PROJECT PRE-FEASIBILITY REPORT

for

Proposed Expansion Projects

at

Reliance
Industries Limited

Jamnagar Manufacturing Division

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Chapter 1

Introduction

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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 (Syngas based) complex

The petcoke gasification generates carbon-rich syngas, an excellent feedstock for carbon-rich syngas based 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 syngas based chemicals:

- Acetic acid and Acetic anhydride
- Acetic acid derivatives of ethyl acetate + VAM, or vinyl acetate monomer
- VAM derivatives of VAE or vinyl acetate ethylene + EVA or ethylene vinyl acetate
- Methanol, formic acid and 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 C_2 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

- POE or Polyolefin elastomers
- Epoxy resins for carbon fibre
- ACN or acrylonitrile for carbon fibre

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. Acrylonitrile support carbon fibre for high performance 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.

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 also, 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^{o}20.115’N and 69^{o}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.
- 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 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, 3 (a) Metallurgical Industries, 4 (a) Petroleum Refining, 4 (d) Chlor-Alkali, 5(a) Fertilizers and 5(c) Petrochemical Complexes.

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.

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**	8500 C_2= + C_3=, 4000 Xylenes and 1600 Benzene	Heavy VGO / HCGO + Light ends	New complex includes product recovery and Aromatic section
3	**Multi-Feed Steam Cracker (MFSC) complex**	6520 C_2= + C_3=	PCN / Offgases / C3s / C4s	New and debottlenecking of existing ROGC includes BD extraction
4	**Aromatic complex**	1300 PX	Naphtha / Methanol	Including new Reformer
5	**PDH**	1500 C_3=	C_3	Propane dehydrogenation
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	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
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	Kr + Ne + Ar
6.15	Oxygen / Nitrogen	360	Air Separation Unit	
6.16	Methanol	3600	Syngas	Syngas derivative

B	**C1 Chemicals**			
6.17	Ethanol	500	Syngas	Syngas derivative
6.18	NH_3	6000	H_2 / Syngas / N_2	Incl. waste water recovery
6.19	Urea	3900	NH_3 / CO_2	NH_3 derivative
C	**C2 Chemicals**			
7.1	Chlor / Alkali	3000 / 3500	Salt	Chlorine / caustic
7.2	EDC / VCM+PVC	3780 / 4500	C_2= / Chlorine	Integrated PVC complex
7.3	MEG / DEG	4500	C_2= / Oxygen	
7.4	PE	2000	C_2=	Multi-grade
7.5	POE	500	C_2= / Octene-1	Solar cell applications
7.6	EPDM	240	C_2= + C_3=	Elastomer
7.7	EVA	450	C_2= / VAM	
7.8	EB / Styrene / PS	1000	C_2= / Benzene	
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
8.11	Propylene Oxide (PO)	1000	C_3=	
8.12	Polyols/Propylene Glycol (PG)	800	PO	PO derivative
8.13	Polypropylene	5200	C_3=	
8.14	Acrylonitrile (ACN)	600	C_3= / Ammonia	Carbon fibre precursor

D	**C3 Chemicals**			
8.15	Epoxy resin	250	BPA / ECH	Carbon fibre precursor
8.16	Carbon Fibre	300	ACN	H_2 storage applications
E	**C4 Chemicals**			
9.1	PBR	280	BD	BD derivative
9.2	S-SBR	650	BD / styrene	BD derivative
F	**Heavies/Others**			
10	PTA	3500	PX	
11	Polyphenelyne sulphide	315	Bz / Sulphur	
12	Carbon Black	600	CBFS / FO	
13	Calcined Petcoke and Graphite grades	500	CSO	
14	Polysilicon / Chloro Silane	90	Silicon/chlorine	For PV applications
15	Petcoke gasification	2250	Coke/coal Refinery / Import	Debottlenecking
16	Metals recovery and Battery Manufacture	35	Petcoke cinder	Gasification
17	Power (MW)	3000	Gas / Liquid (Refinery)	O2C + Giga factories

Chapter 2

Project Description

2. Project Description

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.

The FCCs will be retrofitted with Flue Gas Desulphurization units for control of SO_2 emissions. The FGD units will involve scrubbing of SO_2 from flue gasses. The resultant scrubbing solution of NaOH / Lime will be further oxidized by aeration. The solids will be settled and disposed as waste and the supernatant will be routed through the existing ETP.

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 MCC are optimized for the feed cracking propensity, with different cracking severity + residence time, to maximize ethylene + propylene yields from a range of feeds. A cracking furnace cracks light molecules (C2 and C3) into olefins.

In addition, it will have following sections:

- **C_2= + C_3= recovery**
  The cracked light hydrocarbons are compressed, dried and ethylene + propylene is recovered.
- **BTX+ extraction**
  BTX+ recovery technology uses extractive distillation to remove benzene, toluene, xylene and A9–A11 aromatics (BTX+) from refinery, aromatics streams
- **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.
- **Trans-alkylation**
  Trans-alkylation process produces benzene and xylenes through transalkylation of the methyl groups from toluene and/or heavy aromatics streams.

2.3. Multi feed steam cracker (MFSC)

MFSC can crack naphtha minus light streams into ethylene + propylene + butadiene + BTX or petrochemical building blocks.

The additional Propane feed available at Jamnagar, will help to debottleneck this ROG Cracker for additional olefins.

Additionally, a new MFSC is also planned. The hot section of the cracker consists of pyrolysis furnaces that crack the feedstock into ethylene, propylene and other light hydrocarbons.

The new MFSC comprises of the following constituent sections.

- **C_2= + C_3= recovery**
  The cracked light hydrocarbons are compressed, dried and ethylene + propylene is recovered.
- **Butadiene extraction**
  Butadiene extraction uses N-methylpyrrolidone (NMP) as a selective solvent to recover 1,3-butadiene from a crude C4 mix

2.4. Aromatics complex

The Aromatics Complex comprises of Xylene Fractionation, Crystallization or Selective Adsorption and Isomers units. 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.

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.

2.5. Propane dehydrogenation (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.

2.6. C_1 (Syngas based) chemicals complex

C1 complex will comprise of chemicals based either on carbon-rich syngas or carbon monoxide.

Acetic acid is produced from carbon-rich syngas and further converted to downstream chemicals like acetic anhydride, ethyl acetate and vinyl acetate monomer (VAM). VAM is polymerized to polyvinyl acetate by emulsion polymerization and further to polyvinyl alcohol by hydrolysis of polyvinyl acetate. VAM is also used to manufacture downstream polymers such as Vinyl acetate ethylene emulsions (VAE) and Ethylene Vinyl Acetate copolymer (EVA) by copolymerization of VAM and ethylene.

C1 complex will also include production of methanol, formic acid, di-methyl ether (DME) and Poly-ketone. Methanol will be produced from Synthesis gas, a mixture of hydrogen, carbon oxides, and methane under high pressure operations. Methanol and carbon monoxide react to form methyl formate, which is hydrolyzed to produce Formic acid. Syngas-to-DME shall be a 1-step process, employing novel, high stability catalyst. Poly-ketones are semi-crystalline thermoplastics formed by the copolymerization of CO with ethylene.

Ethanol is synthesized via bio-fermentation of waste gases from petcoke gasification and H_2 recovery. CO is the preferred feed, while pure CO_2 can be added to saturate the carbon requirements for the microbes.

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

Methyl methacrylate (MMA) is produced using methanol, carbon monoxide and ethylene. It is further polymerized to get polymethyl methacrylate (PMMA).

Ammonia is recovered from sour water of refining + gasification process by passing through a de-gasser and de-oiler, where light hydrocarbons and other dissolved gases are removed. In addition, Ammonia is also produced by reacting hydrogen from syngas with nitrogen from air separation units.

Compressed CO_2 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.

The six naturally occurring noble gases are helium, Neon, Argon, Krypton and Xenon and the radioactive Radon. Neon, Argon and Krypton are obtained from air in an air separation unit (ASU) by liquefaction of gases and fractional distillation. Similarly, Oxygen and Nitrogen are also recovered from ASU by fractional distillation.

2.7. C_2 Based Units

2.7.1. Chlor alkali

Chlorine is obtained from chlor alkali unit which electrolyzes salt to make caustic. Chlorine is used for producing EDC.

2.7.2. Integrated PVC complex (EDC + VCM / PVC)

Ethylene-di-chloride (EDC) is produced from ethylene and chlorine. Vinyl chloride monomer (VCM) is produced from EDC and ethylene. The reaction is exothermic and highly selective to VCM, resulting in high yields + product purity.

Poly Vinyl Chloride (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 pelletization.

2.7.3. 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 neutralizing 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 CO_2 removal section for removal of CO_2 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 Tri-ethylene Glycol (TEG).

2.7.4. 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.

2.7.5. POE

POE or poly-olefin elastomer is a copolymer of ethylene and octene or ethylene and butane produced using catalytic process

2.7.6. 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.

2.7.7. EB / Styrene

Benzene and ethylene are fed to the zeolitic, liquid phase reactor. Ethylene feed reacts completely, leaving only inert constituents. Poly ethyl benzene that is produced by successive alkylation is transalkylated with benzene to produce ethyl benzene (EB).

The EB is then catalytically dehydrogenated to styrene in the presence of steam.

2.8. C_3 Based Units

2.8.1. 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.

2.8.2. 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

2.8.3. Oxo-alcohols

2.8.3.1. 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 H_2 gas for hydrogenation to produce n-butanol.

2.8.3.2. 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.

2.8.4. 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.

2.8.5. Cumene / Phenol

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.

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.

Isopropyl alcohol (IPA) is manufactured by indirect hydration of propylene, called the sulphuric-acid process.

2.8.5.1. 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.

2.8.5.2. 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.

2.8.6. Isopropyl alcohol

IPA can be manufactured by indirect hydration of propylene, called the sulphuric-acid process. In the indirect-hydration process, propylene is reacted with sulphuric acid to produce mono- and di-isopropyl sulfates, which are then hydrolysed to isopropanol.

2.8.7. 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.

2.8.8. 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.

2.8.9. 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.

2.8.10. ACN

Acrylonitrile is manufactured by combining propylene, ammonia, and air in a process called ammoxidation.

2.8.11. Epoxy resin

Epoxy resin is produced using bisphenol-A and epichlorohydrin. It is a pre-cursor for production of carbon fiber

2.8.12. Carbon fiber

Carbon fiber is produced using acrylonitrile and epoxy resin. The process for making carbon fibers is part chemical and part mechanical. The precursor is drawn into long strands or fibers and then heated to a very high temperature without allowing it to come in contact with oxygen. Without oxygen, the fiber cannot burn. Instead, the high temperature causes the atoms in the fiber to vibrate violently until most of the non-carbon atoms are expelled. This process is called carbonization and leaves a fiber composed of long, tightly interlocked chains of carbon atoms with only a few non-carbon atoms remaining.

2.9. C_4 Based Units

2.9.1. 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. Vapour 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 vapours 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.

2.9.2. 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.

2.10. PTA

Paraxylene is oxidized to form crude terephthalic acid (CTA) in the oxidation section. This CTA is purified by selective catalytic hydrogenation in purification section to form purified terephthalic acid (PTA). PTA is a fiber intermediate, used for polyester manufacturing along with MEG (Mono Ethylene Glycol).

2.11. Poly-phenylene sulphide

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. This is 2 step process, pre-polymerization, followed by polymerization.

2.12. Carbon Black

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.

2.13. Calcined Petcoke and Graphite grades

Needle coke is produced using CSO from Petro FCC and MCC. It is further converted to different grades of synthetic graphite.

2.14. Polysilicon / Chloro Silane

Polysilicon is produced from metallurgical grade silicon by a chemical purification process, called the Siemens process. This process involves distillation of volatile silicon compounds, and their decomposition into silicon at high temperatures. Chlorosilanes are a group of reactive, chlorine-containing chemical compounds, related to silane and used in many chemical processes

2.15. 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 IGCC project are:

- Feed preparation to prepare petcoke slurry to feed gasifier
- Gasification, partial oxidation at very high temperature to generate syngas
- Effluent 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

2.16. Metals recovery and Battery Manufacture

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.

2.17. 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 it’s 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 analyzed 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.