Chapter
1

Chemical Process Industries

1.1 INTRODUCTION

Chemical industry is one of the oldest industries and plays an important role in the social, cultural and economic growth of a nation in providing basic needs of humankind—food, shelter and clothing that have become an indispensable part of our life. It is knowledge intensive as well as capital intensive industry. It is an integral constituent of the growing Indian Industry (Annual Report 2016–17, Ministry of chemical and fertilizer, Government of India). Figure 1.1 illustrates the role of chemical industry in daily life. It is one of the most diversified of all industrial sectors covering thousands of products. Chemical industry includes basic chemicals and its product, petrochemicals, fertilizers, paints and varnishes, gases, soap and detergent, perfumes, pharmaceuticals and covers thousands of products, which are finding use in our daily life from industrial to household goods. Structure of organic chemical industry is shown in Table 1.1. Various products are finding use in various fields like packaging to agriculture, automobiles to telecommunication, construction to home appliances, health care to personal care, explosive, pesticides to fertilizer, textile to tire cord, chemicals to pharmaceuticals (Table 1.2). Indian chemical industry plays an important role in the overall development of Indian economy and contributes significantly in the GDP growth of the country. It comprises large scale, medium scale and small scale units.

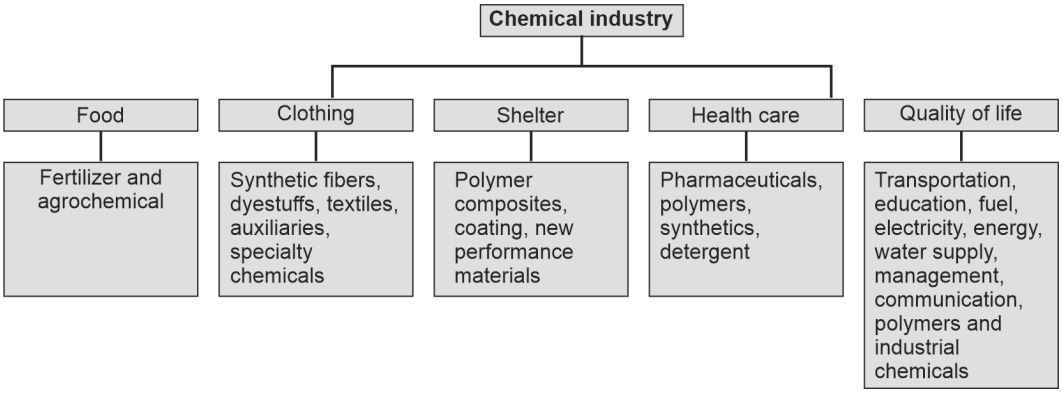

Fig. 1.1: Role of chemical industry *(Sources:* Mall, 2007, 2013, 2017)

Table 1.1: Structure of chemical industry

Inorganic chemical industry	
Industrial gases: Syn. gases, hydrogen Nitrogenous industries: Ammonia, urea, nitric acid	Phosphatic and potassium industries: Rock phosphate, phosphoric acid, phosphatic fertilizers,
Marine chemicals: Salt, bromine iodine, sodium salts	Electrothermal industries: Calcium carbide
Chloralkali industries, soda ash, bleaching powder, poly aluminum chloride	Sulfur and sulfuric acid
Ceramic industries: Cement, refractory and glass	Nuclear industries
Metallurgical industry; ferrous and nonferrous metals	
Organic chemical industry	
Coal and coal chemicals	Petroleum and petrochemicals
Pulp and paper	Polymers, elastomers, synthetic rubbers
Soap and detergent	Agrichemicals
Sugar and alcohol	Pesticides
Explosives	Dyes and intermediates
Surface coating industries: Paints, varnishes and lacquers	Pharmaceutical industries

Table 1.2: Major products of chemical industries and their area of application

Group of product	Areas
Plastics and polymers	Agricultural water management, packaging, automobiles, telecommunications, health and hygiene, education
Synthetic rubber	Transportation industry, textile, Industrial equipment lining
Synthetic fiber	Non-woven and woven fiber in automobile, hosiery, textile
Soap and synthetic detergents	Health and hygiene domestic as well as industrial
Industrial chemicals	Drugs and pharmaceuticals, pesticides, explosives, surface loading, dyes, lube additives, adhesive oil field, antioxidants, chemicals, metal extraction, printing ink, paints
Sugar and alcohol	Food, alcoholic breverages, chemical feed stock, ethoxylate, biofuel
Pulp and paper	Writing and printing paper, culture paper, news printing paper, tissue paper, packaging paper
Fertilizer	Agriculture, Chemical industry (ammonia and urea)
Agrochemicals	Pesticides
Mineral acids and organic acid	Chemical industry—organic and inorganic

Sources: Mall, 2007, 2013, 2017.

The chemical industry is a key contributor to the world economy and produces more than 8000 products. Chemical industry is very important to the economic growth and wealth of a country and the world as a whole. Production/consumption of chemicals in the world rapidly accelerated from $1.45 trillion in 2003 to $4.1 trillion in 2013

with the rapid accelerated global GDP which increased from $39 trillion to 77 trillion (Ganesan, 2017). According to Word Trade Statics Review 2016 the global exports in chemicals is around $1750 billion (Ganesan, 2017). Chemical industry is a vital part of agricultural and industrial development in India and has key linkages with several other down-stream industries such as automotive, consumer durables, engineering and food processing (Chemical Engineering World, 2004). Organic chemicals are one of the important sectors of the Indian chemical industry, which provide a vital development role by providing petroleum products, chemical feedstock, basic chemicals, intermediates, and important products like polymer, synthetic fiber, synthetic rubber, paints, varnish, pesticides and explosives, dyes, specialty chemicals. Major feed stocks for chemical industries are petroleum feed stock like naphtha, natural gas, kerosene, etc. coal, biomass, oils and fats, sulfur, salt, limestone, rock phosphate, etc.

1.2 CHEMICAL INDUSTRY AND TECHNOLOGICAL DEVELOPMENT

Chemical process industry has evolved considerably over the last century largely in response to changing societal requirements and changing raw material availability and environmental issues. Some of the major technological developments in chemical industry are (Mall 2017):

- Leblanc process to Solvay and modified Solvay process
- Lead chamber to contact process (single absorption) and double contact double absorption (DCAA)
- Diaphragm process to mercury and mercury to membrane
- Wet to dry cement process
- Coal chemicals to alcohol-based chemicals to petroleum-based chemicals and vice versa
- Acetylene-based chemicals to alcohol and petrochemical
- Claus to super claus process
- Wood-based paper to agro-based and waste paper-based
- Pulping to bio-pulping
- Stone ground wood pulping to refiner mechanical pulping (RMP), thermomechanical pulping (TMP)
- Chlorine to oxygen bleaching and enzymatic bleaching
- Sulfur to pyrite-based sulfuric acid plant
- Conventional aluminum and iron-based catalyst to zeolite-based catalyst
- Coal-based fertilizer to natural gas and naphtha-based fertilizers
- Coal- and alcohol-based chemicals to petroleum-based chemicals
- Thermal cracking to catalytic cracking
- FCC to deep catalytic cracking for olefin and hydrocracking for processing heavier crude
- Naphtha reforming to isomerization
- Acid catalyst to solid acid catalyst in alkylation process
- Naphtha steam cracking to gas cracking
- Conventional petroleum fuel to biofuel
- Coal as fuel to coal as chemical
- Coal gasification to petrocoke and biomass gasification

- Chemical pesticide to biopesticide
- Chemical fertilizer to biofertilizer
- Soap to detergent, liquid soap, non-biodegradable detergent to biodegradable detergent
- Natural gas to coal bed methane, shale gas, gas hydrate
- Dimethyl terephthalate (DMT) to purified terephthalic acid (PTA)
- Conventional caprolactam to ammonium sulfate free caprolactam
- Natural fiber to synthetic fiber
- Natural rubber to synthetic rubber
- Petroleum refinery to natural gas refinery and biorefinery
- Petroleum refinery to petrochemical refinery
- Conventional gasification to underground gasification
- Conventional drilling to horizontal drilling and hydrofracturing
- Gas to liquid and methanol to olefin technology
- Coal to methanol and olefin
- Conventional desulfurization to ultradesulfurization processes and biodesulfurization
- Polymer to biopolymer
- Conventional Ziegler–Natta catalyst to metallocene catalyst

1.3 STRUCTURE OF CHEMICAL INDUSTRY

Chemical industry can be broadly divided into inorganic and organic chemical industry. Structure of chemical Industry is given in Table 1.1.

Revolutionary innovations in chemical process industries are given in Table 1.3.

Table 1.3: Revolutionary innovations in chemical process industries

Year	Revolutionary innovations
1914	Dubba cracking process
1935	First catalytic process
1938	High octane gasoline
	First fluid catalytic cracking process
1949	First reformer, Platforming™ Process
1953	Synthetic zeolites
1957	Biodegradable detergents
1958	Technologies for lead removal from gasoline
1950–60	Steam cracking of naphtha
1960s	Automotive catalytic converter
1970s	Parex™ Process
1971	CCR platforming commercialization
1978	Etherification of isobutylene
1990	Olex™ process
1990	Olex propane dehydrogenation process
1994	Detal solid bed detergent alkylation

Contd...

Table 1.3: Revolutionary innovations in chemical process industries (*Contd...*)

Year	Revolutionary innovations
2000 onward developments	Coal to chemicals, coal to methanol, DME, coal to natural gas
	Coal liquefaction and coal based syn oil, gasification of coal and petrcoke
	GTL technology, Shale gas by horizontal drilling
	Low CAT proess, oxygen enriched sulfur recovery
	Oxidative coupling of methane to olefin
2000 onward older technologies revived	Biofuel, lingo biomass hydrolysis an fermentation
	Algae biofuel
	GTL technologies
	Nano particles for energy and environmental management
	Application of nano catalyst
	Resid FCC technology for maximum distillate yield
	CO_2 capture technology
	LC fining
	KBR Technology for Phenol
	$Benz^{OUT}$ technology
	Biobased Chemicals
	Electrolysis of water
	Single step process for hydrogen—CNG Production from natural gas
	Developing feed stock in Naphtha-based hydrogen generation units
2010 onwards	Synthetic fuel, dimethyl ether, gas to liquid technologies for gasoline, diesel, methanol to gasoline (MTG), syn gas to gasoline (STG plus)
	Advances in depolymerization of nylons
	First indigenous Indalin technology for upgradation of low value streams to Petrochemicals
	First indigenous diesel hydrotreating technology in India
	Addition of Bharat 6 norms
	Digitalization of chemical industry and adoption of industry 4.0

1.4 GLOBAL AND INDIAN CHEMICAL INDUSTRIES

The chemical industry is one of the world largest sectors of economy and has impact on many other industries. There has been continuous development in chemical industry with age. Technology commercialization with age of chemical industry is given in Figure 1.2. The global chemical industries consists of a very diverse range of product and global market size. As per Hindu Business Line (2017), global chemical industry is estimated at $4.3 and is expected to grow in future. Global chemical industry is expected to grow at a CGR of 3.9% from 2015 to 2030. Faster big row will be seen in Asia rather than Europe and USA (Chemical News April 2018, p.18). Global chemical production especially petrochemical-based organic chemical based and fertilizer industry is likely to show significant growth with evolution of shale gas, and utilization of more and more natural gas. Global market for cosmetic and toiletry ingredient to reach $24.5 billion

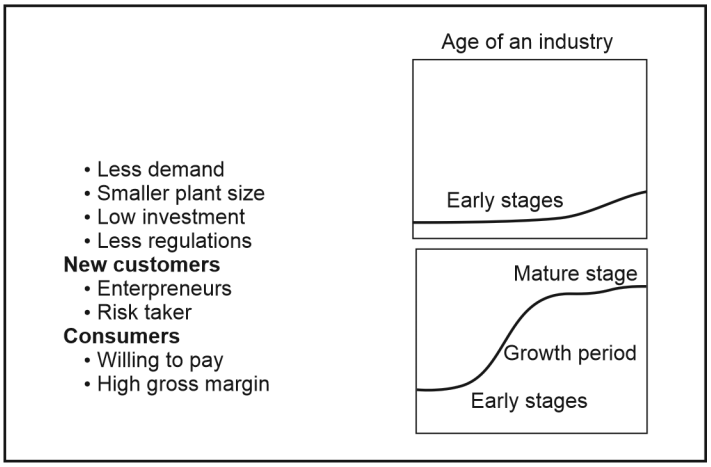

Fig. 1.2: Technology commercialization of chemical industry with age.
Source: Vora BV. International conference organized by Chemtech during CHEMTECH World Expo 2011.

in 2018 from $18 billion in 2011 and $19.6 billion in 2013 (Chemical Industry Digest December 2012, p.30).

Evolution of the Indian chemical industry and technological commercialization with age of industry and age of product is given in Figure 1.3. Revolutionary innovations in chemical process industries are given in Table 1.3.

Indian chemical industry is an important constituent of the Indian economy. As per the Hindu Business Line (March 24, 2017), the Indian chemical industry is expected to grow to $226 billion by 2020. In terms of volume it is 12th largest in the world and 3rd largest in Asia. According to ICC president, Indian chemical industry ranked 7th globally and likely to move 5th position by 2025. Indian chemical industry will be reaching a size of $370 billion by 2025. The specialty chemicals industry has the potential to be a $150 billion market by 2025. High demand supply gap for petrochemical would be by 2025 (Chemical News, April 2018, p.12). Currently, per capita consumption of products of chemical industry in India is about 1/10th of the world average. Over the

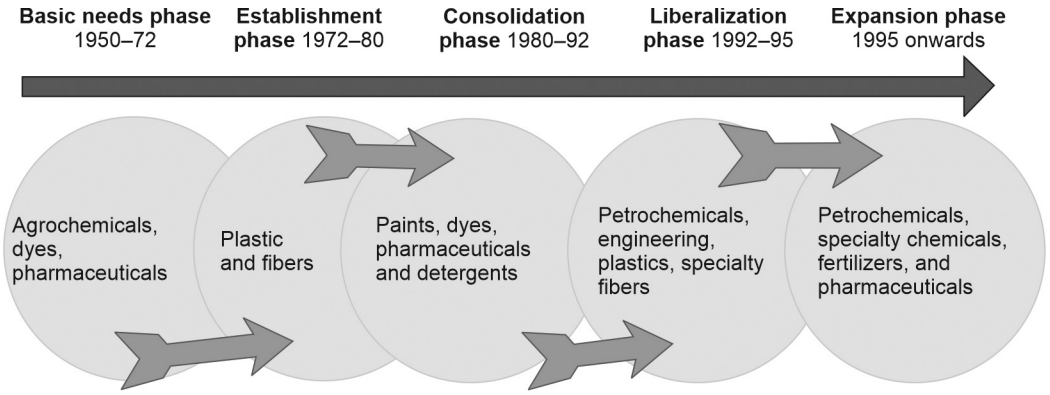

Fig. 1.3: Evolution of the Indian chemical industry and technological commercialization with age of industry and age of product

last decade, the Indian chemical industry has evolved from being a basic chemical producer to becoming and innovative industry. India is the fourth largest producer of agrochemicals. Evolution of the Indian chemical industry and technological driving force for development of chemical industry is given in Table 1.4. With investments in R&D, the industry is registering significant growth in the knowledge sector comprising of specialty chemicals, fine chemicals, and pharmaceuticals with higher annual growth rate.

The chemical industry R&D spends would need to go up from current levels of less than 0.5% to reach closer to global benchmarks of 4% of sales. Industry is expected to grow much more in future due to high end demand based on increasing per capita consumption and population growth, improved export competiveness and resultant growth impact. Indian chemical industry can achieve accelerated growth phase with a strategic roadmap.

Some of the critical issue now Indian chemical industries are facing are availability of feedstock, rising cost of raw material including energy and ease of doing business, availability of indigenous technology, poor infrastructure, small capacity plants, etc.

The total production of organic chemicals during 2008–09 works out to 1.25 million with value of 0.9717 billion. The size of the petrochemicals segment was estimated as 13.96 billion. Total size of dyestuff industry is estimated as $4 billion. There are 50 organized industries and over 900 small-scale industries. India has 8.5–9% global market share. The India pharmaceutical industry is the fourth largest volume terms and 15th largest market in value terms. The market will reach $30 billion by 2020. The size of the agrochemicals industry estimated at over $1 billion. Consumption of various chemical ingredients for cosmetic and toiletry is increasing due to increased population. Global market for cosmetic and toiletry ingredients is increasing.

As a result, the annual consumption of chemical fertilizers has increased in nutrient terms (N, P, K) has increased from 0.7 lakh tons in 1951–52 to 277.39 lakh tons in 2011–12). Per hectare consumption of fertilizer which was less than 1 kg in 1951–52 has risen to a level of 141.30 in 2011–12 (Ministry of Chemicals and Fertilizer Annual Report, 2012–13).

Segments of the Indian chemical industry are given in Table 1.5. Details of major chemical production and growth are shown in Table 1.6. Product-wise production of major chemicals is given in Table 1.7. Value output of different product groups in the chemical and chemical products is given Table 1.8. As per the European Chemical Council, world chemicals (excluding pharmaceuticals) sales in 2012 are valued at 3127 billion. India ranks 10th in world chemical market with chemical 61.1 Euro billon in 2012. As per UN Comrade Data base for 2014, India ranks 14th in the world exports of chemicals (excluding pharmaceutical products) and ranks 8th in the world imports of chemicals (excluding pharmaceutical products). India's export of chemicals (excluding pharmaceuticals) was $29.76 billion in 2014.

Chemical industry is one of the world's largest industry and has significant influence on many other industries. Total global chemical shipments are worth 5 billion dollars. Global chemical industries consists of a very diverse range of products. Global market size was estimated at 3.9 trillion US dollars and is expected to grow at 3–4% per annum over the next five years to reach 4.7 trillion US dollars (*Source:* Global Investors Summit (March 7–8, 2016) Gurugram, India's chemical market to grow $139 billion in FY 2014 to $214 billion by FY2019. With market size of $139 billion the industry accounts for 3.3%

of global market (Table 1.9). Globally India ranks 3rd in terms of volume and 14th in terms of value (*Source:* Global Investors Summit, March 7–8, 2016, Gurugram). India is the second largest producer of cement in the world.

As per the Annual Report of 2017, Ministry of Chemicals and Fertilizer Industry, Department of Chemicals and Petrochemicals, National accounts statistics 2016 chemical and chemical products sector accounted for 2.33 of the GVA in 2014–15 compared to 2.34 5 in 2013–14. The size of the Indian chemical Industry in terms of value of output in the year 2014–15 was 8,33,046 crores.

Table 1.4: Driving force for Indian chemical industry

Surface area	3.287 million km^2
Population	1.2 billion
Coastline	6,000 km
Port traffic	Over 350 million TPA
Road length	Over 3 million km
Railways	100,000 Track km (Largest in Asia, 2nd in the World)
Growth of population 1951	36 crore to present 130 crore
Growth in vehicle population	More than fivefolds
India's passager vehicle production projections	In 2010—2.6 million vehicles By 2015—5.1 million vehicles By 2020—9.7 million vehicles

Contribution of GDP: Agriculture: 25%, Industry: 24% Services: 51%

Table 1.5: Segments of the Indian chemical industry

Basic chemicals (49.05%): Market value: US$32.78
• Inorganic chemicals (Caustic chlorine, soda ash, sodium bicarbonate, carbon black, titanium oxide, sulfuric acid, hydrochloric acid, etc.) • Organic chemicals (acetic acid, acetic anhydride, acetone, phenol, methanol, formaldehyde, nitrobenzene, malice anhydride, aniline, chloromethane, acetaldehyde, ethanol amines, ethyl acetate, etc. • Petrochemicals (Olefins, aromatics-benzene, toluene, xylene, fiber intermediates MEG, PTA, acrylonitrile, propylene, caprolactam, adipic acid, hexamethylenediamine, phthalic anhydride, methanol, LAB, polymers, synthetic fiber, etc.) • Fertilizers (Nitrogenous and phosphatic) • Other industrial chemicals
Specialty chemicals (24.69%): Market value: US$16.50
• Paints and varnishes, Textile chemicals, Dyestuffs and intermediates, Catalysts, Plastic additives, Adhesive sealants, Industrial gases
Knowledge chemicals (26.6%): Market value: US$17.55
• Pharmaceuticals • Biotechnology • Agrochemicals

Source: Lokhapare, 2011.

Table 1.6: Production of major chemicals and petrochemicals, production 1000 tons

Group	Production/Growth rate	2011–12	2015–16	2018–19
Alkali chemicals	Production	6478	6802	8043
	Growth (%)	3.3	2.7	
Inorganic chemicals	Production	881	1002	1064
	Growth (%)	–1.9	6.1	
Organic chemicals	Production	1640	1589	1884
	Growth (%)	5.8	–1.9	
Pesticides technical	Production	156	188	217
	Growth (%)	8.5	0.6	
Dyes and pigments	Production	241	304	382
	Growth (%)	–1.6	6.6	
Total major chemicals	Production	9396	9884	
	Growth (%)	3.2	2.3	
Synthetic fiber	Production	3105	2362	36071
	Growth (%)	–0.6	12.2	
Polymers	Production	6211	8839	100400
	Growth (%)	17.4	17.0	
Elastomers	Production	100	242	351
	Growth (%)	–4.7	40.8	
Synthetic detergents intermediates	Production	623	566	687
	Growth (%)	–2.4	–5.1	
Performance plastics	Production	969	1700	1589
	Growth (%)	–0.7	6.9	
Total basic major petrochemicals	Production	11008	14900	16269
	Growth (%)	8.6	10.8	
Total major chemicals and petrochemicals	Production	20404	24783	27858
	Growth (%)	6.0	7.3	

Source: Annual Report 2015–16, 2016–17, 2019–2020 Government of India Ministry of Chemicals and Fertilizer, Dept. of Chemicals and Petrochemicals.

Table1.7: Product-wise production of major chemicals

Major chemical products	Production 2014–15 in 1000 MT	2018–19
Alkali chemicals		8043
Caustic soda	2439.5	
Liquid chlorine	1717.97	
	2462.00	
Total alkali chemicals	6619.47	

Contd...

Table1.7: Product-wise production of major chemicals (*Contd...*)

Major chemical products	Production 2014–15 in 1000 MT	2018–19
Inorganic chemicals		**1064**
Aluminum chloride, calcium carbide, carbon black, Potassium chlorate, Titanium oxide, Red phosphorous, Hydrogen peroxide, Calcium carbonate	921.60	
Organic chemicals (Acetic acid, Acetic anhydride, Acetone, Phenol, Methanol, Formaldehyde, Nitrobenzene, Maleic anhydride, Pentaerythritol, Aniline, Chloromethanes, Isobutylene, MEK, ONCB, PNCB, Acetaldehyde, Ethanol amines, Ethyl acetate, Nitrotoluene)	1619.11	1884
Pesticides and Insecticides	186.63	217
Dyes and Pigment	285.23	382
Synthetic fibers (Acrylic, Polyester, Nylon, Polypropylene, Fiber	3527	3601
Polymers (Polyethylene, Polypropylene, Polystyrene, Polyvinyl chloride)	6523	10040
Synthetic rubber (Styrene butadiene rubber, Polybutadiene rubber, Ethyl propylene dimmers, Ethyl vinyl acetate, Nitrile rubber)	94	351
Synthetic detergent intermediates		687
LAB	475	
Ethylene oxide	164	
Performance plastics (ABS resin, Polymethylmethacrylate (PMMA), Styrene acrylonitrile (SAN), Nylon	766	1589
Fiber intermediates (Acrylonitrile, Caprolactam, Dimethyl terephthalate, Monoethylene glycol, Purified terephthalic acid)	4877	
Olefins (Ethylene, Propylene, Butadiene)	6276	
Aromatics (Benzene, Toluene, Mixed xylene, Orthoxylene, Paraxylene)	4638	
Other petro-based chemicals (Butanol, C4 raffinate, diethylene glycol, Diacetone alcohol, 2-ethyl hexanol, methyl methacrylate, Phthalic anhydride, Propylene oxide, Propylene glycol, polyvinyl acetate resin, vinyl acetate monomer)	1962	
Total basic major petrochemicals	14905	16269
Total basic major chemicals and petrochemicals	24788	27858

Source: Annual Report 2015–16, 2019–20, Government of India, Ministry of Chemicals and Fertilizer, Department of Chemicals and Petrochemicals.

Table 1.8: Global and Indian chemical Industry	
Global industry revenue	US $3.9 trillion
Industry revenue in India	US $144 billion
Estimated revenue in India 2020	US $300 billion
Total production of Indian chemical industry (Fy 2014)	19,308 × 1000 tons
Contribution to India's GDP 2013	2.5%
CAGR of Revenue in India 2013	13% (Chemicals)
Direct and Indirect Employment (Fy 2012)	1 million
Indian chemical industry	• Eighth largest producer in India, third largest in Asia • Fourth largest of agrochemicals • 16% of word production of dye stuff and dye intermediates

Source: Global Investors Summit, Gurugram, March 7–8, 2016.

Table 1.9: Market size Breakdown of Indian Chemical industry (Market size in $139 billion)	
Agrochemicals (Pesticides, fertilizers)	20%
Bulk chemicals (Organic and inorganic chemicals)	39%
Biotechnology	4
Pharma	17
Specialty chemicals	20

1.5 CHANGING SCENARIO IN CHEMICAL PROCESS INDUSTRY

There has been continuous change in capacity and size of the plant in chemical industry due to development of process technology, equipment and requirement of products. Changing scenario in chemical industry is given in Table 1.10.

Table 1.10: Changing scenarios in chemical process industry		
Sector	**Capacity**	
	Past	**Present and future**
Petroleum refinery	0.4 million tons	34 million tons
Naphtha cracker	20,000 tons/year	>8 lakh tons
Ammonia plant	>500 TPD	>1500 TPD
Urea	300 TPD	>1500 TPD
Sulfuric acid	0.018 million tons/year	0.7 million tons/year
Caustic chlorine	10 TPD	>100 TPD
Cement	0.06–-0.07 million tons	>3 million tons

1.6 CHEMICAL FEEDSTOCKS

With increasing demand of raw material there has been continuous search for new and alternative feedstocks past, present and future, for chemical industry is given in Table 1.11 and in Figure 1.4 (Mall, 2016).

Table 1.11: Chemical feedstocks: Past, present and future

Past	Present and future
Coal, Salt, Biomass, Natural rubber, Cotton	• **Gaseous:** Natural gas, Condensate, Refinery gases, Coal bed Methane, Gas hydrate, Shale gas • **Liquids:** Naphtha, Solvent extracts, Middle distillates • **Solids:** Coal, Coke, Wax, Residues • **Biomass:** Agriculture residue, Algae • **Sea Chemicals:** Salt, Bromine, Iodine, Titanium, Zirconium, etc. More 64 elements

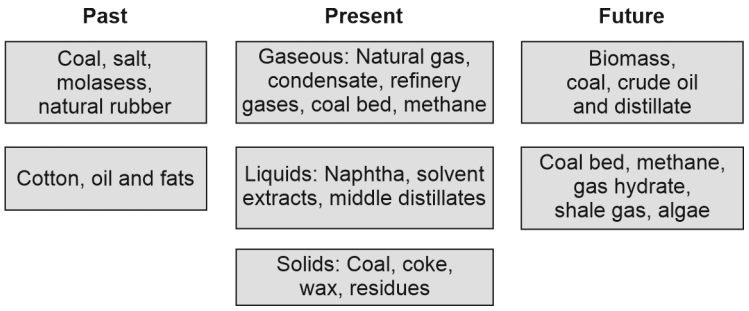

Fig. 1.4: Past, present, and future of chemical feedstocks

1.7 CHARACTERISTICS OF THE INDIAN CHEMICAL INDUSTRY

Characteristics of Indian chemical industry is given below (Lokhapare, 2011):

- High domestic demand potential as the Indian markets develops and per capita consumption levels increases
- High degree of fragmentation and small scale of operations
- Limited emphasis on exports due to domestic market focus
- Low-cost competitiveness as compared to other countries due to the high cost of feed stocks and power
- Low focus on R&D despite initiatives to innovate processes to synthesis products effectively.

1.7.1 INDIAN CHEMICAL INDUSTRY WEAKNESSES

Although Indian chemical industry has made consistent growth during last six decades, however, compare to global level there is lot of scope for further development. Some of the weaknesses are

- Sizes of older units well below global levels
- High-cost structures
- Higher cost of raw materials
- Long gestation periods
- Integration and infrastructure inadequacies
- Process development, low R&D investment
- Mindset.

Diversification, globalization, emerging technologies, etc. has affected the practice of Engineering. Major issues are:

1. Raw material cost reduction, waste minimization and waste utilization and conservation of natural resources
2. Capital investment reduction
3. Energy use reduction and alternate sources of energy
4. Increased process flexibility and inventory reduction
5. Ever greater emphasis on process safety
6. Increase attention to quality
7. Better environmental performance
8. Advance personalized learning and innovative idea
9. Discontinuing certain low value-added products/inefficient technologies
10. Provide access to clean water
11. Better health and safety management strategies.

1.7.2 TYPICAL ISSUES FOR CHEMICAL INDUSTRIES

Due to various technological and engineering developments, chemical industry has been able to reduce the cost of production. Changes in technology and raw materials have shifted regularly and frequently toward lower costs and more competitiveness, better conversion efficiency, high productivity, less energy consumption, and broader spectrum of product grades. However, due to increasing cost of raw materials and stringent environment issues, chemical industry is facing major challenges in future. Typical issues in chemical industry to meet the future challenges are shown in Figure 1.5.

Due to various technological and engineering developments, chemical industry has been able to reduce the cost of production. Changes in technology and raw materials have shifted regularly and frequently to technological development in chemical industry (Fig. 1.6).

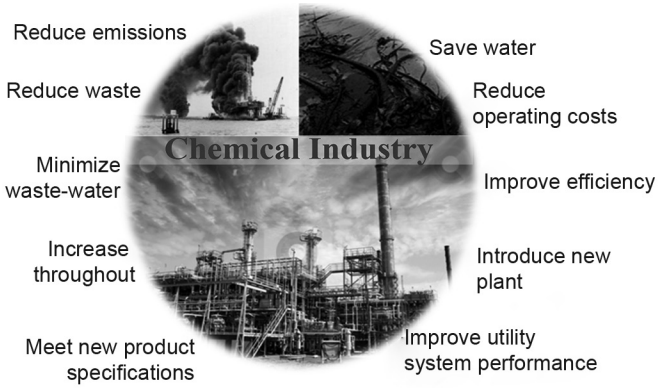

Fig. 1.5: Typical issues in chemical industry (*Source:* Invited talk National conference on Innovation and development in Chemical technology IDCT 2014, Feb. 28–March 1, 2014)

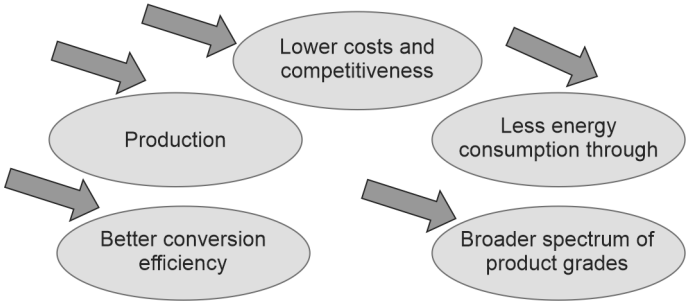

Fig. 1.6: Technological development in chemical industry

Over the next few years, we can expect major shifts in three areas: Organizational structure, talent management and corporate culture (Joshi, 2019). Digitalization has become part of our life. With effect of industry 4.0 is likely to have impact in areas of production and supply chain (Durani, 2019). Adoption of industry 4.0 will bring significant strategic advantage and boom the chemical process industry (Shenoy, 2019)

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