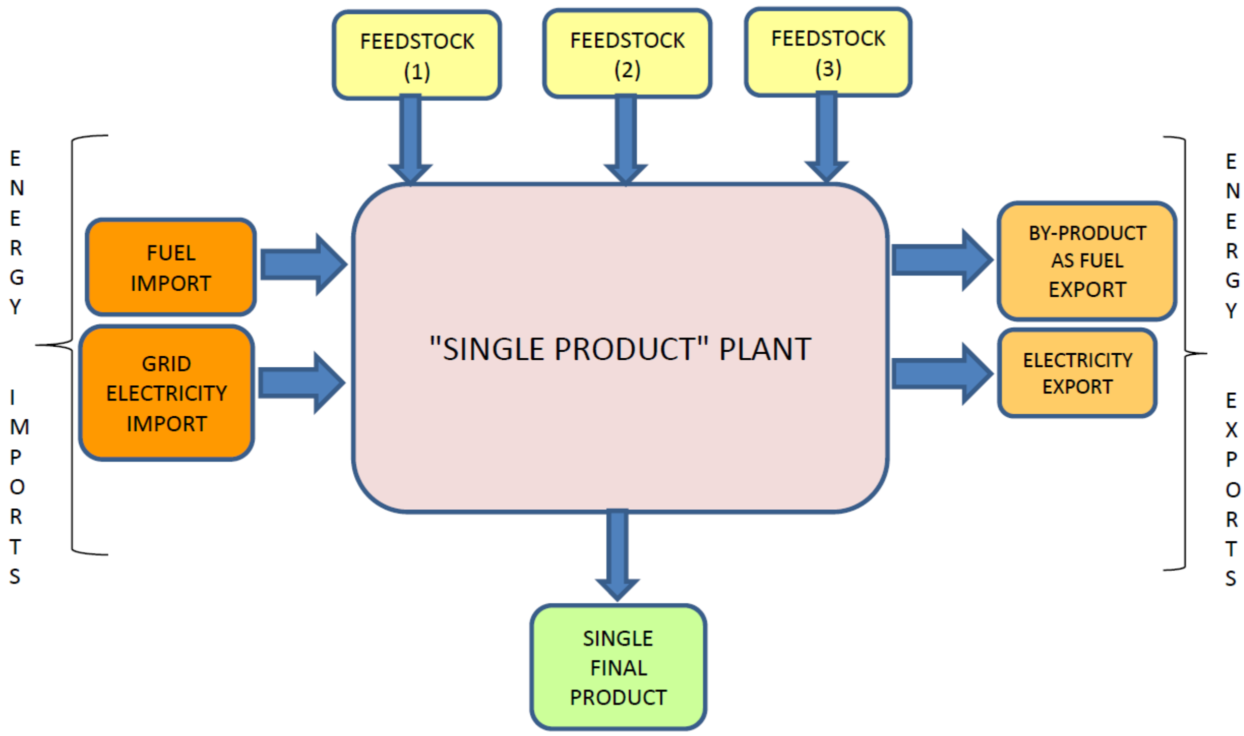

Figure 37: Energy & Mass Flow Chart for “Single Product” Individual Plant

The calculation of SEC in “Single Product” Individual Plants is easy as it only requires correct quantification of all energy imports & exports and production data.

- Energy imports include all fuels and electricity supplied from outside the plant boundary.
- Energy exports include all byproducts or waste products leaving the plant that are used as fuels or any utility like (steam, chilled water, brine, compressed air etc.) or electricity that is exported out of the plant boundary

The flow chart in Figure 37 shows the plant boundary and all imports and exports that are probable in a “Single Product” individual plant. Table 82 in Annexure 5 represents actual values of feedstock, production and energy consumption of a sample Linear Alkyl Benzene (LAB) plant, which falls in this category and the corresponding SEC.

Specific Energy Consumption in “Multi Product” Individual Plants

Two methods are suggested for “Multi Product” plants; **Error! Reference source not found.** shows the typical energy and mass flow diagrams.

Method 1: Correlation of Energy Consumption with the Major Product

For “multi product” plants with shared processes with a single major product and correlation ratios between major major and minor products is in an acceptable narrow band, the SEC may be calculated as the ratio of net energy consumption to the production of the major product.

$$SEC = \frac{(\textbf{\textit{Energy Imports to Plant}} - \textbf{\textit{Energy Exports from Plant}})}{\textbf{\textit{Production of Major Product}}}$$

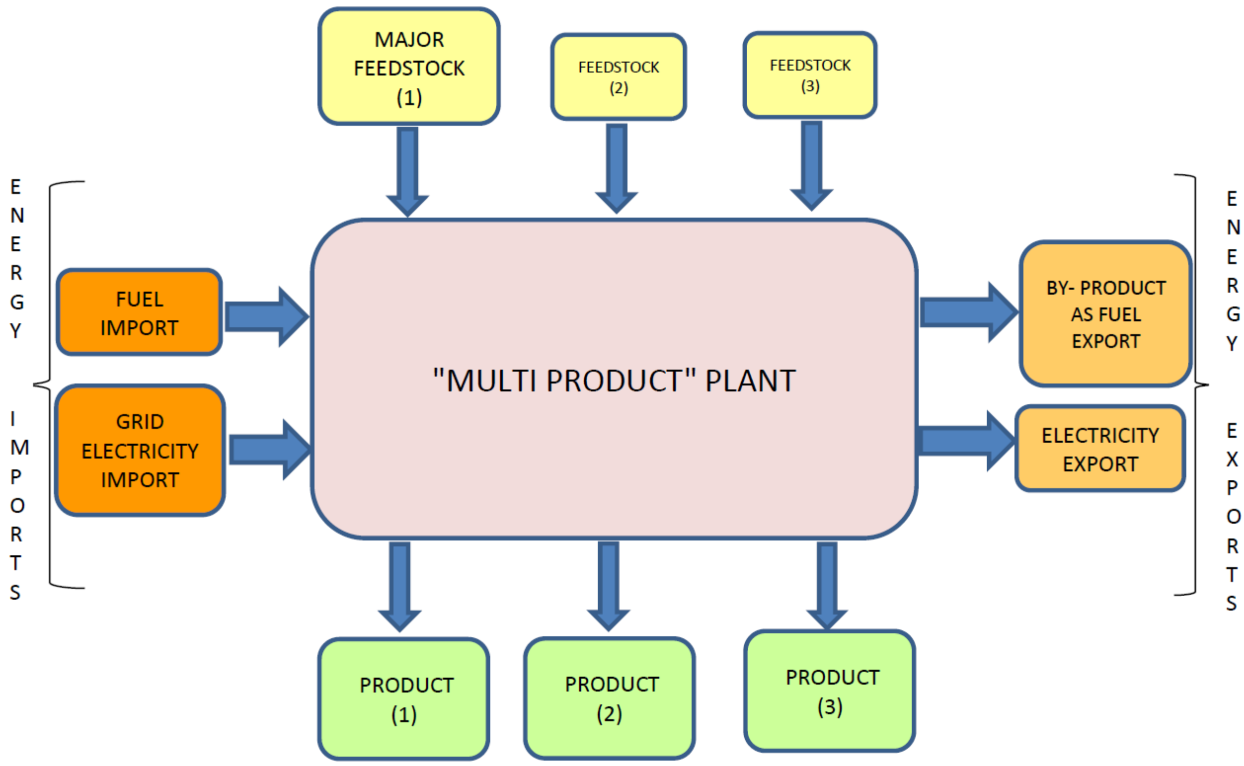

Figure 38: Energy & Mass Flow Chart for “Single Product” Individual Plant

Method 2: Correlation of Energy Consumption with the Major Feedstock

For "multi product" plants with shared processes and absence of a single major product, correlation of the major feedstock with energy consumption is a possibility; of course, this entails that "feedstock to product mix" correlation is understood in relation to the quality of the feedstock and has a correlation ratio that lies in a reasonably narrow range.

$$SEC = \frac{(\textit{Energy Imports to Plant} - \textit{Energy Exports from Plant})}{\textit{Major Feedstock Consumption}}$$

Specific Energy Consumption in "Multi Product, Multi Plant" Petrochemical Complexes

In Petrochemical complexes, the calculation of SEC gets very complicated due to shared processes, multiple intermediate and final products; additional complications arise due to exothermic reactions that often result in export of energy from one plant to another within the complex and, at times, export of energy from the complex to end users outside the complex. All energy exchanges may also be affected by variations in process variables, feedstock mix, quality of feedstock and mix of intermediate and final products. Most of the petrochemical plants and complexes have methods in place for energy accounting; however, these methods may not always be suitable for monitoring specific energy consumption for implementation of PAT scheme.

The interplay between plants in terms for flow of intermediate products, energy and utilities can get even more complicated as the number of plants and products increase; no generalized flow charts can be made, a specific flow chart has to be made for each petrochemical complex.

Method 1: Calculation of SEC Separately for Each Plant in the Complex

For "multi product, multi plant" industrial complexes, SECs for each individual plant can be calculated separately, provided reasonably accurate alloactions of inter-plant energy and utility transfers are available. Extreme care will have to be exercised in calculation of energy equivalent of utilities. SEC can be calculated as the ratio of energy consumption to production for individual plants within the complex after defining a thorough methodology of allocation of energy and utilities from outside the boundary limit of the plant under consideration.

$$SEC = \frac{(\textit{Energy Imports to Plant} - \textit{Energy Exports from Plant}) + (\textit{Utility Imports to Plant} - \textit{Utility Exports from Plant})}{\textit{Production}}$$

Petrochemical complexes, that do not have good sub-metering system to measure and quantify mass, heat and utility transfers between plants, may have to rely on approximate allocations that may lead to serious errors in SEC calculations at the plant level over a period of time.Secondly, plants may use different philosophies for allocation of energy values to electricity and steam generated in cogeneration plants; when part of the electricity is from the grid and the rest from the cogeneration plant, the absolute values of energy allocation to plants may involve complicated calculations. As energy optimisation and conservation opportunities also often lie in the centralised power plants, cogeneration plants and offsite utilities, it may not always be easy to capture the savings by monitoring of SECs of individual plants.

In such a situation the possibility of defining SEC as a ratio of the net energy consumption of the complex to the feedstock needs to be explored. A note of caution for this line of analysis is there may also be plants in the complex that are by the very nature of products are independent and have no relation to the major feedstock i.e. these “Unrelated Plants” do not use either the major feedstock nor any intermediates or byproducts produced from the major feedstock; if the energy and utility imports and exports from these *Unrelated Plants* are correctly accounted for, correlation of rest of consumption of the complex with major feedstock is a possibility.

Method 2: For the Complex as a Whole, Correlation of Energy Consumption with Feedstock

Alternatively, SEC can be calculated as the ratio of the net energy consumption of the entire complex to the major feedstock consumed; due reference has to be made to “feedstock to product mix” correlation.

$$SEC = \frac{\left(\begin{array}{l}\textit{Energy Imports to Complex} - \textit{Energy Exports from Complex} \\ \qquad - \textit{Energy Imports of Unrelated Plants in the Complex} + \textit{Energy Exports of Unrelated Plants}\end{array}\right)}{\textit{Major Feedstock Consumption}}$$

Please refer to Annexure 4 for the Sequence of data collection to arrive at SECs

Observations and Comments on SEC Calculation for Ethylene / Prpylene Complex

- Olefins Plant accounts for about 85% to 90% of the energy consumption of the complex. The cracker generates high pressure steam after the cracking process; fuel gas is also generated in the de-methaniser column, which is fed into the fuel gas header of the complex, mixing with purchased natural gas; this mixed fuel gas is used for combustion in the complex. This implies that a portion of the feedstock makes its way into the fuel stream. Due to this phenomenon, the sum total of fuel consumption in individual plants of the complex may be more than the fuel imported into the complex. Since the PAT scheme is essentially attempting to reduce the energy imports, defining SEC using feedstock as a substitute for production may be a worthwhile exercise.
- The trends of SEC vs. Olefins Production and SEC vs. Complex Feedstock Consumption shows striking resemblance; this probably implies that using feedstock as a substitute for production at the

complex level is a possibility for complexes that do not have many plants that are unrelated to the major feedstock of the complex.

- The annual average SECs for some petrochemical products from a petrochemcal complex in India are shown herewith:

Table 54: SECs for some petrochemical products from a sample petrochemcal complex

Product	SEC
Linear Alkyl Benzene (LAB)	5.052 million kcal/MT
Poly Vinyl Chloride (PVC)	1.566 million kcal/MT
Ethylene Oxide / Ethylene Glycol (EO/EG)	5.938 million kcal/MT
Low Density Polyethylene (LDPE)	2.819 million kcal/MT
Vinyl Chloride Monomer (VCM)	2.689 million kcal/MT
Polypropylene (PP)	2.368 million kcal/MT
Poly Butadiene Rubber (PBR)	3.850 million kcal/MT
Acrylo Nitrile (ACN)	1.352 million kcal/MT

The basis for calculation of these SEC values have not been disclosed due to confidentiality.

Method 3: Defining Plant Efficiency Efficiency Index as Ratio of Reaction Heat to Total Energy Consumed

It may be worthwhile attempting a methodology based on heat of formation of feeds and products, that can perhaps overcome the problems that may be faced in other methods due to variations in composition of feedstock and changes in production mix. This method is focusses on establishing the theoretical heat of reaction of the plant based on heat of formation of feeds and heat of formation of products. The heat of reaction (difference of sum total of heats of formation of products and sum total of heat of formation of feeds) of the plant/complex divided by the actual net energy imports (electricity, fuel, steam etc.) of the plant/complex; this ratio can be called the Energy Efficiency Index (EEI) for the PAT cycle.

For example, an Olefin cracker using ethane feed will have 80% ethylene yield, 1% propylene yield & 1% Butadiene yield as compared to when using Naphtha feed. With naphtha feed, the ethylene yield is about 30%, propylene about 15%, aromatics 15% and butadiene 5%.

Typically, with ethane feed, SEC is about 17-20 GJ/ton and, with Naphtha feed, SEC is about 25-30 GJ/ton. However, when naphtha feed feed is used, many other products like butadiene and aromatics are also formed in good quantities which may be profitable commercially; hence, he choice of feed and fuel is not only an energy efficiency issue; usually, it is availability of feedstock and market demand. Due to these reasons, comparisons of Olefin crackers based on different technologies, feeds or products are not very correct.

For example, consider a cracker complex with ethane feed and products i.e. ethylene, propylene & butadiene.

$$\boldsymbol{Heat\ of\ Formation\ of\ Feed = (Feedstock\ quantity)x\ (Heat\ of\ Formation\ of\ Ethane)}$$

$$\begin{aligned}\boldsymbol{Heat\ of\ Formation\ of\ Products}\\ &= \boldsymbol{(Ethylene\ quantity)x\ (Heat\ of\ Formation\ of\ Ethylene)}\\ &+ \boldsymbol{(Propylene\ quantity)x\ (Heat\ of\ Formation\ of\ Propylene)}\\ &+ \boldsymbol{(Butadiene\ quantity)x\ (Heat\ of\ Formation\ of\ Butadiene)}\end{aligned}$$

There are multiple feeds as in may cracker complexes i.e. some cracker furnaces may be on ethane feed and some others may be on propane feed or mixed feed; in that case, heat of formation of each feed multiplied by the quantity of each feed and summed up to get the total heat of formation of feed. The same method of calculation has to be follwed for all products and byproducts leaving the paln tor complex boundary.

$$\begin{aligned}\boldsymbol{Heat\ of\ Reaction\ of\ the\ Plant\ or\ Complex}\\ &= \boldsymbol{(Heat\ of\ Formation\ of\ Feed) - (Heat\ of\ Formation\ of\ Products)}\end{aligned}$$

This ***Heat of Reaction*** is the theoretical energy change required for production of various products from feed stocks. A positive *Heat of Reaction* implies endothermic reaction and negative *Heat of Reaction* implies exothermic reaction. Exothermic reactions may result in process waste heat utilisation in the plant or complex, export of energy out of the complex (as energy or material reosurce) or dissipation of waste heat to atmosphere.

We define here an ***Energy Efficiency Index*** is defined as as

$$\begin{aligned}\boldsymbol{Energy\ Efficiency\ Index\ of\ the\ Plant\ or\ Complex,}\\ \boldsymbol{EEI} &= \frac{\boldsymbol{(Heat\ of\ Reaction\ of\ Entire\ Plant\ or\ Complex\ )}}{\boldsymbol{Net\ Energy\ Import\ to\ Plant\ or\ Complex}}\end{aligned}$$

This approach can capture various combination of feeds & products and help establish a comparison of a theoretical value of heat of reaction & actual external energy consumed during the baseline of PAT cycle. Please note that this is not Specific Energy Consumption, but a ratio of the theoretical heat of reaction & actual energy supplied to effect the reactions in the complex.

This approach has some very useful advantages:

- BEE can easily determine the change in EEI for an Plant or Complex, even with feedstock and product mix changes.
- If Design energy consumption numbers are available, an “Design EEI” can also be established and the deviation of the actual EEI can be calculated.
- The same analyses can be done at the Plant level to compare the EEIs of different technologies for manufacture of same products.

Illustration of Calculation of EEI at a Plant Level

The following table shows the composition of the feedstock, mass flow, molecular weight, kg-mole flow and heat of formation.

Table 55: Heat of Formation of Feedstocks

Component	% weight	Mass flow kg/h	Molecular weight	Heat of formation ∆Hf kJ/ kg mol	Mole flow kg mol/h	Heat of formation kJ/h
Methane	0.3	245.3	16	-74890	15.330	-1148037
Ethane	64.8	46260.5	30	-83820	1542.017	-129251866
Propane	31.6	22562.7	44	-104680	512.788	-53678613
Butane	0.0	0.0	58	-125790	0.000	0
C_5's n H_{vr}	0.1	98.2	60	-146760	1.637	-240290
Acetylene	0.0	0.0	26	226730	0.000	0
Ethylene	0.2	127.1	28	52510	4.540	238417
Propylene	0.8	548.6	42	19710	13.061	257427
H_2	0.0	0.0	2	0	0.000	0
Other C_4	2.1	1517.2	58	-125790	26.159	-3290564
CO_2	0.0	0.0	44	-393510	0.000	0
TOTAL	100	71359.6				-187113525

The following table shows similar information on all the products of the reaction, including by-products.

Table 56: Heat of Formation of Products

Component	Mass Flow kg/h	Molecular weight	Heat of formation ∆Hf kJ/ kg mol	Mole flow kg mol/h	Heat of formation kJ/h
Methane	5884.825	16	-74890	367.80	-27544661
Ethane	14838.12	30	-83820	494.60	-41457705
Propane	4228.046	44	-104680	96.09	-10058905
Butane	0	58	-125790	0.00	0
C5's n Hvr	590.5022	60	-146760	9.84	-1444368
Acetylene	225.6582	26	226730	8.68	1967826
Ethylene	33996.44	28	52510	1214.16	63755469
Propylene	7574.218	42	19710	180.34	3554472
H2	1952.726	2	0	976.36	0
Other C4	201.2905	58	-125790	3.47	-436557
CO2	0	44	-393510	0.00	0
C3	157.7978	26	226730	6.07	1376057
Butadiene	974.8927	54	109240	18.05	1972172
Benzene	459.6138	78	82880	5.89	488369
C6	83.80549	86	-166920	0.97	-162661
Toluene	92.2738	92	50170	1.00	50319
C7	35.90198	100	-187800	0.36	-67424
C8	11.69379	114	-208950	0.10	-21433
C9-	51.79004	128	-228750	0.40	-92554
TOTAL	71359.6				-8121584

The Heat of Reaction is the difference of the sum total of the heats of formation of the products minus the sum total of the heat of formation all the components of the feedstock.

Heat of Reaction = (-8121584) – (-187113525) = 178991942 kJ

= 42.749 million kcal

Total Energy Consumption during the period = 302.098 million kcal

$$\boldsymbol{Energy\ Efficiency\ Index\ of\ the\ Plant\ or\ Complex,\qquad EEI\qquad = \frac{42.749}{302.098}\ x\ 100}$$

= 14.15%

Comments

- The EEI for a plant, calculated considering all feedstock and all products and by-products, when monitored on a month to month basis, can be an indicator of plant energy efficiency; higher EEIs indicate improved energy efficiency.
- The EEI can also be used to benchmark various technologies and compare technologies using similar feedstock and producing similar products.

Illustration of Calculation of EEI at a Multi Product Complex Level

At the complex level, the *Heat of Reaction* may be defined as the difference between sum of Heats of Formation of all final products and by-products leaving the complex boundary and that of the feedstock. The EEI is then defined as the ratio of total Heat of Reaction of the complex to the net energy import of the complex.

The following table shows the EEI calculated an Ethylene complex manufacturing Polyethylene and Polypropylene.

Table 57: Estimation of EEI

Particulars	Unit	March	April	May	June	July
Heat of Formation of Feedstock						
Liquid Natural Gas (Feedstock to Olefins Plant)	MT	18752	34694	31576	31726	37980
Heat of formation of Feed	kcal/MT	-628093	-628093	-628093	-628093	-628093
Heat of formation of Feed	Million kcal	-11778	-21791	-19833	-19927	-23855
Heat of Formation of Products						
Polyethylene	MT	9841	17285	19988	21872	23449
Heat of formation of Polyethylene	kcal/MT	-478000	-478000	-478000	-478000	-478000
Heat of formation of Polyethylene	Million kcal	-4704	-8262	-9554	-10455	-11208
Polypropylene	MT	4984	3428	5687	4984	4644
Heat of formation of	kcal/	-471000	-471000	-471000	-471000	-471000

Polyproylene	MT					
Heat of formation of Polypropylene	Million kcal	-2347	-1615	-2679	-2347	-2187
Calculation of Heat of Reaction & Energy Efficiency Index						
Total Useful Heat of Reaction of Complex	Million kcal	4727	11915	7600	7125	10459
Total Energy Consumption of the Complex	Million kcal	223177	220616	252682	223934	236626
Energy Efficiency Index	**%**	**2.118**	**5.401**	**3.008**	**3.182**	**4.420**

Observation and Comments

- The EEI for a complex can be used to monitor the energy efficiency of a whole complex, without getting into details of individual plant process.
- The complex level EEI will reflect improvements in efficiency when process waste heat from one plant is used in another plant within the complex.
- Impact on energy efficiency due to improved capacity utilization will also reflect in improved EEI.
- This method may also help obviate the complications arising due to changes in production mix over a period of time and also the real possibility of some of the plants in the complex shutting down due poor market demand or obsolescence of products / technology.

Method 4: Comparison of the Actual SEC with the Technology Lincensor design SEC

The quantum of deviation of the actual SEC for production from the SEC provided by the Technology Licensor can be an indicator the energy performance of the petrochemical plant.

Based upon the data available from Centre for Monitoring Indian Economy (CMIE) for the Production, Electricity and Fuel consumption by major petrochemical plants for each product produced, average energy Consumption and Production data was tabulated for 3 years 2008 to 2011. Similarly the Licensor's SEC data for as many products available through secondary research was tabulated. (Refer Annexure 6)

Comments:

- Data for the actual SEC and the technology and licensor details have to be made available by the industry
- During the life cycle of a plant, the processes are modified for various reasons and hence the deviation alone may not be the correct indicator

Benchmark and Threshold Limit

Guidelines for Inclusion of Plants / Complexes in PAT Scheme and Definition of Baseline SEC

The inclusion of petrochemical plants and classifying them as Designated Consumers can depend on the following issues:

- The contribution to national energy savings expected from the Petrochemical sector.
- Population of plants to be covered with a view point of accounting for at least 80% of the total energy consumption accounted for by the Petrochemcial sector.
- Possibility of focusing on only Petrochemical complexes with crackers manufacturing Ethylene and Propylene, as almost 60% to 70% of the total energy consumption of the sector is likely to be accounted for by these plants.
- Assessment of existing penetration of energy saving technologies in the sector.
- Broad alignment with definition of Designated Consumer in other industrial sectors. For large fuel consumers, BEE has fixed the cut-off baseline energy consumption as 30,000 MTOE; the same cut off can also apply to petrochemical plants.

The sector is characterized with a wide bandwidth of specific energy consumption (SEC) which is also indicative of the large energy-savings potential in the sector.

In particular, most new plants are amongst the most energy efficient. The wide bandwidth is a reflection of the differences in the energy-saving possibilities amongst plants because of their varying vintage, production capacity, raw material quality, product mix etc.

This also makes it difficult to specify a single benchmark SEC for the sector as a whole since it would either be impossible to achieve for the older plant if set at the level of a newer plant, or would be trivial if set at the level of the older plant.

Under the current PAT scheme Designated Consumers (DCs) from the eight energy intensive sectors have been included. The DCs account for 25% of the national gross domestic product (GDP) and about 45% of commercial energy use in India. The genesis of the PAT mechanism flows out of the provision of the Energy Conservation Act, 2001, hereinafter referred to as the Act. Section 14 (e) of the Act empowers the Central Government to notify energy intensive industries, as listed out in the Schedule to the Act, as DCs. The Ministry of Power (MoP) has notified industrial units and other establishments consuming energy more than the threshold in 9 industrial sectors namely Thermal Power Plants, Fertilizer, Cement, Pulp and Paper, Textiles, Chlor-Alkali, Iron & Steel, Aluminum and Railways in March, 2007. The industries of a sector are required to submit their energy consumption every year through a mandatory reporting system which would enable the MoP to decide on DC status. The Ministry of Power's notification issued on 2nd March 2007 under section 14 (e) of the Act is summarized hereunder:

Table 58: Threshold Energy Consumption of Sector under PAT

Sector	Threshold Energy Consumption (tonnes of oil eq.)
Aluminium	7500
Cement	30000
Chlor-Alkali	12000
Fertilizer	30000
Iron and Steel	30000
Pulp and Paper	30000
Textiles	3000
Thermal Power Plants	30000

There is no definitive and accessible rationale behind the MoP's criteria of arriving at the threshold limits for individual sectors.

We have analyzed the available secondary data of energy consumption for select industries in the petrochemical sector. The key aspects coming out of our analysis are:

- 43% of the petrochemical sector accounts for over 90% of the energy consumed
- Threshold value of 30000 tonnes of oil equivalent represents 35% of the petrochemical sector accounting for over 85% of energy consumed
- Threshold value of 12000 tonnes of oil equivalent represents 54% of the petrochemical sector accounting for over 95% of energy consumed
- Threshold value of 7500 tonnes of oil equivalent represents 62% of the petrochemical sector accounting for over 98% of energy consumed
- Threshold value of 3000 tonnes of oil equivalent shall represent 73% of the petrochemical sector accounting for over 99% of energy consumed

The graph below provides the synopsis of this analysis. Based on the secondary data used the threshold value of 30000 tonnes of oil equivalent is a good representation of the petrochemical sector in terms of energy usage, however it scores low on the sector representation as such. The threshold level of 12000 tonnes of oil equivalent seems to be a more reasonable representative of the sector.

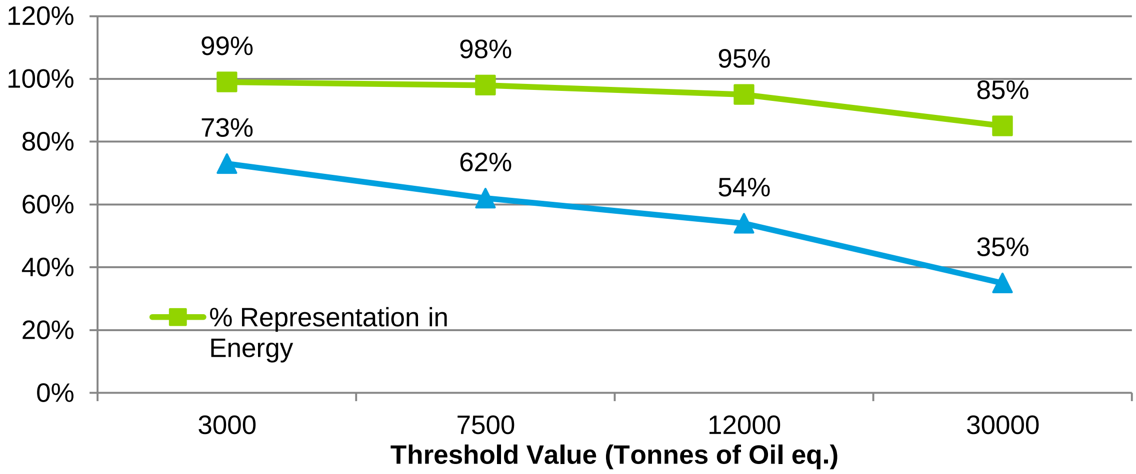

Figure 39: Energy & Mass Flow Chart for "Single Product" Individual Plant

The above approach applied on the actual data received from plants will assist in arriving at a more practical threshold level for the sector. However based on the current available secondary data a threshold level of 12000 tonnes of oil equivalent seems reasonable.

The second method as described above is more reasonable, considering the fact that it is not based on assumptions and it uses the threshold levels used under PAT phase I to analyse the assimilated secondary data for the petrochemical sector for representation in terms of energy and number of units for the sector.

Using the average energy reduction target of 4.2% under PAT phase I the energy reduction potential of the petrochemical sector is estimated to be 0.05 million tons of oil equivalent. This value is estimated on the basis on secondary data of the petrochemical sector and may vary if actual data received from the industry is used for analysis.

Guidelines for Baseline SEC Reduction Target Setting under PAT Scheme

Some of the *Energy Benchmarking* methods followed in the Petrochemical Sector and in the industry in general has been already reviewed. Product-wise energy benchmarking methods, though useful as a guideline, cannot be applied directly for determining the potential for reduction in SEC in petrochemical plants due to differing technologies, differing feedstock quality, varying plant complexities, differences in determining energy values foroff-site utilities, differences in allocation of energy values for heat & power from cogeneration plants and a host of other location specific issues.

The potential for reduction from baseline SEC for a plant or a complex would have to determined keeping in view the following issues:

- The design energy consumption, declared by technology licensor, for the vintage of technology used. Revised values would have to be used in case process revamps or modernisaton has taken place. Scope for further revamp and modernisation to reduce SEC.
- Variations in feedstock from the feedstock defined in design document.
- Extent of exploitation of cogeneration potential.
- Extent of process heat integration done and understanding available waste energy streams.
- Potential for improvement in capacity utilisation.
- Variation in monthly SEC for a period of 36 months; understanding potential for energy saving by replication of performance of “low SEC” months i.e. months having SEC below the weighted mean SEC.
- Potential for reduction in energy consumption determined by previous energy audits.
- Potential for reduction in energy consumption determined by a PAT-specific energy audit, similar to the PAT Baseline audit conducted by BEE for Designated Consumers already under the PAT scheme.
- Constraints in implementation of energy saving measures from the viewpoint of age of existing plant and machinery, likely obsolesence of the products & processes, structural requirements for retrofits, required plant shutdown duration for implementation of energy saving measures, impact on plant safety (especially while attempting modofications on aged equipment) etc. should also be factored in to make realistic projections of SEC reduction targets in the 3-year PAT cycle.

A SEC reduction in the range 5% to 6%, over a 3-year PAT cycle, may be a reasonable target.

Summary of Stakeholder Deliberations on proposed methodology and Way Ahead

A half day consultation workshop was convened by Deloitte on the 9th April 2013 at India Habitat Centre Lodhi Road, New Delhi wherein the findings of the study were presented. The workshop was attended by leading experts in the field of industrial energy in general and petrochemical sector in particular and had delegates from petrochemical industry, petrochemical energy efficiency consultants, industrial energy association and petrochemical process technologists.

The dignitaries were welcomed by Shashank Jain, Sr. Programme Officer (Industry) of Shakti Foundation and bequeathed introductory remarks on the study conducted by Deloitte team. Dr.Pradeep Dadhich, Director, Deloitte Touche Tohmatsu India Pvt Ltd., instigated the technical discussion session by a presenting the approach followed for conducting the study and the selection of petrochemical products. The Overview of the Indian Petrochemical Industry was presented with Petrochemicals value chain and the trends in the Indian petrochemical sector. The projected demand for the petrochemicals (i.e. the Building blocks, Commodity Plastics, Synthetic Rubber, Surfactants, Synthetic Fibres, Fibre Intermediates, Solvents and Intermediates) and the production capacity analysis was presented to the attendees. The Demand and Supply situation in India was put forward to build up the rational for product selection. The Product selection methodology based on the production data published in 'Annual Report of Ministry of Chemicals and Fertilizers' for the year 2009-10, production share of each product in that category and production growth rate calculations were briefly explained. The company and plant selection methodology was also briefly explained and the secondary data of products, capacity and technology was shared with the attendees.

The experts acknowledged the relevance of the approach in context of the complexity and variability of Petrochemical sector. The experts mulled over the philosophy for selection the petrochemicals and concluded that the petrochemical industry is covered in totality.

The Deloitte team further presented the key findings of the study and a conclusive analysis to determine the threshold limits and cut offs to identify Designated Consumers. The following two methodologies for arriving at the threshold level were discussed in detail:

- Using the average energy reduction value of 4.2% as estimated under phase I of PAT.

- Using the threshold levels applied under PAT phase I, comparing with the current sectors having similar energy consumption levels one of the threshold values of 30000, 12000 & 7500 MTOE deem fit.

The attendees concurred that the threshold level of 12000 MTOE seems to be a reasonable representative of the sector and both the methodologies were conceptually agreed and accepted by experts as a logical continuance of BEE’s philosophy to set threshold and identify DCs under PAT.

A brief presentation on the global benchmarking practices with the pros and cons of each method was also presented concluding with identifying the two most relevant methods for establishing baseline for petrochemical sector i.e. the Statistical approach and the Energy Intensity method. The advantages and challenges to success of each method were brainstormed by the participants in minute details. Both of the methods were found by attendees to be equally utilitarian, each one with its key advantages over other. Whereas the statistical method delves upon the micro identification and accounting of each variable (e.g. capacity utilization, feed stock, vintage, etc.) affecting energy consumption, the Energy Intensity is a macro level approach based on heat of formation which is readily available in most of the cases. The experts felt that a broader industry and regulatory involvement is required to select the best of two methodologies. The Bureau of Energy Efficiency (BEE)’s involvement and sharing of the learning from PAT phase 1 would also provide indicators for selection of most suitable approach. Also Industry consensus on the data collection and reporting is required to be sought prior to proceeding with methodology for benchmarking is established.

One of the experts expressed that instead of having gate to gate approach adopted in PAT Phase 1, a project based savings achieved approach backed by an International protocol like IPMVP (International Performance Management and Verification Protocol) could be adopted that is uniform to all plants and the savings are actual and exact. However, other argued that this would result in a paradigm shift in the PAT framework.

The workshop has provided valuable insights from the industry and process experts. We believe that the confidence and conceptual agreement by the experts to the proposed methodologies and the conclusions from the secondary research will form the basis for BEE to establish baseline for the PAT phase II.

Annexure 1 – Global Petrochemical Industry

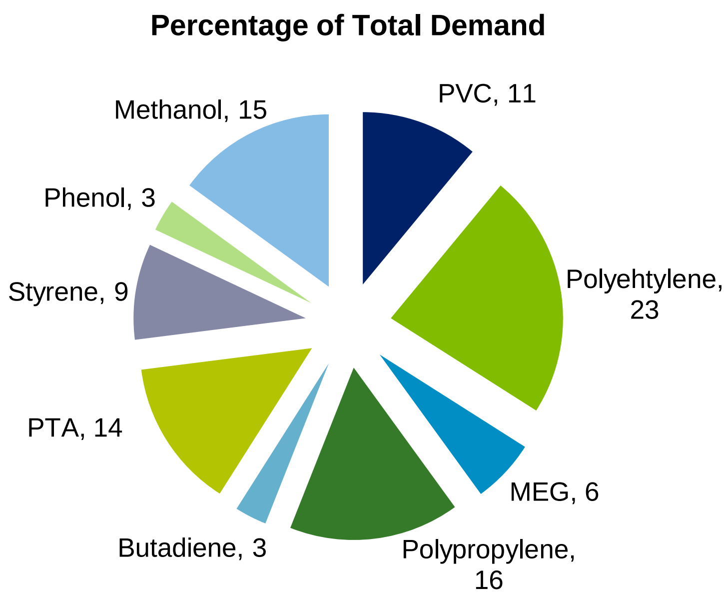

Figure 40: Product-wise Demand Portfolio

Table 59: Top Ethylene Producing Companies in the World

Company	Capacity (MTA)
SABIC	13.39
Dow Chemical	13.04
Exxon Mobil Chemical	12.51
Royal Dutch Shell	9.36
Sinopec	7.57
Total AS	5.93
Chevron Phillips Chemical	5.60
LyondellBasell	5.2

National Petrochemical Company	4.73
Ineos	4.65

Table 60: Major Planned Ethylene Capacity Additions for 2011-13

Company	Location	2011	2012	2013
		MTA	MTA	MTA
Total/Sonatrach	Arzew, Algeria		1.1	
Daqing Petroleum	Heilongiang		0.6	
Sinopec	Guandong	0.32		
OPAL	Dahej		1.1	
Qatar Petroleum/Exxon Mobil	Ras Laffan		1.6	
Saudi Polymers	Al-Jubail	1.2		
Exxon Mobil Chemical Corp.		1		
CPC Corp.	Taiwan	1		0.6
Abu Dhabi Polymers	Abu Dhabi			1.5
Pequive	Venezuela		1.05	
Polimerica	Venezuela	1.3		
Polinter	Venezuela		1	
TOTAL		**4.82**	**6.45**	**2.1**

Annexure 2 – Indian Petrochemical Industry

Table 61: Product-wise installed capacity & production of major petrochemicals (Source: Annual report 2010-11, Ministry of Chemicals & Fertilizers, Govt. of India) (Figures in 000' MT, %)

\	Installed capacity			Production								Growth in production (%)		Cap. Utilization in 10-11 (%)
	2008-09	2009-10	2010-11	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	CAGR (2003-04 to 10-11)	Y-o-Y growth (from 2009-10 to 10-11)	Col. 12/Col.4
I. Synthetic fibres/ yarn														
1.Polyester filament yarn (PFY)	1848	1899	1730	1003	970	1015	1194	1350	1262	1345	1496	5.88	11%	86%
2.Nylon filament yarn (NFY)	36	36	36	31	37	40	32	28	28	30	33	0.92	10%	92%
3.Nylon Industrial yarn	77	77	77	56	48	55	72	84	69	88	86	6.36	-2%	112%

(NIY)													
4.Polypropylene filament yarn (PPFY)	16	15	12	15	11	9	10	10	9	9	6	-12.55	-33%	50%
Sub total yarn (1+2+3+4)	**1977**	**2027**	**1855**	**1105**	**1066**	**1119**	**1307**	**1471**	**1368**	**1472**	**1621**	**5.62**	**10%**	**87%**
5.Acrylic fibre (Inc. dry spun) (AF)	143	143	95	117	128	114	107	85	78	91	76	-5.99	-16%	80%
6.Polyester staple fibre (PSF)	1266	1266	1266	604	639	623	785	919	843	980	1036	8.02	6%	82%
7. Polypropylene staple fibre (PPSF)	8	8	8	3	3	3	4	3	3	3	4	5.39	33%	50%
8. Polyester staple fibrefil (PSFF)	67	67	67	39	40	47	47	45	51	54	53	4.54	-2%	79%
Total synthetic fibre/ yarn	**3461**	**3511**	**3291**	**1868**	**1875**	**1906**	**2250**	**2524**	**2343**	**2601**	**2790**	**5.9**	**7%**	**85%**
II. Polymers														
1.Linear low density polyethylene (LLDPE)	Not separate cap.			606	650	689	772	837	817	683	897	5.76	31%	-
2.High density polyethylene(HDPE)	Not separate cap.			958	1035	1035	958	974	942	856	887	-1.1	4%	-
LLDPE/HDPE (combined)	**1865**	**2085**	**2735**	**1564**	**1685**	**1723**	**1730**	**1811**	**1758**	**1539**	**1784**	**1.89**	**16%**	**65%**
3.Low density polyethylene (LDPE)	200	200	160	184	205	201	195	198	191	193	179	-0.38	-7%	112%

4.Polyestyrene (PS)	462	462	462	274	275	311	285	274	240	270	296	1.11	10%	64%
5. Polypropylene (PP)	2035	2076	2076	1567	1690	1541	2001	1978	1771	1617	1684	1.03	4%	81%
6. Poly Vinyl Chloride (PVC)	1105	1279	1279	878	885	953	926	998	1051	1110	1278	5.5	15%	100%
7. Expandable polystyrene (EX-PS)	53	68	94	31	36	39	46	44	49	63	71	12.35	13%	76%
Total Polymers	**5720**	**6170**	**6806**	**4499**	**4776**	**4768**	**5183**	**5304**	**5060**	**4791**	**5292**	**2.35**	**10%**	**78%**
III. Elastomers														
1.Styrene butadiene rubber (SBR)	62	62	62	19	16	15	13	17	13	19	12	-6.27	-37%	19%
2. Poly butadiene rubber (PBR)	74	74	74	56	64	67	72	74	72	73	76	4.53	4%	103%
3. Nitrile butadiene rubber (NBR)	27	27	25	7	9	9	10	13	11	13	6	-2.78	-54%	24%
4. Ethyl propylene dimers (EPDM)	10	10	10	5	4	4	4	1	0	0	0	0	-	0%
5. Ethyl vinyl acetate (EVA)	13	13	13	0	4	14	3	0	0	0	0	0	-	0%
Total Elastomers	**186**	**186**	**184**	**87**	**97**	**110**	**101**	**106**	**96**	**106**	**94**	**1.05**	**-11%**	**51%**
IV. Synthetic detergent intermediates														
1.Linear alkyl benzene (LAB)	472	497	497	382	409	468	460	471	434	464	475	3.16	2%	96%

2.Ethylene oxide (EO)	120	140	84	71	79	88	96	114	117	154	164	12.61	6%	195%
Total synthetic detergent intermediates	**592**	**637**	**581**	**453**	**488**	**555**	**556**	**585**	**552**	**618**	**639**	**5.02**	**3%**	**110%**
V. Performance Plastics														
1.ABS resin	86	86	107	48	62	76	74	78	68	84	90	9.26	7%	84%
2.Nylon-6 & Nylon-66	16	16	16	11	13	13	15	14	12	13	16	5.27	23%	100%
3.Polymethyl methacrylate (PMMA)	4	4	4	3	2	2	3	3	2	3	3	1.75	0%	75%
4.Styrene acrylonitrile (SAN)	96	96	96	37	36	36	41	61	58	72	83	12.23	15%	86%
Total performance plastics	**202**	**202**	**223**	**99**	**113**	**127**	**133**	**157**	**141**	**172**	**192**	**9.98**	**12%**	**86%**
Total major petrochemicals (I+II+III+IV+V)	**10222**	**10706**	**11085**	**7007**	**7349**	**7467**	**8224**	**8674**	**8193**	**8287**	**9007**	**3.65**	**9%**	**81%**
B. Intermediates														
1.Fibre intermediates														
1.Acrylonitrile (ACN’)	41	41	41	36	39	33	37	39	30	39	38	0.62	-3%	93%
2.Caprolactum	120	120	120	110	122	117	121	86	84	123	123	1.57	0%	103%
3.Dimethyl terephthalate (DMT)	300	300	300	217	239	197	28	4	0	0	0	0	-	0%

4.Mono ethylene glycol (MEG)	820	820	1040	652	714	881	872	923	783	738	746	1.94	1%	72%
5.Purified terephthalic acid (PTA)	3073	3873	2718	1676	1738	1734	2379	2059	2154	2985	3191	9.64	7%	117%
Total fibre intermediates	**4354**	**5154**	**4219**	**2691**	**2851**	**2963**	**3437**	**3111**	**3052**	**3886**	**4098**	**6.19**	**5%**	**97%**
II.Building blocks														
Olefins														
1.Ethylene	2841	3021	3840	2421	2645	2719	2683	2810	2639	2515	2665	1.38	6%	69%
2.Proylene	2270	2387	2387	1746	1892	1745	2089	2157	1887	1859	1930	1.44	4%	81%
3.Butadiene	276	295	295	114	131	207	223	244	214	205	242	11.34	18%	82%
Total olefins	**5387**	**5703**	**6522**	**4282**	**4668**	**4671**	**4995**	**5211**	**4740**	**4580**	**4837**	**1.76**	**6%**	**74%**
Aromatics														
1.Benzene	1111	1158	1149	608	640	686	886	867	880	823	945	6.5	15%	82%
2.Toulene	281	281	281	166	177	159	147	142	139	137	128	-3.61	-7%	46%
3.Mixed xylene	165	165	165	56	63	56	58	74	78	55	44	-3.28	-20%	27%
4.Ortho-xylene	474	474	420	207	146	242	431	269	224	358	400	9.9	12%	95%
5.paraxylene	2296	2296	2296	1389	1425	1394	1925	2137	2155	2223	2137	6.35	-4%	93%
Total aromatics	**4327**	**4374**	**4311**	**2425**	**2451**	**2537**	**3447**	**3488**	**3475**	**3595**	**3654**	**6.03**	**2%**	**85%**

(i) Includes capacity of all the units producing PFY, NFY, NIY and PPFY under broadbanding as Synthetic Filament Yarn

(ii) Independent capacity of units producing only NFY, NIY and PPFY

As the capacities of these products are also included in Synthetic Filament yarn, capacity utilization cannot be worked out.

(iii) Combined capacity to produce both LLDPE and HDPE and hence capacity utilisation can not be worked out. However production is independent.

Table 62: Product-wise Demand-Supply Actuals and Projections

(All Figs in KTs)		Consumption		Consumption Growth (%)		Capacity		Gap		Planned Capacity addition	Capacity Addition (%)
		Actual	**Projected**	**During**	**During**	**Actual**	**Projected**	**Actual**	**Projected**	**Projected**	**Projected**
Group	**Product**	**2011-12**	**2016-17**	**2006-07 to 2011-12**	**2011-12 to 2016-17**	**2011-12**	**2016-17**	**2011-12**	**2016-17**	**2011-12 to 16/17**	**2011-12 to 16/17**
		11th Plan	12th Plan	11th Plan	12th Plan	11th Plan	12th Plan	11th Plan	12th Plan	12th plan	12th plan
Building Blocks	Butadiene	124	470	2.8	30.5	295	528	171	58	233	79%
	Ethylene	3785	6805	7	12.4	3867	7087	82	**282**	3220	83%
	Propylene	3700	4823	11.7	5.4	4117	4987	417	164	870	21%
	Styrene	496	647	4.1	5.5	0	0	-496	-647	0	No plans
	Benzene	595	935	3.1	9.5	1235	2110	640	1175	875	71%
	Toulene	440	650	9.3	8.1	270	270	-170	-380	0	0%
	Mixed Xylenes	88	130	15.5	8	90	90	2	-40	0	0%

	O-Xylenes	266	379	1.5	7.4	420	420	154	41	0	0%
	Total	**9494**	**14839**			**10294**	**15492**	**800**	**653**	**5198**	**50%**
Polymers	LDPE	405	597	9.9	8.1	205	605	-200	8	400	195%
	LLDPE	1198	2076	13.7	11.6	835	1960	-363	-116	1125	135%
	HDPE	1657	2573	10.9	9.2	1825	3090	168	517	1265	69%
	PP	2993	5015	14.4	10.9	4140	4715	1147	-300	575	14%
	PVC	1925	3102	9.6	10	1330	1635	-595	-1467	305	23%
	PS	377	638	8.9	11.1	640	666	263	28	26	4%
	Total	**8555**	**14001**			**8975**	**12671**	**420**	**-1330**	**3696**	**41%**
Synthetic Rubbers	PBR	131	193	10.4	8.1	74	164	-57	-29	90	122%
	SBR	186	275	13.6	8.2	20	370	-166	95	350	1750%
	NBR	31	47	5.3	8.7	20	40	-11	-7	20	100%
	Butyl	87	127	11.3	7.9	0	100	-87	-27	100	Entire capacity addition planned during 12th plan

	EPDM	27	79	11	24	10	90	-17	11	80	800%
	Total	**462**	**721**			**124**	**764**	**-338**	**43**	**640**	**516%**
Surfactants	LAB	483	627	7.8	5.4	530	530	47	-97	0	0%
	EO	165	241	11.9	7.9	209	254	44	13	45	22%
	Total	**648**	**868**			**739**	**784**	**91**	**-84**	**45**	6%
Fibre intermediates	PX	2306	4576	7	14.7	2477	5201	171	624	2724	110%
	PTA	4350	7992	8.1	12.9	3850	7130	-500	-862	3280	85%
	MEG	1836	3024	13.7	10.5	1300	3024	-536	0	1724	133%
	PET	542	1319	25.5	19.5	814	2310	272	991	1496	184%
	ACN-	125	181	0.8	7.6	40	40	-85	-141	0	0%
	Total	**9034**	**16911**			**8441**	**17664**	**-592**	**753**	**9223**	**109%**
Synthetic Fibres	PSF	1100	1600	6.8	7.8	1400	2000	300	400	600	43%
	PFY	2100	3500	10.6	10.8	3000	5216	900	1716	2216	74%
	NFY	56	71	11.8	4.9	32	32	-24	-39	0	0%
	NIY	113	125	2.9	2	74	74	-39	-51	0	0%
	PIY	36	68	-	13.6	21	68	-15	0	47	224%

Total	**3405**	**5364**				**4527**	**7390**	**1122**	**2026**	**2863**	**63%**	

Indicate double digit growth in consumption

Indicate no capacity addition plans

Deficit

More than 50% incremental capacity addition plans

Table 63: Major players in the Petrochemical sector in India

Product/ Facility	Major Players
Crackers	
Gas based	GAIL, RIL (Nagothane, Dahej and Hazira)
Naphtha based	RIL (Patalganga, Vadodara, Hazira), HPL, IOCL
Olefins	
Propylene	BPCL, CPCL, HPCL, Hindustan Organic Chemicals Ltd.
Butadiene	RIL (Hazira, Vadodara), HPL
Aromatics	
Benzene	Major producers (excluding steel plants) are RIL, IOCL, BPCL, KRL and HPL
Toulene	BPCL, KRL, IOCL, RIL
P-Xylene and O-Xylene	RIL, IOCL
Fibre intermediates	
PTA	RIL, IOCL, Mitsubishi Chemical Corporation
MEG	RIL, IOCL, India Glycols Ltd.(IGL)
Caprolactum	GSFC, FACT
Synthetic Fibre/Yarn	
Polyester Chips/Yarn/Fibre	Major players are RIL, Indorama, SAPL, JBF Industries Ltd., Jindal Poly Films Ltd., Ester industries Ltd., IOCL, Nakoda Ltd., Garden Silk Mills Ltd., Chiripal Industries Ltd., Sumeet Textile Mills Ltd., Polyplex Corporation Ltd., Sanghi Polyesters Ltd., Futura Polyesters Ltd.
Nylon chips/Yarn/Fibre	JCT Ltd., SRF Ltd., Century Enka Ltd., GSFC
Acrylic Fibre	Indian Acrylics Ltd., Vardhaman Acrylics Ltd.
Polymers	
PE, PP, PVC	The major polymers players in India are Reliance Industries Ltd. (RIL), Haldia Petrochemicals Ltd (HPL), GAIL (India) Ltd., and Indian Oil Corporation Ltd (IOCL). RIL produces

	all forms of polymers namely Polyethylene (PE), Polypropylene (PP) and Poly vinyl chloride (PVC). HPL produces PE & PP but don't produce PVC. IOCL produces PP, PE at Panipat refinery at Panipat whereas GAIL only produce PE at Pata. Other players PVC segment are DCW, Chemplast Sanmar, Finolex Industries Ltd., DSCL, sanghi Polymers Ltd.
Polystyrene	Supreme PC, BASF and LGP are the three producers in India
Elastomers	
PBR	RIL is the sole producer
SBR	Apcotex Lattices Ltd is the sole producer
Detergent intermediates	
LAB	Major producers are RIL, TPL, Nirma and IOCL
EO	RIL and IGL
Performance Plastics	
ABS/SAN	Major producers are INEOS ABS and Bhansali Polymers

Post-acquisition of IPCL, RIL has obtained majority of the market share of total polymers market in India

Annexure 3 – Questionnaire

A detailed questionnaire has been developed to elicit this information. It is envisaged that the information provided in the questionnaire, after verification and ratification, can be subjected to statistical analyses that will help evolve a statistical model for each petrochemical plant; this model can then be used to set Specific Energy Consumption targets within constraints imposed by technology, feedstock and other process specific issues.

BUREAU OF ENERGY EFFICIENCY, GOVT. OF INDIA

BASELINE ENERGY CONSUMPTION FOR PETROCHEMICAL PLANTS

Questionnaire for Collection of Data from Petrochemical Plants

CONTENTS

The questionaire is in MS-excel format and is provided as soft copy and snapshots are provided herewith.

INTRODUCTORY NOTES

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1 The objective of this questionaire is to calculate the energy baseline for each plant within the petrochemical complex.

2 Explanatory notes are provided along with each sheet to explain terminologies.

3 Kindly please ensure accuracy of information provided.

4 All information provided will be kept confidential and be used only for calculation of energy baseline of your plant.

GENERAL INFORMATION

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Name of Petrochemical Complex:		
Location (City/Town/District):		
Postal Address:		
Telephone no.:		
Fax no.:		
Email id:		
Details of Contact Person:		
Name		
Designation:		
Official email id:		
Direct Telephone nos. / Extension nos.		
Mobile Phone no.:		
Fax nos.:		
Details of Designated Energy Manager:		
Name		
Designation:		
Official email id:		
Direct Phone no. / Extension nos.		
Mobile Phone no.:		
Fax nos.:		
List of Major Products		**Technology Licensees**
1		
2		
3		
4		
5		
6		
List of Major By-products		
1		
2		
3		
4		
5		
6		
List of Major Plants within the Complex		
	Plant	**Year of Commissioning**
A		
B		
C		
D		
E		
F		
List of Major of Feedstocks		**Source of Supply**
1		
2		
3		
4		
5		
6		
List of Major Energy Sources		**Source of Supply**
1		
2		
3		
4		
5		
6		
Do you purchase electricity from grid?		Yes/No
Do you have captive power plant?		Yes/No
Do you have cogeneration plant?		Yes/No

ENERGY INPUT TO THE PETROCHEMICAL COMPLEX

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Notes:

"MTA" is Metric Tons per annum
"MWh" is" kWh/1000". Please report numbers up to three decimal places
"GCV" is Gross Calorific Value of fuel or Higher Heating Value (HHV)
"LCV" is Lower Calorific Value of fuel or Lower Heating Value (LHV)
Add more rows to accommodate more fuels or any other details
Ensure that the measurment units are correct. In case the measurements units used by you are different, you may use those units; however please mention the units being used, by changing the default units mentioned in this sheet.
"MWh" for thermal utilties is the electricity consumption for auxiliaries likecirculation pumps, combustion fans etc.
Thermic fluid implies secondary heating media like Hytherm, Dowtherm etc.

	Unit	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12
Captive Power Plant (Only Electricity Generation without Cogeneration)												
Electricity Generation in Captive Power Plant	MWh per annum											
Fuel type A												
Type (Name of fuel)												
Quantity	MTA											
Calorific value (specify whether it is GCV or LCV)	kcal/kg											
Fuel type B												
Type (Name of fuel)												
Quantity	MTA											
Calorific value (specify whether it is GCV or LCV)	kcal/kg											
Cogeneration Plant												
Electricity Generation in Cogeneration Plant	MWh per annum											
Steam Generation in Cogeneration System												
Steam Generation	MTA											
Steam Pressure	kg/cm^2g											
Steam Temperature	°C											
Condensate quanity recovered	MTA											
Average temperature of returned condensate	°C											
Hot Water Generation from Cogeneration System												
Hot Water Generation	MTA											
Hot Water Pressure	kg/cm^2g											
Hot Water Supply Temperature	°C											
Fuel type A												
Type (Name of fuel)												
Quantity	MTA											
Calorific value (specify whether GCV or LCV)	kcal/kg											
Fuel type B												
Type (Name of fuel)												
Quantity	MTA											
Calorific value (specify whether GCV or LCV)	kcal/kg											
Fuel type C												
Type (Name of fuel)												
Quantity	MTA											
Calorific value (specify whether GCV or LCV)	kcal/kg											
Fuel type D												
Type (Name of fuel)												
Quantity	MTA											

	Unit	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12
Electricity Purchased from Grid												
Purchased Electricity from Grid	MWh per annum											
Steam Generated independently in Offsites Boilers												
Fuel Type (name)												
Fuel consumption	MTA											
Steam Generated in Offsites Boiler	MTA											
Steam Pressure	kg/cm^2g											
Steam Temperature	°C											
Enthalpy of steam	kcal/kg											
Equivalent energy	Million kcal per annum											
Hot Water Generated independently in Offsites Hot Water Generators												
Fuel type (name)												
Calorific Value ofFfuel	**kcal/kg**											
Fuel consumption	MTA											
Totalised Hot Water Generation	MTA											
Hot Water Pressure	kg/cm^2g											
Hot Water Temperature	°C											
Electrical energy consumption for hot water system	MWh per annum											
Thermic Fluid Heatesr in Offsites												
Fuel type (name)												
Calorific Value of fuel	kcal/kg											
Fuel consumption	MTA											
Type of Thermic fluid (name)												
Specific gravity of thermic fluid												
Specific heat of thermic fluid	kcal/kg/°C											
Totalised Thermic Fluid flow	MTA											
Thermic Flluid Pressure	kg/cm^2g											
Thermic Fluid Supply Temperature	°C											
Thermic Fluid Return Temperature	°C											
Electrical energy consumption for thermic fluid system	MWh per annum											
Energy Generation from Renewable Energy												
Electrical energy (from Wind, Photovoltaics etc.)	MWh per annum											
Thermal energy (for steam, hot water etc.)	Million kcal per annum											

ENERGY BASIS FOR IMPORT & EXPORT OFCOMMON UTILITIES

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Notes:

"kWh/kg or kWh/Nm^3" is the specific electrical energy for delivering the utility; it may be pumping power, fan power , compressor power etc.
The thermal energy input of the utilties (steam & hot water) will be calculated from the enthalpies at the given temperatures & pressures

		Design	Actual	Remarks
Boiler Feed Water Import				
Pressure	kg/cm^{2}g			
Temperature	deg.C			
Enthalpy of BFW	kcal/kg			
Specific electrical energy consumption	kWh/m^3			
Boiler Feed Water Export				
Pressure	kg/cm^{2}g			
Temperature	deg.C			
Enthalpy of BFW	kcal/kg			
Hot Water Import				
Pressure				
Temperature	deg.C			
Specific electrical energy consumption	kWh/m^3			
Hot Water Export				
Pressure	kg/cm^{2}g			
Temperature	deg.C			
Enthalpy of BFW	kcal/kg			
Specific electrical energy consumption	kWh/m^3			
STEAM				
"Level 1" Steam				
"Level 1" pressure	kg/cm^{2}g			
"Level 1" temperature	°C			
Specific electrical energy consumption	kWh/m^3			
"Level 2" Steam				
"Level 2" pressure	kg/cm^{2}g			
"Level 2" temperature	°C			
Specific electrical energy consumption	kWh/m^3			
"Level 3" Steam				
"Leve l3" pressure	kg/cm^{2}g			
"Level 3" temperature	°C			
Specific electrical energy consumption	kWh/m^3			
"Level 4" Steam				
"Level 4" pressure	kg/cm^{2}g			
"Level 4" temperature	°C			
Specific electrical energy consumption	kWh/m^3			
Condensate Export				
Pressure	kg/cm^{2}g			
Temperature	°C			
Enthalpy of condensate	kcal/kg			
Raw Water Import				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/m^3			
Raw Water Export				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/m^3			
Demineralized Water Import				
Pressure	kg/cm^{2}g			
Temperature	°C			
Enthalpy	kcal/kg			
Specific energy consumption	kWh/m^3			
Demineralized Water Export				
Pressure	kg/cm^{2}g			
Temperature	°C			
Enthalpy	kcal/kg			
Specific energy consumption	kWh/m^3			
Cooling Water Import				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/m^3			
Cooling Water Export				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/m^3			
Chilled Water Import				
Pressure	kg/cm^{2}g			
Specific electrical energy consumption	kWh/m^3			
Chilled Water Export				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/m^3			
Thermic Fluid Import				
Type (Name of fluid)				
Pressure	kg/cm^{2}g			
Inlet Temperature	°C			
Outlet Temperature				
Specific heat of thermic fluid				
Specific Power	kWh/m^3			
Thermic Fluid Export				
Pressure	kg/cm^{2}g			
Specific Power	kWh/m^3			
Instrument Air Import				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3			
Instrument Air Export				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3			
Compressed Air Import (for Processt)				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3			
Compressed Air Export (for Process)				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3			
Compressed Service/Plant Air Import				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3			
Compressed Service/Plant Air Export				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3			
Nitrogen Import				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3			
Nitrogen Export				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3			

PLANT-1: PRODUCTION, RAW MATERIAL CONSUMPTION, RECYCLING AND ENERGY CONSUMPTION

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Notes:

This sheet is only for Plant 1 in your petrochemical complex. For ther plant in the complex (Plant 2, Plan 3 stc.), please add more similar sheets and enter the relevant data separately in the same fashion. Please name the new sheets correctly.

	Particulars	Unit	2001-02			2002-03			2003-04			2004-05			2005-06			2006-07			2007-08			2008-09			2009-10			2010-11			2011-12		
	Plant Design Capacities																																		
	Main Products leaving Plant battery Limit																																		
1		MTA																																	
2		MTA																																	
3		MTA																																	
4		MTA																																	
5		MTA																																	
	RAW MATERIALS & RECYCLED MATERIALS INTO PROCESS																																		
	Data on Raw Materials to Process entering Plant Battery Limit																																		
	Raw Material Type (add more mix combinations, if required)		Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3
	Details of Raw Materials mix																																		
	Raw material input	MTA																																	
	Number of onstream days with this raw material (total onstream days should not exceed 365 days)	days per annum																																	
	Data on Recycled Steams from Same Plant																																		
	Raw Material Type (add more mix combinations, if required)		Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3
	Details of Raw Materials mix																																		
	Recycled materials input	MTA																																	
	Production Data																																		
	Main Products leaving Plant battery Limit																																		
1		MTA																																	
2		MTA																																	
3		MTA																																	
4		MTA																																	
5		MTA																																	
	Byproducts leaving Plant battery Limit																																		
1		MTA																																	
2		MTA																																	
3		MTA																																	
4		MTA																																	
5		MTA																																	
	FUEL IMPORT FROM OUTSIDE PLANT BATTERY LIMITS																																		
	Fuel no. 1																																		
	Type of fuel (Name)																																		
	Fuel Import	MTA																																	
	Specific Gravity of fuel																																		
	Heat Content of fuel (mention whether GCV or LCV)	kcal/kg																																	
	Fuel no. 2																																		
	Type of fuel (Name)																																		
	Fuel Import	MTA																																	
	Specific Gravity of fuel																																		
	Heat Content of fuel (mention whether GCV or LCV)	kcal/kg																																	
	Fuel no. 3																																		
	Type of fuel (Name)																																		
	Fuel Import	MTA																																	
	Specific Gravity of fuel																																		
	Heat Content of fuel (mention whether GCV or LCV)	kcal/kg																																	

Particulars	Unit	2001-02			2002-03			2003-04			2004-05			2005-06			2006-07			2007-08			2008-09			2009-10			2010-11			2011-12		
FUEL EXPORT OUT OF PLANT BATTERY LIMITS																																		
Fuel no. 1																																		
Type of fuel (Name)																																		
Fuel Export	MTA																																	
Specific Gravity of fuel																																		
Calorific value of fuel (mention whether GCV or LCV)	kcal/kg																																	
Fuel no. 2																																		
Type of fuel (Name)																																		
Fuel Import	MTA																																	
Specific Gravity of fuel																																		
Calorific value of fuel (mention whether GCV or LCV)	kcal/kg																																	
Fuel no. 3																																		
Type of fuel (Name)																																		
Fuel Import	MTA																																	
Specific Gravity of fuel																																		
Calorific value of fuel (mention whether GCV or LCV)	kcal/kg																																	
BYPRODUCT USED AS FUEL WITHIN PLANT BATTERY LIMITS																																		
By-product Fuel no. 1																																		
By-product fuel (Name)																																		
By-product fuel quantity	MTA																																	
Specific Gravity of by-product fuel																																		
Calorific value of by-product fuel (mention whether GCV or LCV)	kcal/kg																																	
By-product Fuel no. 2																																		
By-product fuel (Name)																																		
By-product fuel quantity	MTA																																	
Specific Gravity of by-product fuel																																		
Calorific value of by-product fuel (mention whether GCV or LCV)	kcal/kg																																	
By-product Fuel no. 3																																		
By-product fuel (Name)																																		
By-product fuel quantity	MTA																																	
Specific Gravity of by-product fuel																																		
Calorific value of by-product fuel (mention whether GCV or LCV)	kcal/kg																																	
ELECTRICITY																																		
Electrical Energy Imported from outside Plant Battery Limit																																		
Electrical Energy Imported	MWh per annum																																	
Electrical Energy Generated within Plant Battery Limit																																		
Electrical Energy generated in plant	MWh per annum																																	
Electrical Energy Exported out of Plant Battery Limit																																		
Electrical Energy exported from Plant	MWh per annum																																	

PLANT-1: GENERATION, IMPORT & EXPORT OF UTILITIES

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Notes:

This sheet captures all energy forms and utilities that are being imported, generated and exported from Plant 1.

You may change the measurement units mentioned to units commonly used in your plant; however, please mentione the units used correctly by changing the default units mentioned in this sheet.

You may add more rows, if the existing option are not sufficient and there are more utilities being used in your plant.

Particulars	Unit	Design Value	2001-02			2002-03			2003-04			2004-05			2005-06			2006-07			2007-08			2008-09			2009-10			2000-11			2011-12		
			Generation	Import	Export	Generation	Import	Export	Generation	Import	Export	Generation	Import	Export	Generation	Import	Export	Generation	Import	Export	Generation	Import	Export	Generation	Import	Export	Generation	Import	Export	Generation	Import	Export	Generation	Import	Export
STEAM																																			
"Level 1" Steam																																			
Quanity	MT																																		
"Level 2" Steam																																			
Quantity	MT																																		
"Level 3" Steam																																			
Quantity	MT																																		
"Level 4" Steam																																			
Quanity	MT																																		
BOILER FEED WATER																																			
Quantity	m^3 per annum																																		
CONDENSATE																																			
Quantity	m^3 per annum																																		
HOT WATER (EXCLUDING BOILER FEED WATER)																																			
Quantity	m^3 per annum																																		
THERMIC FLUID																																			
Quantity	m^3 per annum																																		
CHILLED WATER																																			
Quantity	m^3 per annum																																		
BRINE																																			
Quantity	m^3 per annum																																		
Demineralised Water																																			
Quantity	m^3 per annum																																		
Cooling Water																																			
Quantity	m^3 per annum																																		
Instrument Air																																			
Quantity	m^3 per annum																																		
Compressed Air (as Process input)																																			
Quantity	m^3 per annum																																		
Compressed Air (as Plant/Service Air)																																			
Quantity	m^3 per annum																																		
Nitrogen																																			
Quantity	m^3 per annum																																		
Electrical Energy consumption (outside Plant battery limit for Intermediate or Final Storage of Products)																																			
Electricity Consumption (for Offsites product pumps, compressors etc.)	MWh per annum																																		

PLANT-1: OVERALL SPECIFIC ENERGY CONSUMPTION

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Notes:

This sheet captures th "SPECIFIC CONSUMPTION" of all energy sources and utilites consumed in Plant 1. You may provide the information the way it is reported in your regular MIS sheets.

SPECIFIC ENERGY CONSUMPTION

Particulars	Unit	Design Value	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2009-11	2009-12
PRODUCTION	MT												
NET SPECIFIC STEAM HEATING AT PLANT LEVEL	kcal/MT												
NET SPECIFIC HOT WATER HEATING AT PLANT LEVEL	kcal/MT												
NET SPECIFIC THERMIC FLUID HEATING AT PLANT LEVEL	kcal/MT												
NET SPECIFIC UTILITY ELECTRICITY CONSUMPTION AT PLANT LEVEL	kWh/MT												
NET SPECIFIC UTILITY THERMAL ENERGY CONSUMPTION AT PLANT LEVEL	kcal/MT												
NET SPECIFIC PLANT DIRECT ELECTRICAL ENERGY CONSUMPTION AT PLANT LEVE	kWh/MT												
OVERALL NET SPECIFIC ENERGY CONSUMPTION AT PLANT LEVEL (CONSIDERING BOTH ELECTRICAL & THERMAL ENERGY SOURCES)	**kcal/MT**												

Annexure 4 – Sequence of data collection to arrive at SECs

The ensuing tables illustrate the sequence of process form data collection (through questionnaire) to arriving at SECs for a sample Petrochemical complex manufacturing Polyethylene and Polypropylene

Table 64: Questionnaire - Petrochemical Complex - Collection of Information on Plant Capacities, Technology Licensors, Feedstock, Energy Sources & Combined Heat & Power Plant Configuration

Major Intermediates / Products		Capacity	Technology Licensees
1	Olefins - Ethylene & Propylene	Olefins: 440,000 MTA (Ethylene: 230,000 MTA, Propylene: 126,000 MTA)	M.W. Kellogg, USA
2	Polyethylene	360,000 MTA	Nova Chemicals, Canada
3	Polyproylene	120,000 MTA	Basell, Italy
By-products			
1	None		
	Plants in the Complex	**Year of Commissioning**	
A	Olefins	1995	
B	Polyethylene	1995	
C	Polypropylene	1995	
	Major of Feedstock	**Source of Supply**	
1	Liquefied Natural Gas (NGL)	State Utility	
	Major Energy Sources	**Source of Supply**	
1	Natural Gas	State Utility	
Do you purchase electricity from grid?		NO	
Do you have captive power plant?		YES	
Do you have cogeneration plant?		NO	

Table 65: Questionnaire - Petrochemical Complex - Collection of Information on Monthly Production Data

Sr. No.		Name of Mfg Plant in the Complex	Unit	March	April	May	June	July
	Major Feedstock							
1	Liquid Natural Gas (NGL)	Olefins	MT	18740	34694	31576	31726	37980
2	Virgin C5+	Olefins	MT	13	0	0	0	0
	Intermediates							
1	Ethylene	Olefins	MT	10776	22915	20879	20485	25199
2	Propylene	Olefins	MT	2983	4943	4664	4309	5227
	Final Products							
1	Polyethylene	Polyethylene	MT	9841	17285	19988	21872	23449
2	Polypropylene	Polypropylene	MT	4984	3428	5687	4984	4644

Table 66: Questionnaire - Petrochemical Complex - Energy Imported into Petrochemcial Complex Boundary

	Unit	March	April	May	June	July
Primary Fuels Purchased (total for all applications)						
Fuel type A						
Type (Name of fuel)		NG	NG	NG	NG	NG
Quantity	'000 sm^3	25598	26386	26386	24407	24901
	'000 Nm^3	27052	27884	27884	25793	26315
Calorific value - LCV	kcal/Nm^3	8250	7912	9062	8682	8992
Electricity Purchased from Grid						
Purchased Electricity from Grid	kWh	0	0	0	0	0
Energy Generation from Renewable Energy						
Electrical energy (from Wind, Photovoltaics etc.)	kWh	0	0	0	0	0
Thermal energy (for steam, hot water etc.)	Million kcal	0	0	0	0	0

Table 67: Questionnaire - Petrochemcial Complex - Energy for Electricity & Steam Generation

	Unit	March	April	May	June	July
Captive Power Plant (Only Electricity Generation without Cogeneration)						
Fuel type A						
Type (Name of fuel)		NG	NG	NG	NG	NG
Quantity	'000Nm^3	10498	11709	10891	10382	10556
Calorific value (LCV)	kcal/Nm^3	8250	7912	9062	8682	8992
Heat input to Captive Power Plant	million kcal	86609	92639	98697	90134	94921
Electricity Generation in Captive Power Plant	MWh	16798.78	20989.60	22639.92	21640.70	21599.81
Export to Grid	MWh	252.96	391.50	952.32	504.00	358.61
Consumption of Petrochemical Complex	MWh	16545.82	20598.10	21687.60	21136.70	21241.20
Steam Generated by Fuel Firing in Boilers						
Location		Olefins Plant				
Fuel Type (name)		NG	NG	NG	NG	NG
Fuel consumption	'000 Nm^3	16554	16175	16992	15411	15759
Calorific value (LCV)	kcal/Nm^3	8250	7912	9062	8682	8992
Heat input to Boilers	million kcal	136568	127978	153986	133800	141705
Steam Pressure	kg/cm^{2}g	46	46	46	46	46
Steam Temperature	°C	270	270	270	270	270

Table 68: Questionnaire - Petrochemical Complex - Collection of Information on Allocated Energy Values for Fuels and Utilities

		Design	Actual	Remarks
FUEL GAS				
Fuel Gas Import				
Calorific value	kcal/Nm^3		8573	Plant laboratory report
Fuel Gas Export				
Calorific value	kcal/Nm^3		5294	Plant laboratory report
BOILER FEED WATER				
Boiler Feed Water Import				
Pressure	kg/cm^2g	9	9	
Temperature	deg.C	110	110	
Enthalpy of BFW	kcal/kg		110.2	From steam tables
Specific electrical energy consumption	kWh/m^3		0.0	No sub-metering of electricity for BFW pumps
Boiler Feed Water Export				
Pressure	kg/cm^2g	9	9	
Temperature	deg.C	110	110	
Enthalpy of BFW	kcal/kg		110.2	From steam tables
Specific electrical energy consumption	kWh/m^3		0.0	No sub-metering of electricity for BFW pumps
STEAM				
Ultra High Pressure Steam				
Pressure	kg/cm^2g	110	110	
Temperature	°C	500	500	
Enthalpy	kcal/kg		803.0	From steam tables
Specific electrical energy consumption	kWh/kg		0	No sub-metering of electricity for boiler auxiliaries
High Pressure Steam				
Pressure	kg/cm^2g	45.5	45.5	
Temperature	°C	400	400	
Enthalpy	kcal/kg		765.3	From steam tables
Specific electrical energy consumption	kWh/kg		0	No sub-metering of electricity for boiler auxiliaries
Medium Pressure Steam				
Pressure	kg/cm^2g	17	17	

Temperature	°C	206	206	
Enthalpy	kcal/kg		668.5	From steam tables
Specific electrical energy consumption	kWh/kg		0	
Low Pressure Steam				
Pressure	kg/cm^2g	5	5	
Temperature	°C	158	158	
Enthalpy	kcal/kg		659.8	From steam tables
Specific electrical energy consumption	kWh/kg		0	No sub-metering of electricity for boiler auxiliaries
STEAM CONDENSATE				
Condensate Import				
Pressure	kg/cm^2g	6	6	
Temperature	°C	70	70	
Enthalpy of condensate	kcal/kg		69.9	From steam tables
Specific electrical energy consumption	kcal/kg		0	No sub-metering of electricity for boiler auxiliaries
Condensate Export				
Pressure	kg/cm^2g	6	6	

Table 69: Questionnaire - Petrochemical Complex - Collection of Information on Allocated Energy Values for Fuels and Utilities

		Design	Actual	Remarks
Temperature	°C	70	70	
Enthalpy of condensate	kcal/kg		69.9	
Specific electrical energy consumption	kcal/kg		0	No sub-metering of electricity for boiler auxiliaries
RAW WATER				
Raw Water Import				
Pressure	kg/cm^2g			
Specific energy consumption	kWh/m^3		0.414	From sub-meters of Rivers Pumps & filtration plant
Specific energy consumption	$kcal/m^3$		356	
Raw Water Export				
Pressure	kg/cm^2g		0	
Specific energy consumption	kWh/m^3		0	
Specific energy consumption	$kcal/m^3$		0	

DEMINERALISED WATER				
Demineralized Water Import				
Pressure	kg/cm^{2}g	8	8	
Temperature	°C		53	
Enthalpy	kcal/kg		53.0	
Specific electricity consumption	kWh/m^3		0.869	From sub-meters of DM Water Plant
Total specific energy consumption	kcal/kg		53	
Demineralized Water Export				
Pressure	kg/cm^{2}g			
Temperature	°C			
Enthalpy	kcal/kg			
Specific energy consumption	kWh/m^3		0.869	From sub-meters of DM Water Plant
Total specific energy consumption	kcal/kg		747	
COOLING WATER				
Cooling Water Import from Offsites/Other Plants				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/m^3		0.223	From sub-meters of cooling towers
COMPRESSED AIR				
Instrument Air Import from Offsites/Other Plants				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3		0.298	From sub-meters of Compressed Air Station
Instrument Air Export to Other Plants				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3		0.298	From sub-meters of Compressed Air Station
Compressed Air Import (for Process)				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3		0.298	From sub-meters of Compressed Air Station
Compressed Air Export (for Process)				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3		0.298	From sub-meters of Compressed Air Station
General Servicet Air Import from Offsites/Other Plants				
Pressure	kg/cm^{2}g			

Specific energy consumption	kWh/Nm^3		0.298	From sub-meters of Compressed Air Station

Table 70: Questionnaire - Petrochemical Complex - Collection of Information on Allocated Energy Values for Fuels and Utilities

		Design	Actual	Remarks
General Service Air Export to Other Plants				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3		0.298	From sub-meters of Compressed Air Station
NITROGEN				
Nitrogen Import from Offsites/Other Plants				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3		0.357	From sub-meters of Nitrogen Plant
Nitrogen Export One Process Plant to Another Plant				
Pressure	kg/cm^{2}g			
Specific energy consumption	kWh/Nm^3		0.357	From sub-meters of Nitrogen Plant

Table 71: Questionnaire - Olefins Plant - Information on Monthly Consumption of Major Feedstock, Production, Fuels & Electricity

	Particulars	Unit	March	April	May	June	July
	Major Feedstock						
1	Liquid Natural Gas (NGL)	MT	18752	34694	31576	31726	37980
	Production						
1	Ethylene	MT	10776	22915	20879	20485	25199
2	Propylene	MT	2983	4943	4664	4309	5227
	FUEL IMPORT FROM OUTSIDE PLANT BATTERY LIMITS						
	Type of fuel (Name)		LP Gas	LP Gas	LP Gas	LP Gas	LP Gas
	Fuel import	kNm^3	6203	11280	19214	9263	11067
	Heat value	million kcal	53176	96703	164719	79411	94874
	FUEL EXPORT OUT OF PLANT BATTERY LIMITS						
	Type of fuel (Name)		HP Gas	HP Gas	HP Gas	HP Gas	HP Gas
	Fuel Export	MT	1158	2073	2065	2514	2922
	Heat Value	million kcal	5294	5294	5294	5294	5294
	ELECTRICITY						
	Electrical Energy Import						
	Electrical Energy	MWh	1364	1594	1567	1433	1480
	Electrical Energy Exported out of Plant Battery Limit						
	Electrical Energy	MWh	0	0	0	0	0
	Electrical Energy Generated within Plant Battery Limit						
	Electrical Energy	MWh	0	0	0	0	0
	Electrical Energy consumed outside Plant Battery Limit for						

Product Storage or any other activity that has to be allocated to this plant						
Electrical Energy	MWh	75	107	111	107	111

Table 72: Questionnaire - Olefins Plant - Quantification of Imports & Exports of Fuels, Electricity & Utilities

Particulars	Unit	Design Value	March		April		May		June		July	
			Import	**Export**	**Import**	**Export**	**Import**	**Export**	**Import**	**Export**	**Import**	**Export**
FUEL GAS												
Fuel Gas												
Quanity	kNm^3		6203.0	1158.0	11280.0	2073.0	19214.0	2065.0	9263.0	2514.0	11067.0	2922.0
Energy	million kcal		53178.3	6130.5	96703.4	10974.5	164721.6	10932.1	79411.7	13309.1	94877.4	15469.1
STEAM												
High Pressure Steam												
Quantity	MT		0.0	15122.0	0.0	19593.0	0.0	18886.0	0.0	18771.0	0.0	20069.0
Energy	million kcal		0.0	11572.8	0.0	14994.5	0.0	14453.4	0.0	14365.4	0.0	15358.8
Medium Pressure Steam												
Quantity	MT		0.0	3904.0	0.0	4772.0	0.0	4348.0	0.0	4335.0	0.0	4660.0

Energy	million kcal	0.0	2610.0	0.0	3190.3	0.0	2906.8	0.0	2898.1	0.0	3115.4
Low Pressure Steam											
Quanity	MT	0.0	15192.9	0.0	18569.0	0.0	16751.0	0.0	15537.0	0.0	16352.0
Energy	million kcal	0.0	10023.5	0.0	12250.9	0.0	11051.5	0.0	10250.5	0.0	10788.2
BOILER FEED WATER											
Quantity	m^3	234321.3	4656.7	286392.7	5864.6	268435.9	6255.0	251929.6	10095.0	259898.0	6417.2
Energy	million kcal	12419.0	513.0	15178.8	646.1	14227.1	689.1	13352.3	1112.2	13774.6	707.0
CONDENSATE											
Quantity	m^3	0.0	71280.0	0.0	118800.0	0.0	122760.0	0.0	118800.0	0.0	122760.0
Energy	million kcal	0.0	4985.6	0.0	8309.3	0.0	8586.3	0.0	8309.3	0.0	8586.3
Demineralised Water											
Quantity	m^3	234321.3	0.0	286392.7	0.0	268435.9	0.0	251929.6	0.0	259898.0	0.0

Energy	million kcal	150553.1	0.0	184009.3	0.0	172471.9	0.0	161866.5	0.0	166986.3	0.0
Cooling Water											
Quantity	km^3	8584.3	0.0	10153.4	0.0	10746.8	0.0	7470.3	0.0	7752.5	0.0
Energy	million kcal	1644.0	0.0	1944.5	0.0	2058.2	0.0	1430.7	0.0	1484.7	0.0
Compressed Air for Instrumentation											
Quantity	m^3	861.4	0.0	1052.8	0.0	953.2	0.0	908.3	0.0	972.3	0.0
Energy	million kcal	220.8	0.0	269.8	0.0	244.3	0.0	232.8	0.0	249.2	0.0

Table 73: Questionnaire - Olefins Plant - Quantification of Imports & Exports of Fuels, Electricity & Utilities

Particulars	Unit	Design Value	March		April		May		June		July	
			Import	**Export**	**Import**	**Export**	**Import**	**Export**	**Import**	**Export**	**Import**	**Export**
Nitrogen												
Quantity	km^3		272.0	0.0	222.0	0.0	211.2	0.0	356.0	0.0	148.2	0.0
Energy	million kcal		83.5	0.0	68.2	0.0	64.8	0.0	109.3	0.0	45.5	0.0

Electrical Energy											
Electricity Consumption	MWh	1364.0	0.0	1594.0	0.0	1567.0	0.0	1433.0	0.0	1480.0	0.0
Energy	million kcal	1173.0	0.0	1370.8	0.0	1347.6	0.0	1232.4	0.0	1272.8	0.0
Electrical Energy Consumed Outside Plant Battery Limit for this Plant											
Electricity Consumption (for Offsites product pumps, compressors etc.)	MWh	75.0	0.0	107.0	0.0	111.0	0.0	107.0	0.0	111.0	0.0
Energy	million kcal	64.5	0.0	92.0	0.0	95.5	0.0	92.0	0.0	95.5	0.0
TOTAL	**million kcal**	**219336.3**	**35835.4**	**299637.0**	**50365.6**	**355231.0**	**48619.3**	**257727.7**	**50244.7**	**278785.9**	**54024.8**
NET IMPORT	**million kcal**	**183500.8**		**249271.4**		**306611.8**		**207483.0**		**224761.2**	

Table 74: Methodology 1: Calculation of Specific Energy Consumption for Olefins plant

Particulars	Unit	March	April	May	June	July
WITH REFERENCE TO MAJOR INTERMEDIATES / PRODUCTS						
Plant Utilization (on-stream days)	Days	18	30	31	30	31
Production of Olefins (intermediates: Ethylene & Propylene)	MT	13759	27858	25542	24794	30426
Ethylene Production	MT	10776	22915	20879	20485	25199
Propylene Production	MT	2983	4943	4664	4309	5227
Ethylene Production	%	78.32	82.26	81.74	82.62	82.82
Propylene Production	%	21.68	17.74	18.26	17.38	17.18
Total Energy Consumption of the Complex	Million kcal	183501	249271	306612	207483	224761
OVERALL NET SPECIFIC ENERGY CONSUMPTION AT PLANT (CONSIDERING BOTH ETHYLENE & PROPYLENE)	**Million kcal/MT**	**13.34**	**8.95**	**12.00**	**8.37**	**7.39**

Table 75: Questionnaire - Polyethylene Plant - Information on Monthly Consumption of Major Feedstock, Production, Fuels & Electricity

	Particulars	Unit	Design	March	April	May	June	July
	RAW MATERIALS & RECYCLED MATERIALS INTO PROCESS							
	Major Feedstocks							
1	Ethylene	MT		10776	22915	20879	20485	25199
	Number of onstream days	days						
	Production Data							
	Main Products leaving Plant battery Limit							
1	Polyethylene	MT		9841	17285	19988	21872	23449
	FUEL IMPORT FROM OUTSIDE PLANT BATTERY LIMITS							
	Type of fuel (Name)			LP Gas	LP Gas	LP Gas	LP Gas	LP Gas
	Fuel import	kNm^3		6203	11280	19214	9263	11067
	Heat value	million kcal		53176	96703	164719	79411	94874
	FUEL EXPORT OUT OF PLANT BATTERY LIMITS							
	Type of fuel (Name)			HP Gas	HP Gas	HP Gas	HP Gas	HP Gas
	Fuel Export	MT		1158	2073	2065	2514	2922

Heat Value	million kcal	5294	5294	5294	5294	5294
ELECTRICITY						
Electrical Energy Import						
Electrical Energy	MWh	1364	1594	1567	1433	1480
Electrical Energy Exported out of Plant Battery Limit						
Electrical Energy	MWh	0	0	0	0	0
Electrical Energy Generated within Plant Battery Limit						
Electrical Energy	MWh	0	0	0	0	0
Electrical Energy consumed outside Plant Battery Limit for this plant						
Electrical Energy	MWh	75	107	111	107	111

Table 76: Questionnaire - Polyethylene Plant - Quantification of Imports & Exports of Fuels, Electricity & Utilities

Particulars	Unit	Design Value	March	April	May	June	July				
			Import	**Export**	**Import**	**Export**	**Import**	**Export**	**Import**	**Export**	**Import**	**Export**
FUEL GAS												
Fuel Gas												
Quantity	kNm^3		273.0	0.0	349.0	0	356	0.0	340.0	0.0	346.0	0.0
Energy	million kcal		2340.4	0.0	2992.0	0.0	3052.0	0.0	2914.8	0.0	2966.3	0.0

STEAM											
High Pressure Steam											
Quantity	MT	8427	0	10884	0	12241	0.0	12510.0	0.0	13342.0	0.0
Energy	million kcal	6449.2	0.0	8329.5	0.0	9368.0	0.0	9573.9	0.0	10210.6	0.0
Medium Pressure Steam											
Low Pressure Steam											
Quantity	MT	0.0	3103	0	5839	0	2812	0.0	2730.0	0.0	2160.0
Energy	million kcal	0.0	2047.2	0.0	3852.3	0.0	1855.2	0.0	1801.1	0.0	1425.1
BOILER FEED WATER											
Quantity	m^3	4657	0	5864	0	6255	0.0	10095.0	0.0	6417.0	0.0
Energy	million kcal	513.1	0.0	646.0	0.0	689.1	0.0	1112.2	0.0	707.0	0.0
CONDENSATE											
Quantity	m^3	0	9686	0	13367	0	15850.0	0.0	9904.0	0.0	16533.0
Energy	million	0.0	677.5	0.0	934.9	0.0	1108.6	0.0	692.7	0.0	1156.4

	kcal										
Cooling Water											
Quantity	km^3	5119.0	0.00	4705.00	0	4775	0.0	4899.0	0.0	4926.0	0.0
Energy	million kcal	980.4	0.0	901.1	0.0	914.5	0.0	938.2	0.0	943.4	0.0
Compressed Air for Instrumentation											
Quantity	m^3	1456.00	0.00	1772.00	0	1798	0.0	2024.0	0.0	2126.0	0.0
Energy	million kcal	373.1	0.0	454.1	0.0	460.8	0.0	518.7	0.0	544.9	0.0
Nitrogen											
Quantity	km^3	839.00	0.00	1157.00	0	1283	0.0	1104.0	0.0	1347.0	0.0
Energy	million kcal	257.6	0.0	355.2	0.0	393.9	0.0	339.0	0.0	413.6	0.0
Electrical Energy Import											
Electricity Consumption	MWh	3295		4995		5080.0	0.0	5290.0	0.0	5515.0	0.0
Energy	million kcal	2833.7	0.0	4295.7	0.0	4368.8	0.0	4549.4	0.0	4742.9	0.0
TOTAL	**million kcal**	**13747.5**	**2724.7**	**17973.7**	**4787.2**	**19247.1**	**2963.8**	**19946.2**	**2493.8**	**20528.6**	**2581.4**

NET IMPORT	**million kcal**	**11022.8**	**13186.5**	**16283.3**	**17452.3**	**17947.1**

Table 77: Method 1 - Calculation of Specific Energy Consumption for Polyethylene Plant

Particulars	Unit	March	April	May	June	July
WITH REFERENCE TO MAJOR INTERMEDIATES / PRODUCTS						
Plant Utilization (on-stream days)	Full Stream	12	19	21	27	27
	Partial Shutdown	8	7	10	3	4
	Shutdown	11	4	0	0	0
Production of Polyethylene	MT	9841	17285	19988	21872	23449
Total Energy Consumption of the Complex	Million kcal	11023	13186	19247	17452	17947
OVERALL NET SPECIFIC ENERGY CONSUMPTION AT PLANT	**Million kcal/MT**	**1.12**	**0.76**	**0.96**	**0.80**	**0.77**

Table 78: Questionnaire: Polypropylene Plant - Information on Monthly Consumption of Major Feedstock, Production, Fuels & Electricity

	Particulars	Unit	Design	March	April	May	June	July
	Major Feedstocks							
1	Propylene	MT		2983	4943	4664	4309	5227
	Production Data							
	Main Products leaving Plant battery Limit							
1	Polyethylene	MT		1833	3428	5687	4984	4644
	-							
	FUEL IMPORT FROM OUTSIDE PLANT BATTERY LIMITS							
	Type of fuel (Name)			LP Gas	LP Gas	LP Gas	LP Gas	LP Gas
	Fuel import	kNm^3		6203	11280	19214	9263	11067
	Heat value	million kcal		53176	96703	164719	79411	94874
	FUEL EXPORT OUT OF PLANT BATTERY LIMITS							
	Type of fuel (Name)			HP	HP	HP	HP	HP

		Gas	Gas	Gas	Gas	Gas
Fuel Export	MT	1158	2073	2065	2514	2922
Heat Value	million kcal	5294	5294	5294	5294	5294
ELECTRICITY						
Electrical Energy Import						
Electrical Energy	MWh	1364	1594	1567	1433	1480
Electrical Energy consumed outside Plant Battery Limit for product Storage or any other activity that has to be allocated this plant						
Electrical Energy	MWh	75	107	111	107	111

Table 79: Questionnaire - Polypropylene Plant - Quantification of Imports & Exports of Fuels, Electricity & Utilities

Particulars	Unit	Design Value	March		April		May		June		July	
			Import	**Export**	**Import**	**Export**	**Import**	**Export**	**Import**	**Export**	**Import**	**Export**
STEAM												
High Pressure Steam												
Quantity	MT		689	0	927	0	1038	0.0	1002.0	0.0	30.0	0.0
Energy	million kcal		527.3	0.0	709.4	0.0	794.4	0.0	766.8	0.0	23.0	0.0
Medium Pressure Steam												
Quantity	MT		2091	0	3455	0	4144	0.0	4240.0	0.0	4142.0	0.0
Energy	million kcal		1379.5	0.0	2279.4	0.0	2734.0	0.0	2797.3	0.0	2732.7	0.0
Compressed Air for Instrumentation												
Quantity	m^3		0.00	0.00	0.00	0	0	0.0	0.0	0.0	0.0	0.0
Energy	million kcal		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electrical Energy Import												
Electricity Consumption	MWh		946	0	1703	0	2402	0.0	2259.0	0.0	2125.0	0.0
Energy	million		813.6	0.0	1464.6	0.0	2065.7	0.0	1942.7	0.0	1827.5	0.0

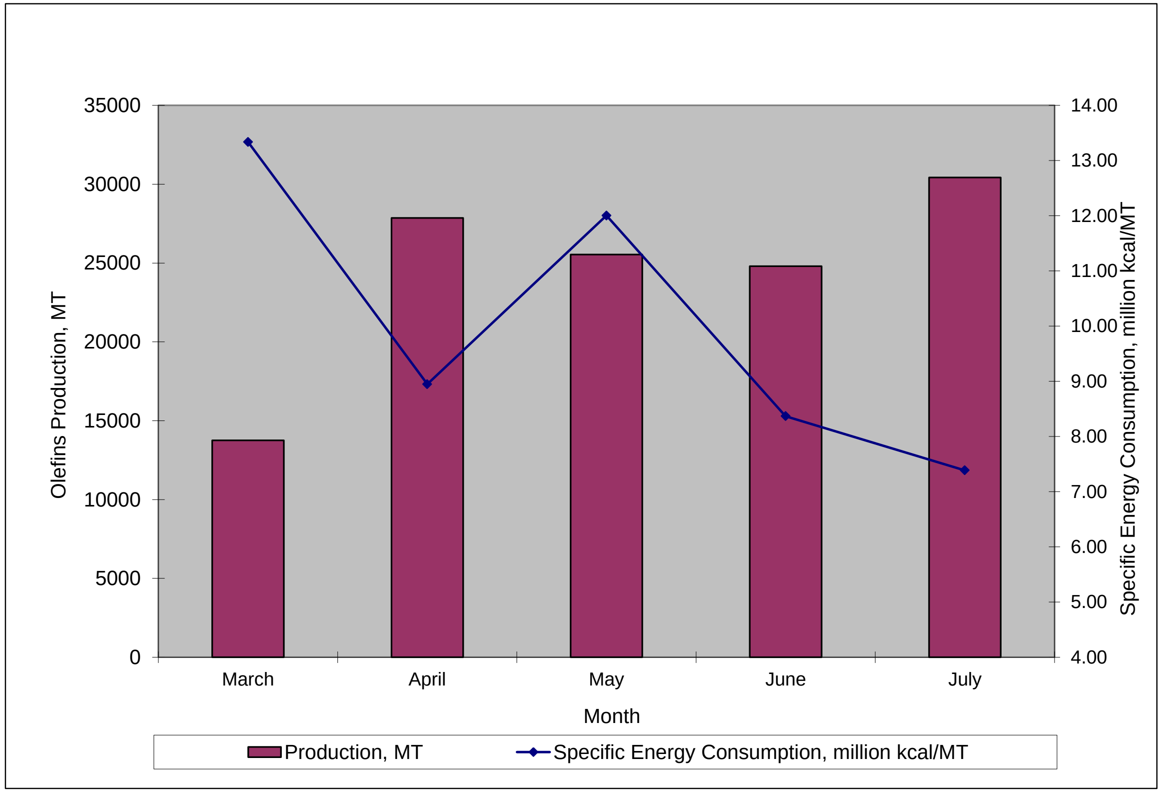
	kcal										
Electrical Energy Consumed Outside Plant Battery Limit specifically for this Plant											
Electricity Consumption (for Offsites product pumps, compressors etc.)	MWh	9.2	0.0	17.6	0.0	26.0	0.0	25.2	0.0	26.0	0.0
Energy	million kcal	7.9	0.0	15.1	0.0	22.4	0.0	21.7	0.0	22.4	0.0
TOTAL	**million kcal**	**2728.3**	**18.5**	**4468.6**	**35.3**	**5616.5**	**52.0**	**5528.6**	**50.4**	**4605.5**	**52.0**
NET IMPORT	**million kcal**	**2709.9**		**4433.3**		**5564.4**		**5478.2**		**4553.5**	

Table 80: Methodology 1 - Calculation of Specific Energy Consumption for Polypropylene plant

Particulars	Unit	March	April	May	June	July
WITH REFERENCE TO MAJOR INTERMEDIATES / PRODUCTS						
Plant Utilization – On-stream Days	Full Stream	11	21	31	30	31
	Partial Shutdown	0	0	0	0	0
	Shutdown	20	9	0	0	0
Production of Polypropylene	MT	1833	3428	5687	4984	4644
Total Energy Consumption of the Complex	Million kcal	2710	4433	5564	5478	4553
OVERALL NET SPECIFIC ENERGY CONSUMPTION AT PLANT	**Million kcal/MT**	**1.48**	**1.29**	**0.98**	**1.10**	**0.98**

Table 81: Methodology 2: Calculation of Specific Energy Consumption for the Petrochemical Complex as a Whole

Particulars	Unit	March	April	May	June	July
Liquid Natural Gas (Feedstock to Olefins Plant)	MT	18752	34694	31576	31726	37980
Total Energy Consumption of the Complex	Million kcal	223177	220616	252682	223934	236626
OVERALL NET SPECIFIC ENERGY CONSUMPTION AT COMPLEX LEVEL (RATIO OF ENERGY TO FEEDSTOCK)	Million kcal/MT	11.90	6.36	8.00	7.06	6.23


35000
30000
25000
20000
15000
10000
5000
0
Olefins Production, MT
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
Specific Energy Consumption, million kcal/MT
March
April
May
June
July
Month
Production, MT
Specific Energy Consumption, million kcal/MT

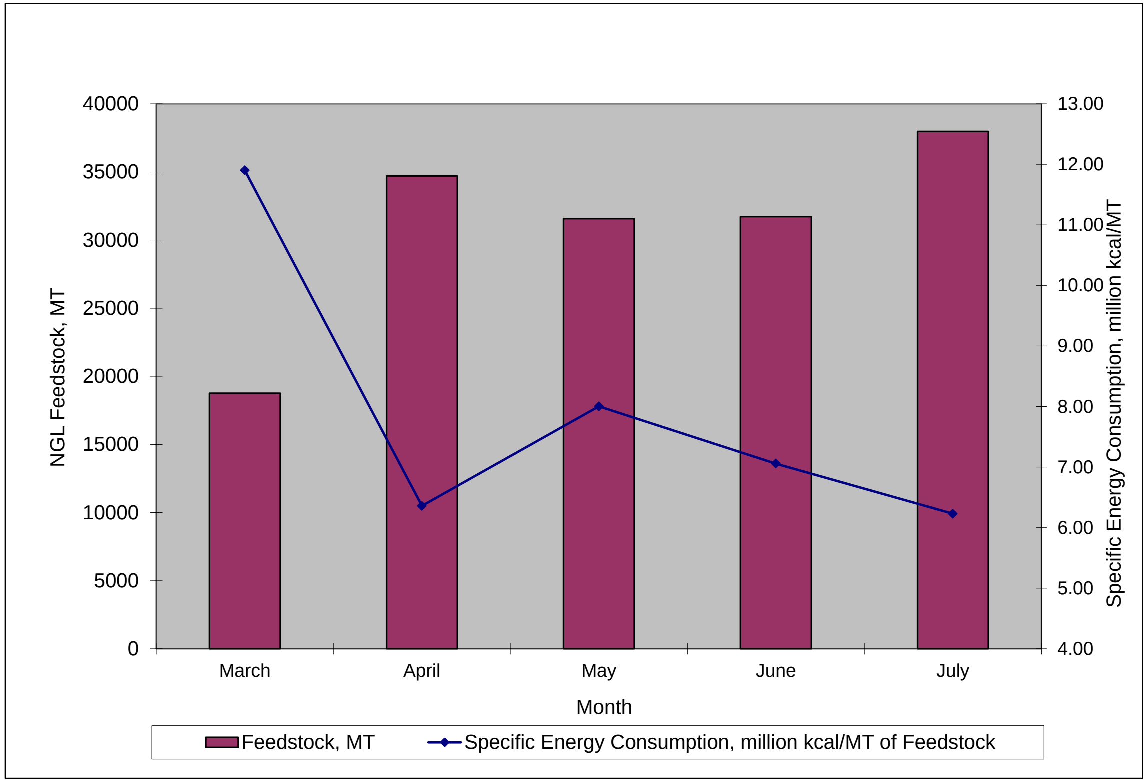


Figure 41: Comparable SEC Trends with reference to Olefins Production & Feedstock Consumption

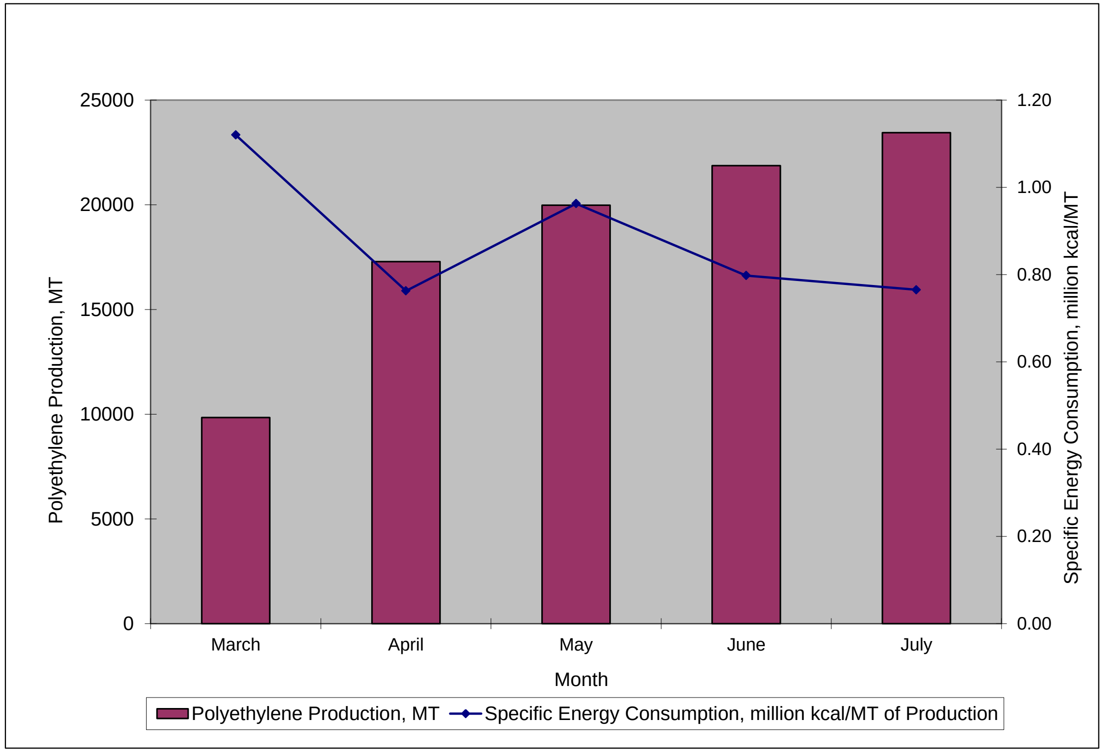


Figure 42: Polyethylene - Production and SEC

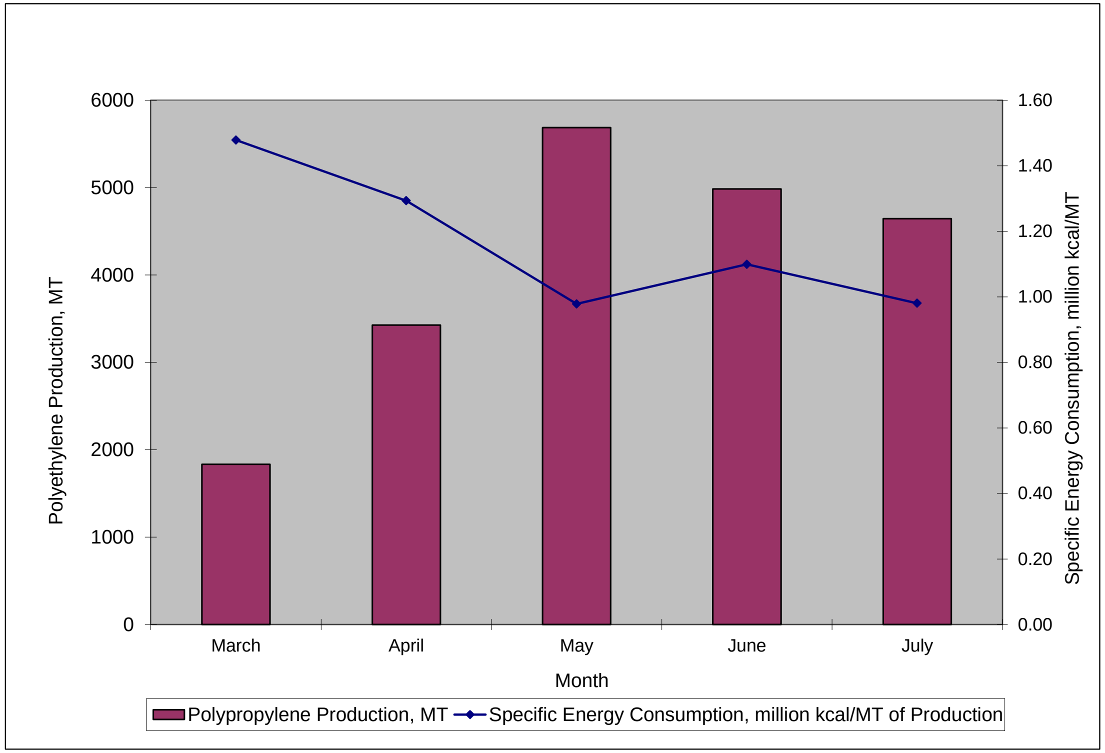


Figure 43: Polypropylene – Production and SEC

Annexure 5: Calculation of Specific Energy Consumption (SEC) in a “Single Product” Plant

Table 82: Calculation of Specific Energy Consumption (SEC) in a “Single Product” Plant

	Unit	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11
Major Feedstock													
Kerosene	MT	38480	6952	34472	39040	39900	37757	39216	35102	32997	37462	34666	38093
Benzene	MT	23767	4294	21292	24113	24644	23321	24222	21681	20381	23138	21411	23528
Intermediate Product													
N- Paraffin	MT	9620	1738	8618	9760	9975	9439	9804	8776	8249	9365	8667	9523
Final Product													

Linear Alkyl Benzene	MT	8081	1460	7239	8198	8379	7929	8235	7372	6929	7867	7280	8000
Fuel													
Type (Name of fuel)		NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
Quantity	Nm^3	5556	2222	4444	5667	5889	5444	5333	5000	4556	5222	5000	5500
Calorific value - LCV	$kcal/Nm^3$	9000	9105	9050	8917	8987	8950	9004	9054	8973	9121	9027	9065
Electricity													
Grid Electricity	kWh	5712660	2437380	5627880	6088680	6087330	5874120	5931900	5679270	5182380	5661450	5084820	5695560
Total Energy Consumption	Million kcal	54913	22329	45062	55766	58159	53780	53123	50154	45334	52501	49508	54756
SPECIFIC ENERGY CONSUMPTION	**Million kcal/MT**	**6.80**	**15.30**	**6.22**	**6.80**	**6.94**	**6.78**	**6.45**	**6.80**	**6.54**	**6.67**	**6.80**	**6.84**

Annexure 6 – Comparison of Actual SEC and the Technology licensor design SEC

			Plant Data						Available Technology SEC			
	Company	Plant Locatior	Final Products	Specific Energy Consumption (MTOE/ton)			Plant mean SEC	Variance	Technology	Electricity (kWh/ton)	Steam (kg/ton)	MTOE
3	**RIL**		HDPE/ LLDPE	0.1376	0.1393	0.1383	0.1384	0.0000	BORSTAR	500	300	0.203857
4	**RIL**		PP	0.0818	0.0759	0.0742	0.0773	0.0000	BORSTAR	160	170	0.08521424
5	**RIL**		PVC	0.2081	0.1054	0.1076	0.1404	0.0034	CHISSO	160	700	0.22831424
8	**GAIL (India)**	Pata	HDPE	0.1555	0.1614	0.1464	0.1544	0.0001	BORSTAR	500	300	0.203857
9	**GAIL (India)**	Pata	HDPE/ LLDPE	0.0680	0.0668	0.1302	0.0883	0.0013	BORSTAR	500	300	0.203857
21	**Chemplast Sanmar**	Mettur, near Salem	PVC	0.4101	0.2992	0.2554	0.3215	0.0064	CHISSO	160	700	0.22831424
24	**Supreme Petrochem**	Nagothane	PS	0.0518	0.0517	0.0554	0.0530	0.0000	BP/Lummus	150	420	0.1502571

Annexure 7 – Representative Statistical Models

Statistical Modeling is a technique that estimates the dependence of a variable of interest on one or more independent variables. Considering the complexity of petrochemical sector it is important to identify such dependent and independent variables and their relationship. This will assist in the use of normalization factors appropriately under the PAT Phase-II for petrochemical sector. With the limited availability of plant level data the representative statistical models prepared are mostly for statistical data available publically like, capacity, production, energy consumption etc.

Considering the type of data available for the various petrochemical products the statistical models have been prepared have been divided in two categories:

a. Data available for more than two variables – capacity, production and energy consumption. The products covered under this category are PSF, PVC resins and HDPE/LLDPE
b. Data available for two variables - production and energy consumption

Category A

Regression Model SPSS output for PSF plants						
Notes						
Output Created		5/12/2013 13:15				
Comments						
Input	Data					
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	Weight	<none>				
	Split File	<none>				
	N of Rows in Working Data File	6				
Missing Value Handlin	Definition of Missing	User-defined missing values are treated as missing.				
	Cases Used	Statistics are based on cases with no missing values for any variable used.				
Syntax		REGRESSION				
Resources	Elapsed Time	0:00:00				
	Memory Required	1628 bytes				
	Additional Memory Required for Re	0 bytes				
Variables Entered/Removed(b)						
Model	Variables Entered	Variables Removed	Method			
1	CUF, Prodn(a)	.	Enter			
a. All requested variables entered.						
b. Dependent Variable: Energy						
Model Summary						
Model	R	R Square	Adjusted	Std. Error of the Estimate		
1	0.992	0.984	0.973	5,220.58		
a. Predictors: (Constant), CUF, Prodn						
ANOVA(b)						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	4,989,876,867.48	2	2,494,938,433.74	91.542	0.002
	Residual	81,763,323.85	3	27,254,441.28		
	Total	5,071,640,191.33	5			
a. Predictors: (Constant), CUF, Prodn						
b. Dependent Variable: Energy						
Coefficients(a)						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	66,829.33	48,755.81		1.371	0.264
	Prodn	0.109	0.012	1.097	9.367	0.003
	CUF	-78,203.84	65,535.81	-0.14	-1.193	0.319
a. Dependent Variable: Energy						
	Overall equation	**y=0.109*P-78,208.84*CUF+66,829.33**				

Explanation:

The secondary sources referred to provided data in terms of energy consumption, capacity and production. A similar set of data was selected for two companies manufacturing same product. Analysis of secondary data collected provided this complete set of data only for PSF. The data so collected was analyzed for the following relationships:

i. Specific Energy Consumption and Production

There is a good relationship between SEC (Dependant Variable) and Production (Independant Variable) at 90% confidence level. The coefficient of determination was also close to unity indicating that production as independent variable quite well explains the variation in SEC.

ii. Specific Energy Consumption and Capacity Utilization Factor

The SEC and CUF do not represent a good relationship in this example with the R-Square value much below unity, as such CUF does not very well explain the variation in SEC

iii. Gross Energy Consumption, Production and Capacity Utilization Factor

The Energy Consumption (Dependent Variable) represents a strong relationship with Production and CUF (Independent Variables). The modelling of this variables provided a good relationship with R-square close to unity at both 90% and 99% confidence levels. As such given the limited availability of data this model represents the best fit for PSF. With the availability of more independent variables and more data points the above equation can further be refined to predict energy consumption as close to the actual energy consumed by the unit.

Regression Model SPSS output for PVC Resin plants

Notes

Output Created		29-May-2013 15:39:44
Comments		
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	N of Rows in Working Data File	6
	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on cases with no missing values for any variable used. Predicted values are calculated for cases with missing values on the dependent variable.
Syntax		MODEL PROGRAM A=0.3 B=-1.3 C=1.2 . COMPUTE PRED_ = A * X ** 2 + B * X + C. NLR Y
Resources	Elapsed Time	0:00:00

Iteration History(b)

Iteration Number(a)	Residual Sum of Squares	Parameter A	Parameter B	Parameter C
1.0	11.435	0.300	-1.300	1.200
1.1	0.445	-6.709	4.229	2.557
2.0	0.445	-6.709	4.229	2.557
2.1	0.445	-6.709	4.229	2.557

Derivatives are calculated numerically.

a. Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b. Run stopped after 4 model evaluations and 2 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

			95% Confidence Interval	
Parameter	Estimate	Std. Error	Lower Bound	Upper Bound
A	-6.709	3.121	-16.642	3.224
B	4.229	4.027	-8.588	17.045
C	2.557	1.012	-0.665	5.779

Correlations of Parameter Estimates

	A	B	C
A	1.000	-0.992	0.909
B	-0.992	1.000	-0.950
C	0.909	-0.950	1.000

ANOVA(a)

Source	Sum of Squares	df	Mean Squares
Regression	19.639	3	6.546
Residual	0.445	3	0.148
Uncorrected Total	20.083	6	
Corrected Total	12.123	5	

Dependent variable: SEC

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .963.

Overall equation y=-6.709*CUF^2+4.229*CUF+2.557

Explanation:

The secondary sources referred to provided data in terms of energy consumption, capacity and production. A similar set of data was selected for few companies manufacturing same product making six set of data points. The data so collected was analyzed for the following relationships:

i. Specific Energy Consumption and Production

The relationship between SEC (Dependant Variable) and Production (Independant Variable) at 90% confidence level does not represent significant dependance. The coefficient of determination was much below unity indicating that production as independent variable does not quite well explains the variation in SEC in this case with the given set of data points.

ii. Specific Energy Consumption and Capacity Utilization Factor

The SEC and CUF not represent a good relationship in this example with the R-Square value very close to unity, as such CUF very well explains the variation in SEC. As such given the limited availability of data this model represents the best fit for PVC Resins. With the availability of more independent variables and more data points the above equation can further be refined to predict energy consumption as close to the actual energy consumed by the unit.

iii. Gross Energy Consumption, Production and Capacity Utilization Factor

The Energy Consumption (Dependent Variable) does not represent a relationship with Production and CUF (Independent Variables). The modelling of these variables provide a very low value of R-square much less than unity.

Regression Model SPSS output for HDPE/LLDPE plants

Notes

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	Definition of Missing	User-defined missing values are treated as missing.		
	Cases Used	Statistics are based on cases with no missing values for any variable used. Predicted values are calculated for cases with missing values on the dependent variable.		
Syntax		MODEL PROGRAM A=10 B=1 C=1 . COMPUTE PRED_ = A+ B * X1 + C * X2. NLR Y		
Resources	Elapsed Time	0:00:00		

Iteration History(b)

Iteration Number(a)	Residual Sum of Squares	Parameter A	Parameter B	Parameter C
1.0	436,243,664,628.275	10.000	1.000	1.000
1.1	1,059,368,688.037	211,534.906	14,364,084.969	-35.418
2.0	1,059,368,688.037	211,534.906	14,364,084.969	-35.418
2.1	296,772,553.286	256,269.390	17,327,615.110	-42.792
3.0	296,772,553.286	256,269.390	17,327,615.110	-42.792
3.1	296,772,553.254	256,279.366	17,328,290.976	-42.794

Derivatives are calculated numerically.

a. Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b. Run stopped after 6 model evaluations and 3 derivative evaluations because the relative reduction between successive residual sums of squares is at most SSCON = 1.00E-008.

Parameter Estimates

Parameter	Estimate	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
A	256,279.366	200,685.418	-382,391.200	894,949.933
B	17,328,290.976	13,590,990.082	-25,924,305.197	##########
C	-42.794	33.632	-149.826	64.239

Correlations of Parameter Estimates

	A	B	C
A	1.000	1.000	-1.000
B	1.000	1.000	-1.000
C	-1.000	-1.000	1.000

ANOVA(a)

Source	Sum of Squares	df	Mean Squares
Regression	4,240,421,834.746	3	1,413,473,944.915
Residual	296,772,553.254	3	98,924,184.418
Uncorrected Total	4,537,194,388.000	6	
Corrected Total	2,349,098,321.333	5	

Dependent variable: Energy

a. R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .874.

Overall equation **y=256279.366+17328290.976*CUF-42.794*Prodn**

Explanation:

The secondary sources referred to provided data in terms of energy consumption, capacity and production. A similar set of data was selected for few companies manufacturing same product making six set of data points. The data so collected was analyzed for the following relationships:

i. Specific Energy Consumption and Production

The relationship between SEC (Dependant Variable) and Production (Independant Variable) at 90% confidence level does not represent significant dependance. The coefficient of determination was much below unity indicating that production as independent variable does not quite well explains the variation in SEC in this case with the given set of data points.

ii. Specific Energy Consumption and Capacity Utilization Factor

The SEC and CUF also do not represent a good relationship in this example with the R-Square value not close to unity

iii. Gross Energy Consumption, Production and Capacity Utilization Factor

The Energy Consumption (Dependent Variable) represents a strong relationship with Production and CUF (Independent Variables). The modelling of this variables provided a good relationship with R-square close to unity. As such given the limited availability of data this model represents the best fit for PSF. With the availability of more independent variables and more data points the above equation can further be refined to predict energy consumption as close to the actual energy consumed by the unit.

Category B

Linear Regression results with Total Energy Consumed(MMKCAL) as Dependent Variable (y) and Production in MT (x) as Independent variable								
			ANOVA output					
Sr No	**Name of Product**	**Value of R square**	**Value of Regression SS**	**Value of Residual SS**	**F test**	**Sig (α)**	**Regression Equation**	**Conclusions**
1	1,3 Butadiene	0.792	1.061E7	2780078.945	38.16	0	Y = 5876.263+ 1.161*x	Value of R square indicates that degree of correlation is high. Values of RSS and ESS (residual) indicate that much of the variability is accounted for by the regression model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.
2	Polyvinyl Chloride (PVC)	0.794	4455623.207	1159329.71	38.43	0	Y = 2767.166 + 1.015 * x	Value of R square indicates that degree of correlation is high. Values of RSS and ESS (residual) indicate that much of the variability is accounted for by the regression model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.
3	Benzene (PGH-BZ)	0.428	9953901.875	1.33E+07	7.48	0.021	Y = 9923.424 + 0.941 * x	Value of R square indicates that degree of correlation is low. Values of RSS and ESS (residual) indicate that much of the variability is accounted for by the residual model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.
4	Propylene (FPU)	0.448	1353866.68	1668367.987	8.11	0.017	y = 1390.848 + 0.825 * x	Value of R square indicates that degree of correlation is low. values of RSS and ESS (residual) indicate that much of the variability is accounted for by the residual model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.
5	Ethylene Oxide (E.I. EQ EO)	0.913	2.64E+07	2.498E+06	105.56	0	y = 469.847 + 5.665 * x	Value of R square indicates that degree of correlation is high. Values of RSS and ESS (residual) indicate that much of the variability is accounted for by the regression model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.

Linear Regression results with Total Energy Consumed(MMKCAL) as Dependent Variable (y) and Production in MT (x) as Independent variable								
			ANOVA output					
Sr No	**Name of Product**	**Value of R square**	**Value of Regression SS**	**Value of Residual SS**	**F test**	**Sig (α)**	**Regression Equation**	**Conclusions**
6	Ethylene, CGP & PGP	0.982	3.15E+09	5.82E+07	144.54	0	y = 48641.360 + 4.842 * x1 + 8.104* x2 – 0.037 * x3	Value of R square indicates that degree of correlation is high. Values of RSS and ESS (residual) indicate that much of the variability is accounted for by the regression model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.
					243.46	0	y = 48763.397 + 4.827 * x1 + 8.074 * x2	Value of R square indicates that degree of correlation is high. Values of RSS and ESS (residual) indicate that much of the variability is accounted for by the regression model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.
7	LDPE	0.925	4.951E+07	4.025E+06	123.00	0	y=3803.12 + 2.281 * x	Value of R square indicates that degree of correlation is high. Values of RSS and ESS (residual) indicate that much of the variability is accounted for by the regression model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.
8	Vinyl Chloride Monomer (VCM)	0.83	1.561E+07	3201424.605	48.77	0	y = 3673.380 + 1.970* x	Value of R square indicates that degree of correlation is high. Values of RSS and ESS (residual) indicate that much of the variability is accounted for by the regression model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.
9	Polypropylene copolymer (PPCP)	0.78	1973573.624	557866.626	35.38	0	y = 1100.837 + 0.989 * x	Value of R square indicates that degree of correlation is high. Values of RSS and ESS (residual) indicate that much of the variability is accounted for by the regression model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.

Linear Regression results with Total Energy Consumed(MMKCAL) as Dependent Variable (y) and Production in MT (x) as Independent variable								
			ANOVA output					
Sr No	**Name of Product**	**Value of R square**	**Value of Regression SS**	**Value of Residual SS**	**F test**	**Sig (α)**	**Regression Equation**	**Conclusions**
10	PP IV	0.535	1922761.722	1669055.278	11.52	0.007	y = 3519.397 + 0.286 * x	Value of R square indicates that degree of correlation is low. Values of RSS and ESS (residual) indicate that much of the variability is account for by the residual model. Since p or α is < 0.05 the model is good enough for predicting the outcome variables
11	PBR -II	0.642	3058013.685	1706778.565	17.92	0.002	y = 4760.903 + 2.497 * x	Value of R square indicates that degree of correlation is high. Values of RSS and ESS (residual) indicate that much of the variability is account for by the regression model. Since p or α is < 0.05 the model is good enough for predicting the outcome variable.
12	PBR - I	0.179	471722.720	2163608.280	2.18	0.171		Sig> 0.05 and R square is not significantly different from zero, hence model is not very significant and we cannot find a satisfactory relationship between the dependent and independent variables using this data.
13	Acrylo Nitrile(ACN)	0.40	2934637.234	4398803.015	6.67	0.027		Value of R square indicates that degree of correlation is low, values of RSS and ESS(residual) indicate that much of the variability is account for by the residual model. Since p or α is < 0.05 the model is good enough for predicting the outcome variables