

PROJECT PRE-FEASIBILITY REPORT

for

Proposed Expansion Projects

at



Jamnagar Manufacturing Division

V 18/10/2019

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Chapter 1

Introduction

1. Introduction

M/s Reliance Industries Limited (RIL) operates an integrated petroleum refinery + petrochemical complex, referred to as the Jamnagar supersite, which includes associated utilities, offsites and infrastructure facilities, at Motikhavdi village, in the Jamnagar district of Gujarat. India.

The Jamnagar supersite represents a prime example of a cluster development, comprising of the following interlinked clusters:

- DTA or domestic tariff area refinery
- SEZ or special economic zone refinery
- Petrochemical complex
- Gasification complex
- Utilities, offsites and infrastructure facilities

The Jamnagar supersite refines crude oil to produce petroleum products and petrochemical feedstocks + products.

Utilities for the Jamnagar supersite include seawater intake and outfall facilities, seawater storage and treatment facilities, integrated desalination and effluent treatment plants. Utilities also include captive co-generation power plant to supply 100% power and steam to the Jamnagar supersite.

Offsites for the Jamnagar supersite include a marine tank farm to logistically support crude receipt + product shipping; refinery tank farm to seamlessly support the supersite operations; and rail/road tank farm + warehouses to support efficient storage + dispatch of refinery products.

The infrastructure facilities, to support the Jamnagar supersite, include deep water Single Point Moorings (SPMs) for the receipt of crude oil + export of petroleum products and associated pipelines; liquid jetties + shipping berths, and associated pipelines + approaches to the jetties for dispatch of products; RO-RO jetty + LO-LO

jetty for handling project cargoes; on-shore terminals for storage of crude + products and rail + road loading and unloading bays.

Jamnagar is connected to the cross-country pipelines for inland LPG distribution + regasified LNG receipt.

The existing Environmental Clearance (EC) for the crude refining capacity of the Jamnagar supersite is 68.2 Million Tons Per Annum (MMTPA).

The Jamnagar refinery, started operations at 18 MMTPA, in 1999. The existing refining capacity was enhanced to 33 MMTPA, via debottlenecking + value / product maximization, plus a new 26.7 MMTPA refinery capacity added, subsequent to obtaining the environmental clearance from the Ministry of Environment and Forest (MoEF), for 59.7 MMTPA, in 2005. Further expansion to 68.2 MMTPA was operationalized, in 2011, after obtaining Environmental Clearance from MoEF, in 2010.

The Jamnagar supersite is a global refinery icon, because:

- Largest refinery, at a single location
- Largest refinery off-gas cracker, for deep refinery-petrochemical integration
- Largest petcoke gasification, for a “bottom-less” refinery
- High complexity, for maximum crude-to-product flexibility
- High energy efficiency, for low ecological footprint
- Advanced automation, for effective monitoring, control and optimization

The Jamnagar supersite represents the pride of a resurgent India.

Aligned to the national “Make-in-India” objective, RIL plans to optimally leverage the Jamnagar refinery + gasification assets, as a future growth platform, to maximize petrochemicals, termed as “crude-to-chemicals”.

1.1. Need for the Proposed Projects.

The proposed Jamnagar growth projects shall boost India’s development and prosperity objectives. Following strategies have been adopted for RIL’s future projects in Jamnagar.

- Upgrade advantage Jamnagar feeds, via molecule management, to value-added petrochemicals and thereby reduce India’s high chemical imports.
- Employ disruptive technology innovation to minimize the cost of chemicals to ensure global competitiveness
- Supply competitive chemicals for labour-intensive secondary and tertiary processing sectors to boost India’s employment potential
- Usher in future-forward digitalization technology for “Smart Manufacturing”
- Leverage existing assets to cost-efficiently transform Jamnagar for crude-to-chemical
- Ensure responsible, circular use of chemicals to eliminate the scourge of plastic waste

The proposed crude-to-chemical mission shall leverage following advantage feeds for competitive chemicals:

- Reroute petcoke gasification derived syngas + CO from fuel to C1 chemicals
- Upgrade refinery streams, to olefins-based C2 + C3 chemicals.
- Value add C6 - C11 streams to aromatics-based chemicals
- Ultimate goal is to maximize value

1.1.1. **Multi-Feed Steam Cracker (MFSC)**

Maximize chemical monomers, by upgrading refinery's saturated light streams, priced lower than crude, via stream cracking, in a MFSC.

1.1.2. **Multi-zone catalytic cracking (MCC):**

Further, maximize chemical monomers, by upgrading refinery unsaturated light streams + heavy streams, via catalytic cracking. MCC represents the ultimate in catalytic cracking conversion + severity, termed as an ultra-severity FCC.

The existing FCCs at Jamnagar shall be sequentially converted to high severity FCC or Petro FCC. Petro FCC maximizes olefins + aromatics instead of gasoline.

The Jamnagar crude-to-chemical transformation is accomplished by an optimal combination of MFSC + PetroFCC conversion + MCC

1.1.3. **C1 complex**

The petcoke gasification generates carbon-rich syngas, an excellent feedstock for carbon-rich C1 chemicals. The Jamnagar growth projects propose to leverage this CO-rich syngas, as a fountainhead for a world-scale + world-class C1 complex, comprising of the following indispensable C1 chemicals:

- Acetic acid
- Acetic anhydride
- Acetic acid derivatives of ethyl acetate + VAM, or vinyl acetate monomer
- VAM derivative of VAE or vinyl acetate ethylene
- DME, or di-methyl ether

DME is especially versatile, as both fuel + petrochemical feedstock. The Jamnagar DME shall be shipped to other RIL sites, to convert to olefins.

1.1.4. **C2 complex**

Ethylene shall be sourced primarily from the MFSC + MCC + ROG Cracker debottlenecking.

Petro FCC conversion increases C₂ content in the refinery off-gas, requiring a ROG Cracker debottlenecking for additional ethane-to-ethylene.

This ethylene shall be the building block for the following C2 chemicals:

- Poly ethylene
- Ethylene oxide + MEG or mono ethylene glycol
- Ethylene oxide derivatives of DEG and TEG
- EDC + VCM + PVC for the vinyl chain

These C2 chemicals are vital because MEG a fibre intermediate, can clothe India and PVC, used for pipes, can support India's agriculture + housing sectors.

1.1.5. **C3 complex**

Propylene shall be sourced primarily from the MCC + MFSC.

This propylene shall be the building block for the following C3 chemicals:

- Poly propylene
- Acrylic acid
- Acrylic acid derivatives of acrylates + SAP
- Oxo alcohols
- Cumene + phenol/acetone
- Acetone derivative of iso-propyl alcohol
- Phenol derivative of polycarbonate, via non-phosgene, safe processing
- PO or propylene oxide

- PO derivative of polyols

Acrylic chemicals support paints for housing and hygiene products. Phenolic chemicals support engineering plastics to light-weight transport. Polyols support polyurethanes a wonder plastic with diversified uses.

1.1.6. C4 complex

Butadiene shall be generated as a co-product from MFSC, supplemented by on-purpose dehydrogenation of butenes.

The Jamnagar butadiene shall be shipped to other Reliance sites, to feed SBR or styrene butadiene rubber + PBR or poly butadiene rubber.

1.1.7. Aromatics complex

Benzene, an exportable Jamnagar surplus, shall be supplemented by MFSC + MCC, via BTX extraction.

This benzene, shall be the building block for following benzene based chemicals:

- Styrene
- Polystyrene

Refinery C7 shall be upgraded to maximum toluene, in a high-severity catalytic reformer.

Toluene, sourced from BTX extraction + high-severity catalytic reformer, shall be converted to additional xylenes via new toluene methylation + debottlenecking alkylation.

Mixed xylenes, sourced from BTX extraction + toluene methylation + transalkylation shall maximize PX, via PX recovery.

The Jamnagar PX shall be shipped to other RIL sites, to feed PTA + polyester for labour - intensive textile sector.

1.2. Proposed Land Use

For setting up the crude-to-chemical growth projects in Jamnagar, RIL proposes to develop a total area of 2000 acres adjacent to the existing Jamnagar supersite.

The plot plan indicating the location of the proposed projects are enclosed as **Figure 1.1.**

1.3. Project Setting

Jamnagar district lies in the peninsular region of North West, India, in the state of Gujarat, known as Saurashtra. The Jamnagar district boundary to the north is the Gulf of Kutch, to the East by Rajkot district, to the South by Junagadh district and to the West by Devbhoomi Dwarka District and the Arabian Sea.

The Jamnagar region falls in an arid zone. The area is covered by Deccan trap basalt of cretaceous age. Existing land use is mainly scrub land (wasteland), followed by fallow land. The site has been selected for the development of proposed projects because it does not compete with agriculture or farming.

Recent, industrial development by public sector undertakings, private sector organizations and port development has ushered in a recognizable economic boom, leading to all-round prosperity + higher standard of living in Jamnagar + surrounding areas.

The latitude and longitude of the center of the proposed complex is 22°20.115'N and 69°53.247' E.

Jamnagar is a recognized centre for the Brass industry + Bandhani fabrics (tie-&-dye work on fabrics) + Zari sarees + Silk & Gold embroidery. Other major

manufacturing sites in the adjoining area include Thermal Power Plant of the Gujarat Electricity Board, Cement manufacturing unit of Digvijay Cements, Refinery of Nayara, earlier Essar, and a Fertilizer unit of the Gujarat State Fertilizer Corporation.

Other industries, including agro & food processing, biotechnology, chemicals & allied industry, drugs & pharmaceuticals, gems & jewelry, engineering including automotive, are also located in the Jamnagar district of Gujarat.

The existing industrial estates by GIDC around the Jamnagar site include:

- Shankar Tekri industrial estate, Jamnagar1
- Kamsudra industrial estate, Jamnagar 2
- Dared industrial estate, Jamnagar 3
- Jam Khambhaliya industrial estate
- Bhatia (RIDC)

The following siting criteria, delineated by MoEF&CC, New Delhi has been strictly followed by RIL, for locating the proposed projects:

- The project will be located on barren land and the proposed expansion shall be within the land belonging to RIL.
- The land proposed for expansion is a barren arid land and has sufficient space to provide for a green belt.
- Layout and form of the project will conform to the landscape, without affecting any geographical features.
- The scenic beauty of the area shall increase with the green belt around proposed growth projects.
- Associated township for the proposed growth project can be developed taking into account the predominant + prevailing wind direction.
- The proposed growth projects will not fall within the prohibited CRZ area or the forest area.

In addition to the siting criteria listed above, the proposed project location has been reviewed for the following salient features:

- Although the site is not prone to natural disasters, the proposed growth projects shall be designed to the seismic codes specified by ISI and allied agencies. It is pertinent to note that Gujarat Earthquake of 2002 with epicenter near Bhuj, did not adversely impact the integrity of the Jamnagar Refinery.
- The process, for which environment clearance (EC) has been available since 2010.
- Water for operation will be made available from the proposed desalination plant.
- Roads with adequate width and capacity are available to handle the increase in traffic load.
- Construction materials will be principally sourced from local & neighboring area to avoid long distance transportation. Stone chips and aggregates for construction will be sourced from within the land acquired by RIL, to be mixed in batching plants. Sand will be sourced from govt. approved vendors / quarries.

1.4. Locational Advantages

The principal drivers for the proposed growth projects in Jamnagar are:

- Maximize value addition of crude refined.
- Minimize the cost of production, with process integration + technology innovation.
- Exploit economies of scale to ensure capex competitiveness.
- Ensure sustainability, with bespoke application + circularity adoption.
- Leverage world class infrastructure and logistics facilities at Jamnagar to ensure global competitiveness.

Proposed growth projects in Jamnagar leverages the following strengths.

- RIL has a successful track record in executing mega + technically complex projects, upholding the highest standards of health, safety and environmental protection.
- An enviable project implementation record of high quality + low capex + accelerated schedule
- The material supply, in the form of polymers + polyesters, shall spawn ancillary and derivative industries, with high employment + import substitution potentials.
- Jamnagar is ideally located in western India, having the highest chemical/polymer consumption + established secondary processing platform for easy product absorption.
- Access to the deep draft port facilities shall streamline machinery intake + product offtake.
- The proposed project location meets the following siting criteria/guidelines of the MoEF:
 - Located away from the CRZ areas
 - Barren land
- The proposed project location is well connected with the national and state highways.

1.5. Proposed Projects

The details of the proposed projects are given in Table 1.1. In addition to the projects listed in Table 1.1 the infrastructure for storage and dispatch of the products will also be established. This will include facilities for road and rail transportation, modification of the existing marine facilities for solid handling etc. The residential township will also be expanded for accommodating additional personnel / employees required for construction as well as O & M of the projects.

1.6. Need for Environmental Clearance: Categorization of the Project

The company needs to obtain the Environmental Clearance prior to construction of the proposed expansion projects as per the EIA Notification of 14th September 2006 including its amendments. The proposed projects, as per the Schedule of the EIA Notification 2006, may be categorised to be covered by 1 (d) Thermal Power Plant, 4 (a) Petroleum Refining, 5(a) Fertilizers, 5(c) Petrochemical Complexes, 5(f) Petrochemicals with Synthetic Rubbers and 1(a) mining of minor minerals .

The water requirement for the projects will be met by desalination and the return sea water discharge from the desalination plant will require CRZ clearance for discharge as it will be in CRZ IV region.

Mining of minor minerals to source stone for crushing to stone chips, within the site, will also be required to be approved vide the same clearance.

1.7. Capital Cost of the Project

The overall capital cost of the proposed project will be Rs. 70,000 Crores.

Table 1.1 - Details of the proposed unit capacities at JMD

Sr.	Projects	Growth Projects		Remarks
		Capacity	Feedstock	
		(kTA)	Feed stock	
A	Building blocks			
1	High severity FCCs	Conversion of FCCs to Petro FCC	Existing	Petro FCC conversion
2	MCC / HSFCC complex	320 kbpd feed	Heavy VGO/HCGO + cracked naphtha	New
2.1	C ₂ = + C ₃ = Recovery	8500 C ₂ = + C ₃ =	Light ends from MCC	
2.2	BTX+ Extraction	3500 feed	Aromatic naphtha from MCC	
2.3	Toluene Methylation	2600	Toluene / Methanol	From BTX+ extraction
2.4	Trans Alkylation	1000 feed	C ₉ + feed	From BTX+ extraction
2.5	Paraxylene	4000 PX + OX	Mix Xylenes	
2.6	Benzene	1600	Crude Benzene	From BTX+ extraction
3	ROG Cracker	520 C ₂ =	Propane / Off Gases	Debottlenecking
4	Multi-Feed Steam Cracker (MFSC) complex		PCN / LPG	New
4.1	C ₂ = + C ₃ = Recovery	4100 C ₂ = + C ₃ =	Offgases / C ₃ S	From MFSC
4.2	Butadiene (BD) Extraction	700	C ₄ mix	From MFSC
5	Aromatic complex	1300 PX	Naphtha / Methanol	Expansion
5.1	High Severity Reformer	90 kbpd feed	Naphtha / Imports	New
B	C1 Chemicals			
6.1	Acetic Acid (AA)	3000	CO / Methanol	
6.2	Acetic Anhydride	750	AA	AA derivative
6.3	Ethyl Acetate	1500	AA / Ethanol	AA derivative
6.4	VAM	1050	AA / C ₂ =	AA derivative

6.5	VAE + EVA	900	VAM / C ₂ =	VAM derivative
6.6	Poly Vinyl Acetate (PVAc)	300	VAM	VAM derivative
6.7	Poly Vinyl Alcohol (PVA _L)	150	PVAc	PVAc derivative
B	C1 Chemicals			
6.8	Formic Acid	400	CO	Syngas derivative
6.9	DME	2700	Syngas	Methanol substitute
6.10	Polyketone	350	CO / C ₂ =	Syngas derivative
6.11	Iso-Nonyl Alcohol (INA)	300	CO / C ₄ =	Syngas derivative
6.12	MMA	700	CO / C ₂ = / C ₄ =	Syngas derivative
6.13	PMMA	350	MMA	MMA derivative
6.14	Rare Gases	50	Air Separation Unit	Xe+Kr+Ne+Ar
6.15	Methanol	3600	Syngas	Syngas derivative
6.16	Ethanol	500	Syngas	Syngas derivative
6.17	NH ₃	1500	Syngas / N ₂	Incl. waste water recovery
6.18	Urea	2600	NH ₃ / CO ₂	NH ₃ derivative
C	C2 Chemicals			
7.1	VCM+PVC	4500	C ₂ = / Chlorine	EDC imports
7.2	MEG / DEG	4500	C ₂ = / Oxygen	
7.3	PE	3000	C ₂ =	Multi-grade
7.4	EPDM	240	C ₂ = + C ₃ =	Elastomer
D	C3 Chemicals			
8.1	Acrylic Acid	720	C ₃ =	
8.2	Glacial Acrylic Acid	150	Acrylic Acid	Acrylic Acid derivative
8.3	Oxo-Alcohols	740	C ₃ =	
8.4	Acrylates	800	Acrylic Acid	Acrylic Acid derivative
8.5	Cumene	1500	C ₃ = / Benzene	Phenol intermediate
8.6	Phenol	1000	Cumene	
8.7	Acetone	620	Cumene	Phenol by product
8.8	Bisphenol-A (BPA)	500	Phenol / Acetone	Phenol derivative

8.9	Polycarbonate	600	BPA / EO	Phenol derivative
8.10	Iso-Propyl Alcohol	250	Acetone	Acetone derivative
D	C3 Chemicals			
8.11	Propylene Oxide (PO)	1000	C ₃ =	
8.12	Polyols/Propylene Glycol (PG)	800	PO	PO derivative
8.13	Polypropylene	5200	C ₃ =	
E	C4 Chemicals			
9.1	PBR	280	BD	BD derivative
9.2	S-SBR	6500	BD / styrene	BD derivative
F	C6 and heavies			
10.1	Styrene, Polystyrene (PS)	1000	Benzene / C ₂ =	
10.2	Carbon Black (CB)	600	CSO	
10.3	Polyphenylene sulphide (PPS)	315	Benzene + S	
11	PDH	1500 C ₃ =	C ₃	Propane dehydro
12	Petcoke gasifier	8250	Coke/coal Refinery / Import	Debottlenecking
13	Battery Manufacture and Metals recovery	35	Petcoke cinder	Gasification
14	Power (MW)	2000	Gas / Liquid (Refinery)	
15	Mining of minor minerals (Stone chips)	25 Ha	Within RIL land area	

Chapter 2

Project Description

2. Introduction

The Jamnagar Refinery complex comprises of 2 existing side-by-side refineries – Domestic Tariff Area (DTA) and Special Economic Zone (SEZ), at Jamnagar, Gujarat.

The Jamnagar refinery complex has processed 150+ crude grades, which represents almost half of crudes grades traded globally. The Jamnagar refinery complex primarily produces transportation fuels and petrochemical products. Approx. 60% of products from the Jamnagar refinery complex are exported. The Jamnagar refinery complex is integrated with petrochemicals, utilities & power and ports & terminal facilities. Self-sufficiency in utilities and power is achieved, by sea water desalination, captive power plant and recycle & reuse of water. Technology is licensed from global licensing leaders for the Jamnagar refinery complex.

2.1. PetroFCC

Existing FCCs in the Jamnagar refinery complex maximizes yields of gasoline followed by propylene + ethylene. Increasing the operating severity, these FCCs can be converted to PetroFCC, which maximizes yields of propylene + ethylene

followed by gasoline. PetroFCC enables the Jamnagar transformation for oil-to-chemicals.

2.2. MCC / High Severity FCC

Multi-zone catalytic cracking (MCC) an ultra-severity FCC or high severity FCC (HSFCC) with customized catalyst, beyond the high severity PetroFCC. MCC / HSFCC employs a FCC type reactor – regenerator platform. The different zones of the MCC are optimized for the feed cracking propensity, with different cracking severity + residence time, to maximize ethylene + propylene yields from a range of feeds. Unlike Petro-FCC, MCC produces no gasoline, DME from the C1 complex can be a beneficial co-feed to the MCC. The reactor effluents are then sent to main fractionator for separation. The gases from main fractionator are concentrated in a typical FCC gas plant, to be sent to C₂= + C₃= recovery section. The bottoms from the main fractionator are recycled to the MCC reactor, after aromatics or BTX + recovery.

The spent catalyst from reactor flows to regenerator where the deposited carbon is burnt off to regenerate the catalyst.

2.3. ROG Cracker

ROG Cracker is operating above nameplate capacity. The additional Propane feed available at Jamnagar, will help to debottleneck the ROG Cracker. With additional Propane cracking and utilization of all Off Gas feed from refinery (including additional gases from revamp of DTA coker), ROG Cracker can be debottlenecked to sweat existing assets for additional olefins.

2.4. Multi feed steam cracker (MFSC)

As the name indicates, MFSC can crack naphtha minus light streams in to ethylene + propylene + butadiene + BTX or petrochemical building blocks. The hot section of the cracker consists of pyrolysis furnaces that crack the feedstock into ethylene, propylene and other light hydrocarbons. The hydrocarbon feedstock is preheated and cracked in the presence of steam in tubular SRT (Short Residence Time) pyrolysis furnaces. The cracked hydrocarbon products exit the furnace at >820°C and are rapidly quenched in the transfer line exchangers (TLE) that generate high pressure steam to boost energy efficiency. The pyrolysis/ quench systems are often designed to handle the full range of gaseous and liquid feedstock from ethane to naphtha. The number of cracking furnaces required is determined by ethylene output.

The MFSC comprises of the following constituent sections.

- Contaminant removal
- Cracking furnaces
- Primary fractionation
- Cracked gas compression and drying
- Cold box / demethanizer
- Refrigeration section
- Deethanizer/ethylene recovery
- Depropanize/propylene recovery

2.5. C₂= + C₃= recovery

The cracked gases from MCC + pyrolysis section of MFSC are routed to the common, integrated cold section. They are quenched first. The heavy hydrocarbons are separated from the light hydrocarbons. The light hydrocarbons are compressed, dried and sent to a series of fractionators termed as the cold section of the MFSC for primary ethylene + propylene recovery. First fractionator is demethanizer which separates the lightest gases, such as hydrogen and methane, out through the

overhead and into the cold box unit for providing cryogenic cooling of the cold section. The bottoms stream of the demethanizer flows to the deethanizer where in ethane, ethylene, and acetylene are recovered. The mixture is hydrogenated in an Acetylene Converter Reactor to reduce the acetylene levels to meet the final ethylene product specifications. The effluent from the reactor is fractionated in the C2 Splitter. Ethane leaves the bottom of the ethylene fractionator and is recycled back to feed the cracking furnaces of MFSC. The final ethylene product stream leaves the overhead of the C2 Splitter. The deethanizer bottoms and the heavy hydrocarbons from the compression system are routed to depropanizer. Polymer-grade propylene is produced by further purification of the depropanizer overhead; the MA/PD convertor removes the methylacetylene and propadiene from the C3's. The C3's are then split into the propylene product and propane. The depropanizer bottoms are separated into mixed C5+ and mixed olefins for sales or use in other process plants.

2.6. BTX+ extraction

BTX+ recovery technology uses extractive distillation to remove benzene, toluene, xylene and A₉-A₁₁ aromatics (BTX+) from refinery, aromatics streams.

The BTX+ extraction process consists of two columns: an extractive distillation column and a solvent recovery column. Hydrocarbon feed is preheated with hot circulating solvent and fed at a mid-point into the extractive distillation column. Lean solvent is fed at an upper point and selectively extracts the aromatics into the tower bottoms in a vapor/liquid distillation operation. The non-aromatics hydrocarbons exit from the top of the column. A portion of the overhead stream is returned to the top of the column as reflux, which washes back any entrained solvent.

Rich solvent from the bottom of the column is routed to the solvent recovery column (SRC), where the aromatics are stripped overhead. The SRC is operated under a vacuum to reduce the boiling point at the bottom of the column.

Lean solvent from the bottom of the SRC is passed through a heat exchanger before returning to the extractive distillation column. A small portion of the lean circulating solvent is processed in a solvent regeneration step to remove heavy decomposition products. The SRC overhead mixed aromatics product is routed to the purification section, where it is fractionated to produce chemical-grade benzene, toluene, xylenes and A₉-A₁₁ aromatics for downstream processing.

2.7. Toluene methylation

Toluene methylation is an effective and economical solution to maximize the PX yields by adding the methyl group from low-cost methanol or DME to the aromatic ring. DME / methanol and toluene, are fed to a reactor where in the toluene is alkylated into xylenes. The reactor effluent is processed in the fractionation section to produce the mixed xylene product. Unconverted toluene is separated and recycled back to the reactor. C₉+ aromatics fraction is also produced and separated, and is available as feedstock to the transalkylation unit, as the C₉+ cut is rich in tri-methyl benzene.

2.8. Trans-alkylation

Trans-alkylation process produces benzene and xylenes through transalkylation of the methyl groups from toluene and/or heavy aromatics streams. The technology features zeolite catalyst and can accommodate varying ratios of feedstock, while maintaining high activity and selectivity. The manufacturing process comprises of three main processing areas: splitter, reactor, and stabilizer sections. The heavy-aromatics stream (C₉+ feed) is fed to the splitter. The overhead A₉-A₁₁ product is the feed to the transalkylation reactor section. The splitter bottoms are exchanged with other streams for heat recovery before leaving the system. The aromatic product is mixed with toluene and hydrogen, vaporized, and fed to the reactor. The

reactor gaseous product is primarily unreacted hydrogen, which is recycled to the reactor. The liquid product stream is subsequently stabilized to remove light components. The resulting aromatics are routed to product fractionation to produce the final benzene and xylene products. The reactor is charged with zeolite catalyst, which exhibits both long life and good flexibility to feed stream variations including substantial A₁₁ aromatics.

2.9. Paraxylene (PX)

The Aromatics Complex comprises of Xylene Fractionation, Crystallization or Selective Adsorption and Isomers units. Xylene Fractionation column feeds mixed xylenes to the PX recovery process. PX is recovered from mixed xylenes, because of differences in either crystallization or adsorption, leading to PX, with a purity of 99.8 wt%, and recovery of 94-97 wt% of PX in a single pass.

In crystallization, successive crystallization is performed in 3 stages and the PX crystals are separated from the melt by multiple centrifuges.

In selective adsorption, PX gets adsorbed on molecular sieves and subsequently desorbed to get high purity PX.

2.10. Butadiene extraction

Butadiene extraction uses N-methylpyrrolidone (NMP) as a selective solvent to recover 1,3-butadiene from a crude C4 mix.

Before entering the extractive distillation, light components are separated from the crude C4 mix in a pre-distillation column. Then the feedstock enters the main washer column representing the first stage of the extractive distillation process. Butadiene and a part of the butenes are absorbed in the NMP solvent fed in from the top. The C4 raffinate is drawn off as the overhead product of the main washer column.

In the second extractive distillation stage after washer and part of the rectifier column separate the C4 acetylenes. In the degassing column the hydrocarbons are stripped from the solvent and recycled to the rectifier column using a compressor. The diluted C4 acetylenes are withdrawn as a side stream and, after passing a scrubber, are discharged to battery limits. The crude butadiene from the second stage of the extractive distillation is sent to the butadiene column for final purification. The butadiene product is withdrawn as a liquid side stream.

2.11. High Severity Reformer

High severity reformer is used to maximize the naphtha conversion to Aromatics-rich reformate, a feed source for PX recovery. High severity reformer adds a supplementary stand-alone reactor to the standard, moving bed, 3 reactor configuration to maximize C7 conversion to toluene. The reactors are integrated with fired heaters to support the endothermic reforming or crystallization process to aromatics. The reactors are supported by continuous catalyst regeneration. The catalyst contains Platinum, noble metal. The reforming reaction is driven by high temperature and low pressure, just above atmospheric.

2.12. C₁ based Units

2.12.1. Acetic Acid

Methanol and carbon monoxide are fed to the reactor, containing acetic acid, water, hydrogen iodide, methyl iodide, and the rhodium catalyst complex. Methanol reacts with hydrogen iodide to form methyl iodide, and in presence of rhodium catalyst reacts with carbon monoxide to yield product acetic acid.

Unconverted carbon monoxide leaves the top of the reactor and is cooled before flashing. The overhead stream from the reactor contains acetic acid, methyl iodide, water, methyl acetate, and traces of carbon monoxide and hydrogen iodide. This

stream is fed to the product separation column wherein a concentrated acetic acid stream is recovered as a side stream containing water, methyl iodide, methyl acetate, and traces of hydrogen iodide.

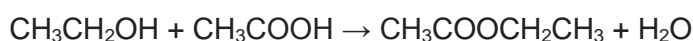
The concentrated acetic acid side stream from the product separation column is sent to the crude acetic acid column for further purification. The bottoms product from the crude acetic acid column consists of acetic acid with traces of water and hydrogen iodide. The acetic acid stream containing traces of water and iodine is fed to the acetic acid finishing column. High purity acetic acid is removed as a liquid side draw near the top of the column.

2.12.2. Acetic Anhydride

Acetic anhydride is manufactured by dehydration of acetic acid via ketene. Acetic acid is first thermally dissociated into ketene and H₂O, in the presence of tri-ethyl phosphate, at 700 - 750 °C and reduced pressure. The higher boiling components (acetic anhydride, acetic acid, and water) are separated from the gaseous ketene in a system of graduated coolers. After removing the water, they are recycled to the cracking stage. The ketene is fed directly into acetic acid, and converted at 45-55 °C and reduced pressures of 0.05-0.2 bar into acetic anhydride.

2.12.3. Ethyl Acetate

Ethyl acetate is synthesized via the Fischer esterification. Acetic acid and ethanol are mixed in presence of acid catalyst at room temperature to yield ethyl acetate.



Above reaction is an equilibrium reaction and yields 65% of ethyl acetate. To enhance the conversion, the reaction is shifted by continuous removal of water.

2.12.4. Vinyl Acetate Monomer (VAM)

Gas, containing ethylene, oxygen and acetic acid, is passed through tubular reactors containing supported palladium-gold and potassium acetate catalyst. At high temperature and pressure, ethylene is converted to vinyl acetate. The reaction product is cooled and the condensate is distilled to get vinyl acetate-water.

The distillate consisting of vinyl acetate and water is decanted with the organic layer distilled to remove acetaldehyde. The crude vinyl acetate, free of light ends and water is then further distilled and refined to pure vinyl acetate.

2.12.5. Vinyl Acetate Ethylene (VAE)

Vinyl acetate ethylene (VAE) emulsions are based on the copolymerization of vinyl acetate and ethylene, in which the vinyl acetate content can range between 60 and 95 percent, and the ethylene content ranges between 5 and 40 percent of the total formulation.

2.12.6. Ethylene Vinyl Acetate (EVA)

Ethylene Vinyl Acetate copolymer (EVA) is produced by the copolymerization of Ethylene and Vinyl Acetate under pressure, using free-radical catalysts. Many different grades are manufactured, with the Vinyl Acetate content varying from 5 to 60% by weight. High vinyl acetate content is termed as VAE. Low vinyl acetate is termed as EVA

2.12.7. Polyvinyl Acetate

Polyvinyl acetate is produced through emulsion polymerization.

The process involves the reaction of monomer molecules of Vinyl Acetate by submerging them into water resulting in the formation of a Polyvinyl Acetate emulsion that is milky white in color.

2.12.8. Polyvinyl Alcohol

Polyvinyl alcohol is prepared by partial or complete hydrolysis of polyvinyl acetate to remove acetate groups. The process of hydrolysis is based on the partial replacement of ester group in vinyl acetate with the hydroxyl group, and is completed in the presence of aqueous sodium hydroxide.

2.12.9. Formic acid

Methanol and carbon monoxide are combined in the presence of a strong base, to form methyl formate. This reaction is performed in the liquid phase at elevated pressure. Typical reaction conditions are 80 °C and 40 atm., with sodium methoxide as base.

Hydrolysis of the methyl formate produces formic acid. Efficient hydrolysis of methyl formate requires a large excess of water. For energy-efficient separation, the formic acid is removed from excess water by liquid-liquid extraction, with an organic base.

2.12.10. Di Methyl Ether (DME)

The syngas, derived from petcoke gasification, is cooled, compressed and passed to a tubular DME reactor. Reactor effluent is cooled, liquid separated and gas recycled to synthesis loop. The crude DME is filtered and distilled in columns.

Syngas-to-DME shall be a 1-step process, employing novel, high stability catalyst.

2.12.11. Poly-ketones

Poly-ketones are semicrystalline thermoplastics formed by the copolymerization of CO with ethylene.

A proprietary Palladium-based catalyst system is used for the liquid-phase polymerization reaction of CO, ethylene, and propylene. Polymerization takes place in a liquid reaction medium, of methanol, at 78-90°C and 45-50 bar. The reaction products are cooled and depressurized to flash unconverted CO and olefins, which are recycled to the process. The insoluble copolymer is concentrated and separated from the mother liquor by a solid-liquid separation technique. The copolymer product is then dried and bagged. Solvent is recovered through distillation or evaporation and recycled to the process. Reaction by-products and spent catalyst are discharged from the bottom of a distillation column/evaporator. These waste streams are sent for recovery of associated palladium.

Polyketones are either copolymer of CO + C₂= or terpolymer of CO + C₂= and C₃=

2.12.12. Isononyl Alcohol (INA)

Jamnagar is surplus in butenes. Dimerize butenes by liquid-phase oligomerization.

In the reaction section, dimerization takes place in multiple liquid-phase reactors using homogeneous catalysis and an efficient recycle mixing system. The catalyst is generated in situ by the reaction of components injected in the recycle loop.

The catalyst in the reactor effluent is deactivated in the neutralization section and separated for safe disposal.

The stabilization section separates unreacted olefin monomer and saturates from product dimers. The second column separates the octenes, and the third column separates dodecenes. Nearly 80% conversion of butenes can be attained with 85% selectivities toward octenes.

INA is obtained by hydroformylation of octene, to the corresponding C₉ aldehydes and the subsequent hydrogenation thereof.

2.12.13. Methyl Methacrylate (MMA)

This Isobutylene-based production of methyl methacrylate is a three-step process. The process employs a Pd₅Bi₂Fe catalyst supported on finely divided SiO₂-MgO.

In first step, isobutylene is sent through a vapour-phase fixed bed reactor with air or oxygen. Methacrolein is produced at 96% conversion. About 4%, of methacrylic acid is coproduced.

In the second step, the reactor effluents from first reactor are directly sent to a second vapour phase reactor in which the methacrolein is converted to additional methacrylic acid in about 76% yield.

Esterification of methacrolein takes place in a third slurry phase reactor with methanol. In the final step of the process, methacrolein, methanol, and oxygen (air) are reacted in the presence of a catalyst comprising transition metals such as nickel or cobalt and gold nano-particles. The catalyst is supported on a silica-magnesia or silica-alumina-magnesia carrier. The reaction takes place at 90–95°C and 85–110 psia. Methacrolein per-pass conversion is about 70%, and selectivity to MMA is 95–97%.

2.12.14. Polymethyl Methacrylate (PMMA)

Polymethyl Methacrylate is the homopolymer of Methyl Methacrylate (MMA). PMMA is produced through radical chain polymerization of MMA. Some product grades require comonomers.

2.12.15. Rare gases

The six naturally occurring noble gases are helium, neon, argon, krypton and xenon and the radioactive radon. Neon, argon, krypton, and xenon are obtained from air in an air separation unit by liquefaction of gases and fractional distillation. Distillation is a 2 step process for all rare gases except argon. First a concentrated solution is made. Each rare gas, except argon, is separated by super fractionation.

2.12.16. Methanol

Methanol will be produced from Synthesis gas, a mixture of hydrogen, carbon oxides, and methane under high pressure operations.

These gases react in the methanol converter in presence of Zinc-copper-aluminium oxide catalyst to form methanol and water. Gases departing from the bottom of the converter are cooled to condense crude methanol and water. This condensate flows to a pressure blow-down drum and then to a crude methanol storage tank. Uncondensed gases are recycled to the synthesis gas compressor.

The crude methanol is purified in fractional distillation column where low boiling compounds, like dimethyl ether, are removed overhead.

2.12.17. Ethanol

Waste gases, from petcoke gasification, H₂ recovery can synthesize ethanol via bio-fermentation.

CO is the preferred feed for microbes. Pure CO₂ can be added to saturate the carbon requirements for the microbes.

The bio-process has multiple bio-reactors to which waste gas steam is fed for fermentation which produces dilute ethanol mixture in water.

Fermentation media is fed to each bio-reactor to maintain optimal microbe performance. The fermentation broth contains a gas-liquid mixture to provide sufficient mass transfer between the phases.

Dilute ethanol is further concentrated and separated in vacuum column plus rectification column followed by ethanol dehydration.

2.12.18. Ammonia (NH₃)

Ammonia recovery from sour water

Sour water from refining + gasification process is passed through a de-gasser and de-oiler, where light hydrocarbons and other dissolved gases are removed.

The degassed sour water is settled in tank, to remove entrained oil and solids, via a solids filter and liquid-liquid coalescer. It is then fed to acid gas stripper, to remove acid gases.

The acid gas stripper bottoms, is fed to the ammonia stripper. The overhead gas contains raw ammonia. After purification, via water wash + caustic wash, the pure ammonia is compressed with inter-stage cooling, and sent to storage.

Ammonia from syngas

Syngas is first shifted to produce H₂. Hydrogen is then reacted with nitrogen to produce Ammonia to supplement NH₃ recovered from sour water.

2.12.19. Urea

Compressed CO₂ and ammonia are mixed in the urea reactor to form urea. Weak urea solution generated is concentrated in multiple stages. Final urea concentration is done in evaporators.

2.13. C₂ Based Units

2.13.1. Vinyl Chloride Monomer (VCM)

VCM is produced from ethylene-di-chloride and ethylene, over a mercuric chloride catalyst to produce vinyl chloride. The reaction is exothermic and highly selective to VCM, resulting in high yields + product purity.

2.13.2. Poly Vinyl Chloride(PVC)

PVC is produced by the suspension polymerization of VCM or vinyl chloride monomer. VCM and water are introduced into the reactor along with a polymerization initiator viz. dioctanoyl peroxide and/or dicetyl peroxydicarbonate. The contents of the reaction vessel are continuously mixed to maintain the suspension and ensure a uniform particle size of the PVC resin. The reaction is exothermic and requires cooling. PVC is denser than VCM hence the volume is reduced during the reaction, and hence water is continuously added to the mixture to maintain the suspension. The average molecular weights range from 45,000 to 64,000. PVC slurry is degassed and stripped to remove excess VCM, which is recycled. The polymer is then passed through a centrifuge to remove water. The slurry is further dried in a hot air bed, and the resulting powder is sieved before storage or pelletisation.

2.13.3. Ethylene Glycol (EG)

Principal EG products are mono ethylene glycol (MEG) and di ethylene glycol (DEG). Ethylene glycol is produced from ethylene in a 2-step process via ethylene oxide (EO) as an intermediate.

The MEG is produced by first converting ethylene-to-ethylene oxide (EO) through a direct oxidation process and then hydrolyzing the same.

Ethylene, recycle gas and oxygen are thoroughly mixed, preheated and passed through the EO reactor, where ethylene is converted into EO at elevated temperature and pressure. The reaction product gas is scrubbed with neutralising liquid to remove acidic compounds and further cooled in EO absorber by counter contact with water, which absorbs EO and forms a dilute aqueous solution. The gas after scrubbing and absorption of EO is recycled back to the reactor via a recycle

gas compressor. A small slip stream is taken to CO₂ removal section for removal of CO₂ formed in the reactor, by absorption in hot potassium carbonate solution. Dilute aqueous solution of EO in water is stripped off. EO from stripper are cooled, condensed and purified by passing through light ends columns, which removes lighter fractions. Purified EO mixture is heated, mixed with additional water and passed through tubular glycol reactor. The reaction takes place in liquid phase under elevated temperatures and pressure. The conversion is almost complete and the glycol water mixture is sent for evaporation.

In evaporation section, water is separated from glycol mixture in a triple effect evaporator with subsequent vacuum column.

Crude glycol mixture is separated into MEG, Diethylene Glycol (DEG) and Triethylene Glycol (TEG).

2.13.4. Poly Ethylene (PE)

Principal polymers of ethylene, or polyethylene, can be high density PE (HDPE), low density PE (LDPE) and linear low density PE (LLDPE). The process involves converting gaseous ethylene into solid phase PE by solution polymerization process, using cyclo-hexanes as the solvent.

A purified solution of ethylene, solvent and co-monomer (octene or butene or both) is fed to the reactor. Co-monomer is added for low-density PEs. Catalyst helps to polymerise the ethylene and co-monomer. A chain terminator agent is used to control molecular weight (polymer chain length).

About 95% of the ethylene is converted to PE on each pass. The molten polymer solution flows to the extruder which feeds an underwater pelletizer. The pellets formed are water conveyed to a continuous stripper to remove residual solvent, which is condensed and recovered. The stripped PE pellets are dried and fed to pneumatic blenders for blending into uniform lots.

2.13.5. Ethylene Propylene Diene Monomer (EPDM)

This process involves solution polymerization of monomers; ethylene, propylene and diene in the presence of Ziegler Natta catalysts. The solution polymerization process is the most widely used and is highly versatile for making a wide range of EPDM Rubber grades. Ethylene, propylene and dienes are polymerized in the presence of catalyst systems in an excess of hydrocarbon solvent. Stabilizers and oils, if used, are added directly after polymerization. The polymer, which is in crumb form, is dried with dewatering screens, mechanical presses and then by drying ovens. The crumb is formed into wrapped bales or extruded into pellets. The high viscosity crystalline polymers are sold in loosely compacted, friable bales or as pellets. The amorphous polymer grades are typically packed in solid bales.

2.14. C₃ Based Units

2.14.1. Acrylic acid

The propylene is oxidised with compressed air, and is converted into Acrolein and further the Acrolein is oxidized to Acrylic Acid. The effluent gas containing Acrylic Acid is quenched and absorbed with the descending water and the aqueous solution of acrylic acid is obtained. Part of the off gas with non-condensables such as acrolein, acetaldehyde, propane and unreacted propylene is recycled to the oxidation reactor.

Water and acetic acid are eliminated by azeotropic distillation. Ester grade acrylic acid is obtained from the top, while the bottom contains acrylic dimer and other heavy ends. Aldehydes and ketones contained in the crude acrylic acid react with the hydrazine hydrate forming hydrazone compounds. These are separated by distillation in the High Purity Acrylic Acid (HPAA) distillation column.

2.14.2. Glacial acrylic acid

The acrylic acid monomer solution is purified to produce glacial acrylic acid which can be polymerized to produce super absorbent polymer or SAP

2.14.3. Oxo-alcohols

2.14.3.1. n-Butanol

Syngas and propylene are fed to a primary hydroformylation reactor, over aqueous catalyst solution of Rhodium complex. The effluent then passes to decanter to separate the aqueous from the organic phase and to degas any entrained gases. The product is then passed through a decanter to remove remaining aqueous catalyst solution, prior to purification. The liquid effluent is distilled to separate the aldehyde products from the catalyst and the high-boiling byproducts. The crude butyraldehyde product from the secondary reactor system is combined with the product from the primary reactor system for purification.

Butyraldehyde is fed to cross-countercurrent heat exchanger where it is mixed with recycle H₂ gas for hydrogenation to produce n-butanol.

2.14.3.2. 2-Ethyl Hexanol

2-Ethyl Hexanol is also produced by catalytic hydroformylation of propylene with syngas, using rhodium catalysts. Since, the reactor effluent contains butanol and water impurities, the crude 2-ethyl hexanol product is purified by fractionation.

2.14.4. Acrylates

n-Butylacrylate is produced by esterification of acrylic acid in presence of acid catalyst. Acrylic acid and n-butanol in an equi-molar ratio are fed continuously to an agitated reactor in presence of acid based catalyst and polymerizing agents. The reactor is maintained at high temperature for faster reaction.

Ethyl acrylate is produced by substituting n-butanol with ethanol. Methyl acrylate is produced by substituting alcohol with methanol. 2-ethyl hexyl acrylate is produced by substituting alcohol with 2-ethyl hexanol.

2.14.4.1. Cumene

The Cumene process primarily consists of following sections:

- **Alkylation:** Alkylation of Benzene by propylene
- **Benzene recovery:** The benzene column recovers excess benzene from the alkylation and transalkylation reactor effluents for recycle to the reactors, removes the nonaromatic components which are contained in the benzene feedstock, and dries the fresh benzene being fed to the unit.
- **Cumene Column:** The bottoms from the benzene column is fed to the cumene column. This column separates the final cumene product from PIPB and heavies. The column is reboiled by high pressure steam, and low pressure steam is generated in the condenser. Cumene product is recovered as a distillate and the bottoms are pumped to the PIPB column.
- **PIPB Column:** The PIPB column recovers DIPB and most of the TIPB from the cumene column bottoms for recycle to the transalkylation reactor. PIPB is recovered as a side stream from this column, and fed to the transalkylation reactor for conversion to cumene.
- **Transalkylation:** The DIPB product from the PIPB column is mixed with benzene, and fed to the transalkylation reactor. DIPB and TIPB are partially converted to cumene with benzene. The effluent from the transalkylator flows to the benzene column for removal of the excess benzene and the subsequent recovery of cumene and PIPB.

2.14.4.2. Phenol and Acetone

Phenol and acetone are jointly produced from cumene by liquid phase oxidation of cumene to cumenehydroperoxide (CHP) followed by catalytic de-composition of CHP to phenol and acetone. Phenol, acetone, unconverted cumene, and by-products are then distilled in a series of distillation towers to recover high purity acetone and phenol, and recycle cumene.

Fresh and recycle cumene is fed to a series of oxidizers where cumene contacts air and is converted to cumene hydroperoxide (CHP). Over-head vapors from the oxidizers are cooled and condensed to recover cumene. Spent air is treated by passing it through carbon beds to adsorb residual cumene.

2.14.4.3. Bis phenol A (BPA)

BPA is produced by the condensation of phenol and acetone in the presence of an acid catalyst typically hydrochloric acid and methyl mercaptan as promoter. Acid and phenol are recovered from the reactor effluents. The BPA is washed with water, neutralised with calcium hydroxide and distilled under vacuum to purify the BPA.

2.14.4.4. Polycarbonate

Polycarbonate is produced by trans-esterification of di phenyl carbonate (DPC) with BPA in two stages. The process is commonly known as melt process having advantage of producing polycarbonate in undiluted form which can be directly palletised.

DPC is produced by using an intermediate di-alkyl carbonate, usually dimethyl carbonate (DMC), as the source of carbonate functionality. In first step phenol is reacted with dimethyl carbonate to make phenyl methyl carbonate. In second step phenyl methyl carbonate is reacted with phenol to convert to DPC.

BPA and DPC are reacted and phenol is removed to produce a pre-polymer of Polycarbonate. Polymerisation to a higher molecular weight polycarbonate occurs primarily through an ester disproportionation whereby DPC is formed and recycled.

2.14.5. Iso-propyl Alcohol (IPA)

IPA can be manufactured by indirect hydration of propylene, called the sulfuric-acid process. In the indirect-hydration process, propylene is reacted with sulfuric acid to produce mono- and di-isopropyl sulfates, which are then hydrolysed to isopropanol. In the two-step strong-acid process, separate reactors are used for the propylene-absorption phase and the hydrolysis of the sulfate esters. The reaction occurs at high sulfuric acid concentration (> 80% wt) and low temperature (e.g. 20–30 °C).

2.14.6. Propylene Oxide (PO)

The unit consists of three process sections:

- Reduction and oxidation of a working solution
- Recovery and purification of hydrogen peroxide solution
- Working solution regeneration.

The working solution selected is a mixture of ethylanthraquinone (EAQ), tetrahydroethylanthraquinone (THEAQ), its corresponding hydroquinone (THEAHQ), and inert compounds in a mixed solvent of 21.4-wt% triethylhexyl phosphate and 76.6-wt% aromatic solvent (mixed alkylbenzenes). The purified product is a 37-wt% hydrogen peroxide solution. The propylene and hydrogen peroxide solution flow counter-currently in the epoxidation reactors. The bottom stream from reactor is fed into crude PO column. Crude PO stream is recovered as overhead and is sent to the PO purification section for further purification to recover PO with 99.98% purity. The TBA/water solvent is recycled after the removal of methanol in column.

2.14.7. Polyols / Propylene Glycol (PG)

Catalytic polymerization of PO result in the production of polyols.

Propylene Glycol is produced by high pressure, high temperature, noncatalytic hydrolysis of Propylene Oxide. A large excess of water is used in the conversion of Propylene Oxide to a mixture of Mono-, Di-, and Tripropylene Glycols. This increases the selectivity of desired Mono-product. Water is recycled. Typical product distribution is 90% Propylene Glycol and 10% coproducts.

2.14.8. Polypropylene (PP)

PP can be in 3 product forms, termed as either homopolymer or random copolymer or impact copolymer.

Propylene polymerisation to PP, in presence of hydrogen and catalyst, in a fluidized bed reactor form homopolymer resin.

Polymerisation of ethylene and propylene to PP in presence of hydrogen and catalyst in a fluidized bed reactor form random copolymer resin.

Homopolymer PP reacted further, with ethylene, propylene and hydrogen in a second reactor form impact copolymer resin.

Only one type of resin can be produced per line in a batch mode. The resin is then sent to resin degassing and unreacted monomers are sent to vent recovery and are recycled back to reactors after separation.

Wet degassed resin is sent to finishing section, wherein additives are added to stabilize the resin, and extrude it to pellets of uniform size.

2.15. C₄ Based Units

2.15.1. PBR

First step is purification of solvent and monomers through distillation operations, and catalyst preparation. It is fed to the first reactor of the polymerization train. The dry mix feed (butadiene and hexane) coming from the purification systems is fed to the reactor together with the catalyst solution. Butadiene polymerization takes place in continuous stirred reactors operating in series.

The polymer solution leaving the reactors is mixed with the stopping agent to destroy the catalyst and then is discharged into blend tanks in order to homogenize the product. Vapor coming from blend tanks are condensed and sent to column to separate and recycle the non-reacted monomer. The blended solution with the antioxidant agents is fed to the stripping section where the solvent is removed by steam distillation in the presence of a dispersing agent aimed to control the crumb size in the slurry.

The crumb slurry is then pumped to the finishing unit, where the crumb is dewatered on a shaker screen, being the water partly re-circulated to the strippers and partly sent to waste water treatment. The vapors obtained from the stripping section are otherwise condensed and the solvent, separated from water by a decanter, is sent to the wet solvent tank. The dewatered crumbs are dried in two mechanical extruders in series, cooled with air, weighed and baled.

2.15.2. S-SBR

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 bales and wrapped in bags for shipment.

2.16. C₆ + Units

2.16.1. Styrene / Polystyrene

The benzene and ethylene are fed to the zeolitic, liquid phase reactor. Ethylene feed reacts completely, leaving only inert constituents. Poly ethyl benzene that are produced by successive alkylations are transalkylated with benzene to produce additional EB.

The benzene column recovers and recycles benzene from the reactor effluent. Two other columns recover EB which is sent to the dehydrogenation section, and PEBs which are recycled to the reactor section. The EB is then catalytically dehydrogenated to styrene in the presence of steam.

Polystyrene is formed from styrene through suspension polymerization, a process by which tiny drops of the monomer (in this case, styrene) are completely surrounded by water and a mucilaginous substance. Supporting and surrounding the styrene globules, the suspension agent produces uniform droplets of polystyrene.

Next, a polymerization initiator is added to the droplets, which are suspended by heat radiation of about 100°C. This results in free radicals, a group of atoms particularly likely to react with others because they contain unpaired electrons which are available for molecular bonding. Free radicals then combine at randomly to form chains of polystyrene.

Stopping the polymerization process is difficult. Terminators are introduced to the process to end it at the appropriate time. Though variable, chain length must fall within a certain range, because polystyrene with overly long chains won't melt readily, and polystyrene with short chains will be brittle.

2.16.2. Carbon Black (CB)

Carbon Black is produced by partial oxidation of highly aromatic oils like CSO from FCC. in a reactor. The reactor effluent is carbon laden flue gas along with some combustible materials. Sensible heat from the flue gas is recovered in a waste heat boiler to produce high pressure steam. Cooled flue gas containing carbon black product is sent through bag filters to recover carbon black. Carbon black recovered is sent to pelletizer and then to packing.

2.16.3. Poly-phenylene Sulfide (PPS)

Poly-phenylene sulphide (PPS), a form of engineering plastic is composed of sulphur and benzene. Benzene reacted with sulphur to produce phenylene-sulphide, which is then polymerized to PPS. Poly-phenylene sulphide can be moulded, extruded, or machined to high tolerances.

The process is 2 step, a pre-polymerization, followed by polymerization.

This process replaces the conventional process which produces large quantity of effluents, and also leads to presence of salts in the conventional PPS process. Unlike conventional processes, it doesn't need solvent during polymerization of PPS.

2.17. PDH

Propane, sourced from the refinery complex can be dehydrogenated to propylene. Process is catalytic dehydrogenation of propane to propylene. The unconverted propane is recycled back with the fresh propane.

There are 3 reactor options for the highly endothermic PDH reactions:

- Fixed bed, swing reactor, with heat generating matter

- Moving bed reactor, with continuous catalyst regeneration
- Fluidized bed reactor- regenerator, similar to a FCC

The propylene-rich reactor effluent is compressed, dried and sent to a cryogenic separator where hydrogen is recovered. The olefin product is then sent to a selective hydrogenation process where dienes and acetylenes are saturated to mono-olefins.

2.18. **Petcoke Gasification:**

The processing objectives for the expansion of Petcoke Gasification are:

- Support expanded crude oil refining and petrochemicals manufacturing, with cost competitive, petcoke based energy supply
- Maximize reliability and availability of energy supply to the Jamnagar supersite
- Generate on-site syngas via petcoke gasification to minimize costly LNG imports
- Reform CO_2 , a gasification waste, to manufacture additional syngas, as petrochemicals feedstock
- Minimize carbon footprint + environmental impact with clean syngas instead of dirty petcoke/coal via petcoke gasification
- Supply syngas as an advantage feed for the C1 chemical complex.

The gasification is partial oxidation of coke with O_2 . Coke gasification reaction converts coke into syngas. The primary constituents of syngas are CO and H_2 . Syngas can be a gas turbine fuel, which can produce power in a combined cycle. Syngas can produce hydrogen, C1 chemicals and oxygenated chemicals.

The major elements or processing sections for the project are:

- Feed preparation to prepare petcoke/coal slurry to feed gasifier
- Gasification, partial oxidation at very high temperature to generate syngas
- Gas handling, to clean-up and cool raw syngas
- Sour block, to recover acid gases and generate sulphur
- Air Separation Unit (ASU) to supply O_2

2.19. **Battery Manufacture and Metals recovery**

Batteries are basic components to ensure wide spread and efficient usage of renewable energy. It is proposed to manufacture state of the art high capacity batteries due to the resources available at Jamnagar. The high capacity batteries will require raw materials like vanadium and Nickel.

Metals are natural ingredients of crude. In the refining and coking process these metals are retained in the petcoke. In the process of Gasification of petcoke these metals are retained in the petcoke cinder produced. The recovery of these metals like Vanadium will provide valuable resources for the endeavor towards renewable energy and India's self sufficiency in valuable raw materials required for manufacture of batteries using indigenously available materials.

Metals recovery is a combination of roasting + pyro-metallurgy + hydro-metallurgy. Pyro-metallurgy can recover the metals as ferro-vanadium and Ni as ferro-nickel by exploiting the eutectic temperature differences in a series of furnaces, to progressively separate into metal phase. Further Hydro-metallurgy can recover V as V_2O_5 from V rich intermediate sourced from the furnaces.

V_2O_5 is used as an electrolyte in large, stationery batteries to stabilize fluctuating, renewable power grid. The metals so recovered are also important ingredients for manufacture of stainless-steel.

2.20. Captive Co-generation Gas/Liquid Based Power Plant

A Gas / liquid based power plant based on the cogeneration concept of GTs, STGs & boilers will be installed for captive power and steam generation, to support the Jamnagar Oil-to-Chemical project.

Chapter 3

Environmental Aspects

3.0 Environmental Aspects

Environmental aspects and impacts is a way of 'mapping' the environmental consequences of the project. Every project has environmental aspects that can have its impact on air, noise, water, land, biological and social impacts. One of the most important considerations of the project should be identifying various environmental aspects. Once the aspects are identified, several techniques and methodologies are in vogue for predicting anticipated impacts due to projects on natural and social aspects of the environment. These predictions are superimposed over the baseline (pre-project) status of the environment to derive the ultimate scenario of environmental conditions. These conditions are then subsequently evaluated for acceptability by screening them against standards for ambient environmental quality, against toxic effect, thresholds, etc. Based on results of prediction and evaluation, pollution abatement and control measures in order to mitigate the adverse impacts on the environment are delineated in an Environmental Management Plan for further implementation during the construction and commissioning of the proposed activities, as well as during the operational phase.

Impact predictions are made against a 'baseline' established by the existing environment (or by its future state) known as baseline studies, the collection of data on relevant biophysical, social and economic aspects provides a reference point against which the characteristics and parameters of impact-related changes are analysed and evaluated. In many cases, it is likely that the current baseline conditions will still exist when a project is implemented.

The characteristics of environmental impacts to be taken into account in impact prediction and decision-making include:

- i) Nature (positive, negative, direct, indirect, cumulative);
- ii) Magnitude (severe, moderate, low);
- iii) Extent/location (area/volume covered, distribution);
- iv) Timing (during construction, operation, decommissioning, immediate, delayed, rate of change);
- v) Duration (short term, long term, intermittent, continuous);
- vi) Reversibility/irreversibility;
- vii) Likelihood (probability, uncertainty or confidence in the prediction); and
- viii) Significance (local, regional, global)

3.1 Air Emissions

The impacts on air quality from any project depend on various factors like design capacity, configuration, process technology, raw material/fuel used, envisaged emission control measures, operational and maintenance practices. The emission rates of air pollutants due to proposed operations will be considered for evaluating their impact. The licensors will be required to meet the National standards prescribed for every unit proposed to be set up. The stack details like stack height, stack top internal diameter, stack gas velocity, stack gas temperature will also be defined to facilitate the impact prediction. In the complex, stack emissions are the major source of air pollution. Additionally, the logistics requirement will also be established so that the transport requirements and its impact can also be evaluated.

3.2 Water Requirement and Wastewater Generation

3.2.1 Water Requirement

Considering the water shortage in the region, seawater will be used for the proposed projects after desalination to meet the water requirement, which will be used for various purposes viz. service water, fire water, process water, boiler feed water, cooling water etc. The water required will be supplied by the proposed desalination plants. For this purpose, seawater will be supplied to the desalination units. The desalination units proposed at Jamnagar will be combination of Thermal Desalination Plant and Reverse Osmosis Plant, based on availability of steam.

The water requirement for the complex is currently being met by desalination of the seawater. The Ministry has granted CRZ approval for intake of seawater and desalination facilities in 2015.

3.2.2 Waste Water Generation

The wastewater generated from the proposed projects will be characterized and quantified through the licensors so as to design the required treatment methodology to meet the National standards. The wastewaters generated from the processes, tank drainage from the proposed project area and sanitary sewage will be treated at the Effluent Treatment Plant (ETP) to be set up for the projects.

In order to maximise the re-use of the wastewater within the J Complex, the wastewaters will be segregated into low total dissolved solids (LTDS), oily water sewer (OWS) and high total dissolved solids (HTDS) streams etc. Interconnectivity through the plants will need to be provided, to enable maintenance to be selectively carried out on the equipment within each treatment train. The refinery wastewater

shall be collected via separate, dedicated effluent collection systems as required for the optimum treatment and recycling.

The ETP will be designed to cope with the maximum oil & solids loading and the sludge removal should be robust enough to operate given these peaks. A diversion system will be used to store high volume flows (over the design flow) to the ETP in a guard tank within the ETP prior to treatment. The ETP will be properly designed considering the influent characteristics of the wastewater from different streams. The treated effluent will be reused in the cooling towers to reduce the water consumption within the complex.

The return seawater from the proposed desalination plant and the reject stream from the tertiary treatment facility of the ETP will be discharged through the return seawater pipeline and diffuser, the location of which will be identified by NIO. The design of the discharge system will be at a point so located as to give the maximum dispersion so as to minimize the foot print of the discharge and thus the impact.

3.3 Solid / Hazardous Waste Generation

The solid / hazardous waste expected to be generated from the proposed project operations will be delineated by the licensors so as to design the storage facilities for the type of wastes generated. The disposal of the generated waste will be planned considering the hierarchy of the disposal methods with reuse and co-processing given the topmost priority.

3.4 Biological Environment

No protected areas or eco-sensitive areas are located within the proposed project area. Given that the potential impacts of operation and commissioning of the project are likely to be localised, and good site management practices will be implemented, no significant effects are anticipated. However, greenbelt in the Jamnagar complex will be further strengthened, which will be a positive impact in the region.

3.5 Socio Economic Environment

Considering the size of the project, the direct and indirect employment will increase tremendously. Approx. 50,000 construction workers and 1,000 operational workers will benefit from the proposed projects. The proposed projects will also provide indirect employment to the local inhabitants. The construction workers will be housed in properly designed worker accommodation which will have proper infrastructure provided so as to minimize the impacts on the surrounding population.