Indian Petrochemical Industry  
Challenges and Opportunities

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\textbf{Abstracts}: Petro-chemical industries ought to be regarded as the most significant branches of industry necessary for fulfillment of human needs. The energy and organic chemicals consumptions are growing (7\% per annum) incessantly due to rapid increase of world's population with improved standards of living. The increasing energy demands, gradual depletion of fossil fuels and hence rise of crude oils price are foremost motivations for exploration of renewable resources for sustainable production of electricity, heat, fuels, organic chemicals and polymers. Therefore, new manufacturing concepts are continuously evolving to produce an array of bio-fuels and multitude of bio-products from biomass. These complex processing technologies are analogous to today's integrated petroleum refinery and petrochemical industries commonly known as bio-refinery. Furthermore, the article provides an overview of hydrocarbon biorefinery for production of hydrocarbon fuels and building block chemicals from biomass.

\textbf{Keywords}: Petro-chemical industries , sustainable production, bio-refinery, biomass

\textbf{Introduction}

Petro-chemical industries are considered as the most significant branch of industry necessary for fulfillment of human needs. There are more than 10,000 petrochemical which could either be used as raw materials for other industries or go for ultimate utilization. These could be ranged from solvent, detergents, synthetic resins, and pesticides to acetone, glycol phenol, and chemical fertilizers. At present our society is extremely dependent on finite fossil fuels (petroleum, coal and natural gas) to meet basic needs of energy, fuels, organic chemicals and polymers at the moment, more than 80\% of energy and 90\% of organic chemicals in the world are derived from fossil fuels alone [1,2]. Moreover, the energy and organic chemicals consumptions are growing (7\% per annum) incessantly due to rapid increase of world's population with improved standards of living. The increasing energy demands, gradual depletion of fossil fuels and hence rise of crude oils price are foremost motivations for exploration of renewable resources for sustainable production of electricity, heat, fuels, organic chemicals and polymers [3]. The deterioration of environmental cleanliness due to emissions of harmful and greenhouse gases (CO\textsubscript{2}, CH\textsubscript{4}, N\textsubscript{2}O etc.) by large scale usage of fossil fuels is another motive for shifting dependency away from limited fossil fuels to carbon-neutral renewable resources. The global energy consumption was 12,150million tons equivalent in 2009 with only 20\% share of renewable energies (nuclear, hydro, bio-fuel and waste and others). The biomass (bio-fuels and waste together) alone contributes more than 50\% of world's renewable energy. The contribution solar power to world's renewable energy is how ever negligibly small at the moment. But it has enormous forthcoming potentials if scientific advancements results novel materials for efficient capture of solar energy. However, with exception of biomass, all other renewable energies are incompetent to deliver societal needs of transportation fuels, organic chemicals and polymers. On the other hand, the biomass has tremendous potentials to deliver societal needs of all useable forms of energies (electricity, heat and transportation fuels), organic chemicals and polymers. A number of evaluations indicate that new process technology based on renewable carbon offers a way to reduce the industry's environmental footprint [4]. In his review of progress on sustainable development, Metzger concluded, "renewables are the only workable solution" [5]. Yet the chemical feedstock supply of the U. S. remains completely dominated by nonrenewable carbon – only about 2\% comes from biomass Therefore, new manufacturing concepts are continuously evolving to produce an array of bio-fuels and multitude of bio-products from biomass is the need of the hour. These complex processing technologies are analogous to today's integrated petroleum refinery and petrochemical industries commonly known as bio-refinery.

1. Analyzing industrial energy efficiency  
the IEA approach for Chemical and Petrochemical Industry in India

The industrial sector in India used 5.1 EJ of final energy in 2004 (1 ExaJoule equals 1018 Joule). This represents 4.5\% of total global energy use in this sector [6]. Industry accounted for 27\% of total final energy use in India in 2004, roughly the same share
Outlook energy consumption in Indian industry is projected to more than double by 2030 and so increase its share of total final energy consumption to 31% [7]. The final energy mix of industry is dominated by coal and oil. The share of biomass use in industry is large compared to other countries (19% in India, while the world average is 7%). Industry accounts for 45% of total electricity consumption, which is also a high share compared to other countries. In comparison, the world average is only 35%. Electricity accounts for 14% of industrial final energy use. However, it should be noted that The Energy Research Institute (TERI) reports a power consumption in industry of 720 PJ in 2004, which is 40 PJ lower than the figure reported in IEA statistics [8].

The chemical and petrochemical industry in India is dominated by ammonia production for nitrogen fertilizers. The ammonia industry represents half of total energy use in this sector, production of petrochemicals (plastics, fibers and solvents) and products such as chlorine account for the other half. Oil and gas are the main energy and feedstock sources. The fertilizer industry has high energy intensity, energy cost account for 56% of total production cost [9]. The industry has been sheltered from global competition due to a national self-sufficiency policy and subsidized production. However India lacks the necessary gas reserves that would be the basis of the same production elsewhere. Therefore in contrast to the rest of the world, oil feedstock play an chief role in ammonia production in India, accounting for 25% of all feedstock in 2005/2006 [10]. It should be noted that this share is rapidly declining in favor of gas due to the current high oil prices. Also recent offshore gas discoveries may favor a switch to gas. Average energy use per ton of ammonia was 38 Gigawatt hours per ton (GWh) in India in 2006, compared to 28 GWh for the best available gas-based technology. About half of the gap can be attributed to the oil feedstock use. Petrochemical production in India is relatively small. The production capacity for ethylene amounted to 2.48 million tons (Mt) in 2006, 18% ethane based, 11% propane based and 71% naphtha based [11]. Ethane and propane crackers tend to be less energy efficient than naphtha crackers. Chlorine production amounted to 1.7 Mt in 2003/2004, 29% of which is based on the less energy efficient mercury process and the other 71% based on the membrane process. Soda ash production amounted to 2.24 Mt in 2003/2004 [8].

Energy indicators for petrochemicals are unlike that of the other sectors because part of the oil and gas serves as feedstock. This is accounted for separately in the IEA energy statistics, but the allocation to energy and feedstock is not always clear for a range of countries, so in this analysis the two have been aggregated. A lack of energy use data on a specific product level for most countries makes individual process indicators infeasible. Much of the energy data necessary to perform a more detailed analysis is not available for most countries due to anti-trust issues, limitations on statistical data and site energy integration. Thus the concept of the energy efficiency index (EEI) based on BPT is used to derive the improvement potentials. Forty-nine products have been included in this aggregate indicator. These products represent more than 95% of all energy used in the chemical and petrochemical industry [12]. They suggest an improvement potential that ranges from 6.2 to 29.8%. The Indian potential of 15.8% is close to the world average.

2. Feedstock commonly used by Indian Petrochemicals Industries

Four crucial factors govern the choice of feedstock in petrochemical plants: availability, cost, power consumption and the product portfolio to be produced. With respect to availability, the plant owners need to be assured of continuous availability of feedstock. Even though power accounts for 10 per cent of the cost involved in the cracking of feedstock, an uninterrupted high quality power is required for the same. Hence, many petrochemical complexes use captive power. As per the portfolio of products, naphtha is used when a wide range of co-products (including propylene and butadiene derivatives) is desired while natural gas and NGL are preferred when the ethylene output of a cracker is to be maximized since they yield a higher proportion of ethylene [13].

3.1. Naphtha for Petrochemicals

Domestic naphtha production has been increasing overtime. As expected, there is a slight dip in the year 2008-09 due to the global recession. However, production picked up in the next year i.e. 2009-10. In following years, this trend has continued. The share of naphtha in total production of petroleum products has, however, been declining in recent times. Currently, naphtha accounts for approximately 8.7 per cent of total production of petroleum products.

3.2. Natural Gas for Petrochemicals

According to the BP Statistical Review 2013, India's proven gas reserves currently stand at 1.3 trillion cubic meters, which are 0.7 per cent of the world's total proven gas reserves. In 2011-12, the production of gas in the country was 47.56 billion cubic meters (bcm) while imports constituted 13.67 bcm. In 2010-11, while India's proven gas reserves were estimated
to be 1.45 trillion cubic meters, and the production was 52.2 bcm. Around half of the production for domestic natural gas was contributed by the state-owned ONGC and OIL.

A large part of demand is met with domestic production (around 80 per cent) with the balance fed by LNG imports. The massive jump in the production from private/JV in 2009-10 categories is also a notable feature. The discovery of D-6 block of the Krishna Godavari (KG) basin was one of most prolific gas discoveries under NELP and is the major reason for the sharp increase in private sector gas production. Other NELP discoveries in the eastern offshore basin include those by ONGC (KG-DWN-98/2) and the Gujarat State Petroleum Corporation (KG-OSN-2001/3).

Olefins are generally produced in the world over either by gas cracking (gas-based petrochemicals) such as ethane, propane and butane, or from naphtha (naphtha-based petrochemicals). Paraffins, like straight chain hydrocarbons, yield olefins when heated at a high temperature. Thus, the lighter fraction is suitable for petrochemical plants in the production of olefins and hydrogen because of the presence of paraffinic hydrocarbons. Hence, in the refinery, C5–90°C cut is separated in the naphtha redistillation unit and is sold to the petrochemical industry. The heavier fraction, i.e., naphtha in the boiling range of 90°C–200°C is catalytically reformed in a refinery either to produce high-octane gasoline and/or aromatics (benzene (B), toluene (T), and xylenes (X)). Gas based petrochemicals are manufactured using different streams of natural gas liquids as their feedstock. Natural gas liquids (NGL) are heavier than the methane and are recovered from natural gas.

It needs to be highlighted that the yield of olefins decreases with the increasing molecular weight (hence with boiling point) of hydrocarbons. Thus, if ethane is thermally cracked, it will yield 80 percent ethylene. When propane, butane, naphtha, and gas oil are used as feedstock for cracking, the yields will be lower at 45 per cent, 37 per cent, 30 per cent, and 25 per cent respectively. In India, olefins are produced primarily by thermal cracking of hydrocarbons. Naphtha and/or natural gas, diluted with steam, is fed in parallel to a number of gas or oil fired tubular pyrolysis furnaces. In the cracking process, a heavier hydrocarbon molecule is fractured or broken into two or more lighter fragments. These light hydrocarbons are thereupon further cracked to lighter olefins and propagated till the reaction temperature is brought down. After cracking, the remaining processes involve a series of fractionators in which the various product fractions are successively separated. Table 5 shows the cost of production for ethylene using naphtha and natural gas. It should be noted that the following calculation assumes that naphtha was available at the rate of US$ 940 per tonne and ethane was available at US $8.3 per mmbtu. The capital expenditures for the two crackers are US$ 715 million (naphtha) and US$ 718 million (ethane) respectively (14).

3. Integration of Refinery with Petrochemical

Advances in processing technologies are playing a larger role in integrating refining and petrochemical facilities [15]. In the changing scenario, petroleum refining and petrochemical production integration will be of vital importance for maximizing the use of byproducts and improving the overall economy of a petroleum refinery. A great deal of synergy exists between the refinery, aromatics complexes and steam cracker complex. Off gases from the FCC unit and coker containing ethylene and propylene can be integrated with the cold section of steam cracker. Pyrolysis gasoline is a good source of aromatics which can be integrated with the catalytic reforming process. Propylene from FCC and benzene from aromatics are feed stocks for the production of cumene and phenol [16].

4. Biorefinery

The concept of biorefinery was originated in late1990 as a result of scarcity of fossil fuels and increasing trends of use of biomass as a renewable feedstock for production of non-food products [17]. The term “Green Biorefinery” was first introduced in 1997 as: “Green biorefineries represent complex (to fully integrated) systems of sustainable, environmentally and resource-friendly technologies for the comprehensive (holistic) material and energetic utilization as well as exploitation of biological raw materials in form of green and residue biomass from a targeted sustainable regional land utilization”. According to US Department of Energy (DOE) “A biorefinery is an overall concept of a processing plant where biomass feedstock are converted and extracted into a spectrum of valuable products” [18]. The American National Renewable Energy Laboratory (NREL) defined biorefinery as: “A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power and chemicals from biomass” [19]. These definitions of biorefinery are analogous to today’s integrated petroleum refinery and petrochemical industry that produces multitude of fuels and organic chemicals from petroleum. So, in brief biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass. [20] The International Energy Agency
Bioenergy Task 42 on Biorefineries has defined biorefining as the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, materials) and bioenergy (biofuels, power and/or heat).

By producing multiple products, a biorefinery takes advantage of the various components in biomass and their intermediates therefore maximizing the value derived from the biomass feedstock. Some researchers have considered the exploration of a biorefinery as a practical method of improving the economic performance of stand-alone biomass to bioenergy system since biochemicals are produced[21] A biorefinery could, for example, produce one or several low-volume, but high-value, chemical or nutraceutical products and a low-value, but high-volume liquid transportation fuel such as biodiesel or bio-ethanol. At the same time generating electricity and process heat, through combined heat and power (CHP) technology, for its own use and perhaps enough for sale of electricity to the local utility. The high-value products increase profitability, the high-volume fuel helps meet energy needs, and the power production helps to lower energy costs and reduce greenhouse gas emissions from traditional power plant facilities. Although some facilities exist that can be called bio-refineries, the bio-refinery has yet to be fully realized. Future biorefineries may play a major role in producing chemicals and materials that are traditionally produced from petroleum.

![Figure 1 Ligno-Cellulosic Biorefinery](image)

**5. Availability of Biomass Resources**

In recent years, a large number of processes for producing fuels and chemicals from biomass have been demonstrated.[22] When the potential of these processes is discussed, it is often done in the context of the current world situation. This approach gives an unclear picture of the actual merit of the process, as
large-scale industrial production using biomass will drastically alter the premises. To consider the true potential of a process and its ability to substitute or compete with a fossil-based analogue, absolute numbers of the demand and the amount of potential feedstock must be considered. In the U.S., the total demand for crude oil is approximately one billion, i.e. 109 metric tons per year. [23] In comparison, the amount of biomass used for electricity generation and the production of biofuels and other nonfood bioproducts constitutes about 190 million tons.[24] As a consequence, biomass production must be increased drastically to replace all products derived from petroleum with biomass. The total sustainable biomass potential is estimated by the U.S. Department of Energy to be at least 1.2 billion tons per year in the U.S., a target reachable within 50 years. This rough comparison illustrates how present demand for oil and future availability of biomass can become comparable on a weight basis, and although the quantities reported are based on U.S. statistics, and are thus not necessarily representative of other countries, the conclusions can be extrapolated to the rest of the world. The comparison on a weight basis is, however, somewhat misleading, as biomass has a lower energy and carbon density than crude oil; on a weight basis, oil contains approximately twice the amount of carbon atoms and chemically stored energy as biomass. Therefore, the proposed sevenfold increase of the U.S. biomass production will not constitute a large enough resource to completely replace the current demand for oil. Thus, as the use of biomass in industry increases, it will at some point become a scarce resource, and its utilization should for this reason be considered wisely.

6. Chemistry of Biomass

The knowledge of chemistry of biomass is extremely important for developments of energy-efficient biorefinery processes. In general, the chemistry of biomass is quite complex in nature involving extensive ranges of chemical compounds. The carbohydrates, lignin, proteins and fats are the primary chemical compounds present in the biomass together with lesser extents of several other chemicals such as vitamins, dyes and flavors. The chemistry of such wide ranges of biomass is beyond the scope of the present article. In the present article, the most commonly used biomass for biorefinery is classified into three broad categories based on their chemical nature [25].

(i) Triglycerides feedstock (TGF) Examples are vegetable oils, animal fats, waste cooking oils and micro algal oils. 
(ii) Sugar and starchy feedstock (SSF)

(a) Sucrose containing biomass like sugarbeet, sweet sorghum, sugarcane etc.
(b) Starchy biomass like wheat, corn, barley, maize etc.

(iii) Ligno-cellulosic feedstock (LCF) like wood, straw, grasses etc.

About 75% of the biomass is carbohydrate in nature mainly in the form of cellulose, starch and saccharose [26]. Only 20% of the biomass is composed of lignin and remaining 5% is natural compounds such as oils, proteins and other substances. Only 3–4% of the total biomass is currently used by human beings for food and non-food purposes.

7.1 Triglycerides Feedstock

The TGF include vegetable oils, animal fats, waste cooking oils and micro algal oils. The vegetable oils are generally two types: edible (like rapeseed, coconut, sunflower etc.) and non-edible (like jatropha, mahua, karanja etc.). In TGF, one molecule of glycerol is bonded with three molecules of fatty acids by ester bonds. The three fatty acids present in the TGF maybe same or different. The fatty acid composition of TGF generally varies significantly depending on the source and geographical origin [27, 28].

7.2. Sugar and Starchy Feedstock

Sucrose is commonly known as table sugar or sometimes called saccharose. Chemically sucrose is a disaccharide composed of two different C6 monosaccharides: α-glucose and β-fructose. These monosaccharides are linked together by α-1 glucosidic-β-2 fructosidic bond. The starch is a polymer of α-glucose linked by α-1, 4 glucosidic bond (as in amylose) and α-1,6glucosidic bond (as in amylo-pectin). Starch usually comprises of 20–25 wt % amylose and 75–80 wt% amyllo-pectin depending on the source. The typical molecular weight of amylose is in the range of 105–106 kg kmol\(^{-1}\)[29]. On the other hand, the amylo-pectin is one of the largest biopolymers with typical molecular weight of about 1 x 10\(^6\) kg kmol\(^{-1}\). In plants, the starch molecules arrange themselves in semi-crystalline granules. Starch is thus insoluble in cold water; but completely soluble in hot water.

Figure 2

7.3 Lignocellulosic feedstock

LCF is primarily composed of cellulose (40–50%), hemicelluloses (25–35%) and lignin (15–20%) [30]. The LCF also contains small quantities of pectin, protein, extractsives (nonstructural sugars, nitrogenous material, chlorophyll and waxes) and ash. The compositions of LCF vary significantly depending on types and geographical origin. The
softwood lignin is primarily build of coniferyl alcohol with small amounts of coumaryl alcohol. The lignin in hardwoods is composed of both coniferyl and sinapyl alcohol together with small quantity of coumaryl alcohol. The lignin obtained from grass and herbaceous crops composed of all three phenylpropane units together with p-hydroxycinnamic acids [31].

8. Different Value Chains in the Conversion of Biomass

It is useful to discuss value chains of chemicals to get a simple overview of the necessary conversion and purification steps in the production of target chemicals from renewable resources. When addressing the issue of how biomass can be converted into useful chemical products, there are two overall strategies can be undertaken. Figure 3 summarizes these two strategies through renewable chemical value chains and their fossil counterparts. The strategies differ in their compatibility with the existing fossil value chain and therefore also in the extent to which existing processing technology and infrastructure can be adapted. Both value chains start with a biomass resource, which is converted to a higher-value product by means of either a conversion or a purification step.
Figure 3 Drop-in Strategy for processing of Biomass to end products

The “drop-in” strategy is characterized by the conversion of a biomass resource into a platform from which existing intermediates can be obtained. Typically the challenges are to develop a competitive process targeted towards a predetermined end product and initially to compete with fossil equivalents. An example of this strategy is the conversion of sugar cane or corn (biomass resources) by fermentation into ethanol (platform chemical) and then by dehydration into ethylene, which can serve as an intermediate for polymerization, oxidation, halogenation, alkylation, or other reactions to produce target chemicals or products. In this approach the scene is already set; the product can enter a mature market, and furthermore a large part of the necessary infrastructure and technology already exists to capitalize upon the value added chemical product. Note that the point of entry from the renewable value chain does not necessarily lie before the existing fossil intermediate. They may also converge later in the value chain. This is the case with target chemicals such as propylene glycol made from glycerol, for which the market may not yet be fully matured and which as such represent borderline cases.

The “emerging” strategy represents a completely new value chain with an emerging product in the end. This situation imposes several challenges as compared to the former, albeit also advantages. Typically the final product does not have to compete directly with existing products and the inherent functionality present in the parent compound or biomass feedstock can be exploited to a much larger extent. The product may emerge as a consequence of utilization of the functionality of the feedstock or of the most suitable and cost-effective conversion route for the feedstock, rather than the resource needing to be converted into an already-existing product. In this case, new markets may have to be developed; the entire technology to produce the added-value chemical should be developed or, at best, extensive modification of existing technology is required. This approach therefore requires extensive initial investments and long-term commitment compared to the former “drop-in” strategy. At present, possible examples could include 2,5-furandicarboxylic acid or levulinic acid ketals, which are both products of hexose dehydration reactions. Both of these are, however, still at an early development stage.[32]

9. Status In India

The accurate estimates of availability of surplus biomass are however very scarce in India. According to Ministry of New and Renewable Energy,™ 120–150 million metric tons of surplus biomass (agricultural and forestry residues) are available annually in India which is equivalent to power generation potential of about 18,000MW [33]. If entire surplus biomass is diverted to bio-fuels production, it can potentially produce 1.35 10^7 tons of oils equivalent (toe) or 1.34 x 10^7 tons of diesel or 1.29 x 10^7 tons of petrol (assuming 1 toe = 41.87GJ; 1 ton diesel = 1.01toe; 1 ton petrol = 1.05 toe). The petroleum consumption in India during 2010–11 was14.18 x 10^7 metric tons with contributions of major transportation fuels were 1.42x10^7, 5.08 x 10^6 and 5.99 x10^7 metric tons for MoGas, ATF and
HSDO respectively [34]. The surplus biomass thus can potentially reduce consumption of nation's 10% petroleum, 90% petrol or 22% diesel. Apart from this, 5000 MW power could be generated through bagasse based cogeneration in the country's 550 sugar mills. Pandey also reported similar estimates of availability of surplus crop residues [35]. Their estimates showed that 164.5 MMT of surplus crop residues were available in India during 2007–2008 which was 26.4% of overall agricultural biomass generation. The sugarcane tops are highest surplus crop residue followed by oilseed residue, cottonstalks, rice straw and wheat straw. Additionally, India has estimated annual production potential of 20 million tons of non-edible oilseeds which is equivalent to 3.69 x10⁶ toe or 2.5% of petroleum consumptions during 2010–2011.

India’s First Integrated Bio-refinery for Renewable Fuels & Chemicals for producing ethanol from a variety of biomass. The plant is situated at Rahu in Pune district of Maharashtra. The demonstration plant has been built by Praj industries. The inaugurated Bio-refinery plant is capable of producing one million litres of ethanol per annum by processing a variety of biomass like rice and wheat straw, cotton stalk, bagasse, cane trash, corn cobs & stover with superior product yields [36]

10. Challenges faced by Indian Petrochemical Industries

Indian Petrochemical industry face a number of challenges which needs to be trounced are multifarious for example high inflation rate, rising prices, weak customer and business sentiment coupled with a complicate access to lending are few of the problems faced by almost all sectors of Indian economy. Few of the industry specific challenges are discussed below:

10.1. Shortage of Petroleum Crude

Petroleum industry in India has been suffering from the problem of shortage of raw materials, i.e., petroleum crude. Total refining capacity in the country has reached the level of 148.97 million tones in 2006-07 as against the total indigenous production of only 34.0 million tones. Thus, the petroleum industry has to depend too much on the imported crude. Due to the increasing volume of demand-supply gap, the petroleum refiners in India have failed to utilize their production capacity fully.

10.2. Dependence on Foreign Countries

Petroleum industry in India has been depending too much on foreign countries for the supply of petroleum crude and machineries. Total consumption of petroleum crude has increased to 146.5 million tones in 2006-07 as against the total production of petroleum crude of 34.0 million tones. This has resulted in the import of 105.5 million tones of petroleum crude in 2006-07. Moreover, the petroleum industry of the country depends too much on some foreign countries for meeting its requirement of various drilling and refining machineries.

10.3. Price Hike

The international prices of petroleum goods have been maintaining a constant hike since 1973-74. This has led to the excessive rise in our import bill on petroleum goods. In 2011-12, total import bill on petroleum oil and lubricants was to the tune of Rs 7, 43,075 crore as against Rs 5,587 crore in 1980-81.

10.4. Shortage of Oil Refining Capacity

In India there is a shortage of oil refining capacity as compared to total demand for petroleum products. Total refining capacity of the country stands at 214.1 million tones as compared to the total consumption of 220.5 million tones of petroleum products in 2011-12. This has necessitated the expansion of existing refineries and also setting up of new refineries under the joint sector.

10.5. Exploration of New Reserves

In India, the production of petroleum crude of existing old reserves has been shrinking due to normal technical reasons. The proved oil reserves in India constitute only 0.5 per cent of the world oil reserves (proved). At this present level of consumption, the proved reserves will be depleted within next 15 to 20 years. The country has now increasingly facing the growing demand-supply gap of petroleum crude. The country has also been facing the problem of mounting import bill of POL items. Under the present circumstances, it is quite urgent to intensify the exploration activities of the oil sector sincerely.

10.6. Technical Problems

The petroleum industry of the country is also suffering from numerous technical problems in respect of production of middle distillates, activating its fire fighting systems etc. which need to be corrected and updated at the earliest possible time. The R and D facilities in the industry should be expanded with the maximum possible limit to face these technical problems.
10.7. Pollution

The growing pollution near the refineries and oil fields is a big problem for the industry. The Government is trying to control such pollution by adopting certain effective measures.

10.8. Lack of Market-Determined Pricing System

The lack of a well functioning market determined pricing system, partly because of the lack of vibrant competition among the companies with diversified ownership, continues to constrain the performance of petroleum industry. Despite the surge of international prices of petroleum touching record level, the petroleum companies are not allowed to revise their market price of petrol and HSD accordingly and allowed only a limited freedom to revise the prices as per revised methodology. This has resulted in a severe depletion of the financial wherewithal of the petroleum companies. [37]

10.9 Compatibility with refinery infrastructure

Today's complex petroleum processing technologies and associated infrastructures were developed with continuous efforts of last two century. The compatibility of biorefinery with existing petroleum refinery and petrochemical industry infrastructures is thus essential to eliminate the needs of capital-intensive new infrastructures. The compatibility will also facilitate rapid growths of biorefinery. Instead of oxygenated bio-fuels and platform chemicals, production of hydrocarbon fuels and building block chemicals (compatible with existing infrastructures) from biomass should be encouraged. In early concepts of biorefinery, the shale gas was thus considered as a potential platform chemical as existing gasification technology enables production of shale gas from biomass.

10.10. Market and economic viability

Integrated biorefinery must optimize use of biomass to create products matched perfectly with market demands. These products should be economically competitive with fossil fuels. At present, ~ 85–90% petroleum refinery output goes for production of fuels with only ~ 10–15% being diverted to petrochemical industry for production of organic chemicals. The biorefinery in principle should also produce similar proportion of fuels and organic chemicals to match exactly with market demands.

10.11 Sustainability

The life cycle analysis must be carefully modeled and monitored for various feedstock to understand economic, environmental and social impacts of biorefinery. Only a few life cycle analysis were however reported so far using agricultural residue, switch grass as energy crops and wood residue [38].

10.12. Consistent Research and Development investments

Government, academia and industry made significant contributions in developing feedstock and technologies to foster growth of nascent biorefinery. Many of these technologies remain in early stages of development. Therefore, an on-going and consistent support is essential for scientific understanding and technological developments of profitable manufacturing processes for biorefinery.

11. Conclusions

The energy efficiency of Indian industry varies widely. Certain sectors and companies are leading in terms of efficiency, such as large-scale cement kilns and certain ammonia producers. In other cases, the efficiency is clearly below world average. The country specific feedstock situation is a factor that affects the level of efficiency negatively. The Indian coal has a high ash content, which reduces the energy efficiency. Small-scale cement kilns have been built in order to exploit small limestone deposits that could not support large kilns. The small-scale pulp and paper plants can be explained by the lack of large forest areas that can support large plants. These disadvantages are structural, the only alternative would be to import materials from elsewhere, which is often a challenge because of the transportation infrastructure constraints. Indicators must account for such structural factors.

The biorefinery was classified into three broad categories based on the chemical nature of biomass: TGB, SSB and LCB. Consistent quality and easy to process feedstock for TGB and SSB leads technological realization relatively easy. Extensive usages of expensive edible-biomass for these biorefinery however pose serious threats of food crisis, escalation of food prices and economic imbalance. LCB uses world’s most abundant and inexpensive non-edible biomass, is most promising one. However, availability of huge quantities of biomass with consistent quality and cost-competitive processing technologies are key bottlenecks for its large-scale implementation. Cultivation of short rotation and fast growing energy crops or highly productive microalgae should be emphasized to fulfill long-term goal of complete replacement of fossil fuels with minimal sacrificing of arable lands. The small scale biomass processing technologies must be emphasized for decentralized biorefinery to avoid expensive transportation of biomass.
platform chemicals derived from carbohydrates of SSF and LCF provides notable opportunities to produce an array of derivatives to fulfill societal needs of organic chemicals and polymers. However, new chemistry and process based on these oxygen-functionalized platform chemicals are unsuitable with existing petrochemical industry infrastructures. New manufacturing concepts are thus evolving for production of hydrocarbon fuels and building block chemicals from biomass. The promise of utilization of existing petroleum refinery and petrochemical industry infrastructures are the advantages of hydrocarbon biorefinery.

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