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INVITED REVIEW

# Biofuels: opportunities and challenges in India

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**Abstract** Energy plays a vital role in the economic growth of any country. Current energy supplies in the world are unsustainable from environmental, economic, and societal standpoints. All over the world, governments have initiated the use of alternative sources of energy for ensuring energy security, generating employment, and mitigating $CO_2$ emissions. Biofuels have emerged as an ideal choice to meet these requirements. Huge investments in research and subsidies for production are the rule in most of the developed countries. India started its biofuel initiative in 2003. This initiative differs from other nations' in its choice of raw material for biofuel production—molasses for bioethanol and nonedible oil for biodiesel. Cyclicality of sugar, molasses, and ethanol production resulted in a fuel ethanol program which suffered from inconsistent production and supply. The restrictive policies, availability of molasses, and cost hampered the fuel ethanol program. Inconsistent policies, availability of land, choice of nonnative crops, yield, and market price have been major impediments for biodiesel implementation. However, a coherent, consistent, and committed policy with long-term vision can sustain India's biofuel effort. This will provide energy security, economic growth, and prosperity and ensure a higher quality of life for India.

**Keywords** Biofuels · Biodiesel · Fuel ethanol · India

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## Global Energy Overview

Ensuring an adequate and reliable energy supply at competitive prices to support economic growth and meet essential population needs is vital for any country. The volatility of the market and of energy prices, declining production rates, and recent geopolitical acts of war and terrorism has underscored the vulnerability of the current global energy system to supply disruptions. According to World Energy Outlook (2008), current energy supplies are unsustainable from environmental, economic, and societal standpoints. In addition, it is projected that world energy demands will continue to expand by 45% from 2008 to 2030, an average rate of increase in 1.6%/yr. In 2007, the intergovernmental panel on climate change (IPCC 2007) released its fourth assessment report confirming that climate change is accelerating and if current trends continue, energy-related emissions of carbon dioxide ($CO_2$) and other greenhouse gases will rise inexorably, pushing up average global temperature by as much as 6°C in the long term. Recent floods, cyclones, tsunamis, sea rise, droughts, and famines throughout the world were implicated as a part of climate change resulting from unabated burning of fossil fuels (IPCC 2008). Climate change threatens water, food production, human health, and the quality of land on a global scale (OCC 2006; IPCC 2008). Preventing catastrophic and irreversible damage to the global climate ultimately requires a major decarbonization drive. Globally, 80% of total primary energy supply depends on the fossil fuels coal, gas, and petroleum-based oils. Renewable energy sources represent only 13% of total primary energy supply currently, with biomass (the material derived from living organisms) dominating with 10% in renewable sector (IEA 2007a). Traditional biomass, including fuel wood, charcoal, and animal dung, continues to provide important sources of bioenergy for most of the world population who live in extreme poverty and who use this energy mainly for cooking. More advanced and efficient conversion technologies now allow the extraction of biofuels in solid, liquid, and gaseous forms from a wide range of biomass sources such as woods crops and biodegradable plant and animal wastes. Biofuels can be classified according to source, type, and technological process of conversion under the categories of first, second, third, and fourth generation biofuels. First generation biofuels are biofuels made from biomass consisting of sugars, starch, vegetable oils, animal fats, or biodegradable output wastes from industry, agriculture, forestry, and households using conventional technologies. Second generation biofuels are derived from lignocellulosic biomass to liquid technology, including cellulosic biofuels from nonfood crops such as the stalks of wheat, corn, wood, and energy-dedicated biomass crops, such as miscanthus. Many second generation biofuels are under development such as biohydrogen, biomethanol, dimethyl furan, dimethyl ether, Fischer–Tropsch diesel, biohydrogen diesel, mixed alcohols, and wood diesel. Third generation biofuels are in the nascent stage of development and are derived from low input/high output production organisms such as algal biomass. Fourth generation biofuels are derived from the bioconversion of living organisms (microorganisms and plants) using biotechnological tools (Rutz and Janseen 2007; FAO 2008).

National governments are setting targets and developing strategies, policies, and investment plans in biofuels to enhance energy security and exploit alternative energy to mitigate $CO_2$ emission. The recent increase of oil prices, energy security fears, and the domestic reform of agricultural policies (in the context of international negotiation for agricultural trade liberation) give cause for a more serious consideration of biofuel in most of countries. USA, Europe, and Brazil are leading proponents of these initiatives. Mandates for blending biofuel into vehicle fuels have been enacted in at least 37 countries (Martinot 2008). Most mandates require blending of 5–10% ethanol with gasoline and 2–5% biodiesel with diesel fuel. In developed countries, government support for the domestic production of energy crops for biofuel seems to be the rule (Dufey 2006). In the USA, estimated subsidies to the biofuel industry may reach US $13 billion in 2008 and federal tax credit could cost US $19 billion/yr by 2022 (Koplow 2007). In the European Union (EU), biofuel support of €0.52/l will end up costing its tax payers €34 billion/yr (Kutas et al. 2007; Steenblik 2007; Bailey 2008). These initiatives contributed to the rapid growth of liquid biofuels in terms of volume and share of transport fuels. Since 2001, biofuel production has increased almost sixfold to 6 billion liters in 2006 and is projected to grow to 3.0–3.5% of total global transport energy by 2030 from the present 1.9% (IEA 2007b; Worldwatch Institute 2007).

However, environmental groups have been raising concerns about the trade-off in food *vs.* fuel and effectiveness of biofuels in mitigating green house gas emissions. Recent rise in food prices, shortage of food, conflicting demands of arable land, heavy use of fertilizers for biofuel production, and deforestation of rain forests escalated the debate to a global scale (Worldwatch Institute 2007; Bailey 2008; FAO 2008; Mitchell 2008; Searchinger et al. 2008; World Bank 2008). On the other hand, several studies show that biofuel production can be significantly increased without affecting food crops. Further reports suggest that Brazil's sugar-based ethanol production has not contributed to the food crisis (Dufey et al. 2007; Banse et al. 2008; DEFRA 2008; UNICA 2008a, b). Many reports suggest that the success of second and third generation technologies dealing with nonfood biomass will play much bigger role than expected in coming years (IEA 2007a, b; FAO 2008). However, the investment, trade, and subsidy policies around these technologies continue to play critical role for successful exploitation of biofuels.

## Indian Energy Challenges

India is a rapidly expanding large economy and faces a formidable challenge to meet its energy needs in a responsible and sustainable manner. To sustain India's 8% average annual economic growth and to support its growing population, India needs to generate two- to threefold more energy than the present (IEA 2007b). This means an increase in energy supply from 542 million tons of oil equivalent in 2006 to 1,516 million tons of oil equivalent in 2031–2032 (GOI 2006a). The nature, dimensions, and complexities of achieving this challenge are analyzed based on the present energy capacity, context, and potential. The country is rich in coal and abundantly endowed with renewable energy in the form of solar, wind, and hydro-generated energy, bioenergy, and large reserves of thorium. Unfortunately, reserves of hydrocarbon, gas, and uranium are meager. At the current level of production and consumption, India's coal reserves are estimated to last more than 200 yr. India is currently the third largest coal-producing country in the world (behind China and the USA) and accounts for about 7.5% of the world's annual coal production (IEO 2008). India is also currently the third largest coal-consuming country (behind the China and the USA) and accounts for nearly 9% of the world's total annual coal consumption (MoC 2009). More than half of India's energy needs are met by coal, and about 80% of India's electricity generation is now fueled by coal. The annual demand for coal has been steadily increasing over the past decade. Despite a production increase from 70 million tons in early 1970s to 456 million tons in 2007–2008 (CIL 2009), India continues to face shortages of high quality coal for steel manufacturing (44 million tons in 2007–2008) which is imported. Over the last 7 yr, imports have doubled from 20 million tons in 2000–2001 to 44 million tons 2007–2008 and are expected to triple in 2030 (EIA 2008).

The country has made significant progress toward the augmentation of power infrastructure with an installed capacity of 147,457 MW as of January 2009. Of this, 93,392 MW is accounted for by thermal power plants (coal, gas, diesel), 36,762 MW by large hydroelectric plants, 4,120 MW by nuclear, and the remainder from renewable sources (CEA 2009). Despite the significant growth in electricity generation, significant problems persist, such as poor quality, power shortages, load shedding, fluctuating voltage, erratic frequency, and frequent power cuts. On top of this, currently 400 million Indians are reported to have no access to electricity (IEA 2007b). Even after the signing of a nuclear cooperation treaty with USA, India's nuclear contribution to the energy mix is at best expected to be 3–4% unless vast thorium resources are exploited.

It is estimated that India has only 0.4% of the world's proven reserves of crude oil. The production of crude oil in the country has increased from 6.82 million tons in 1970–1971 to 34.12 million tons in 2007–2008 (MoP 2009). However India's oil consumption increased by 5.7% per annum from 1980 to 2001 periods to 11.9% from 2001 to 2006, and it now stands at 156 million tons, or 3% of global oil consumption (IEA 2007b; MoP 2009). In India, oil provides energy for 95% of transportation needs and the demand for diesel is fivefold higher than the demand for petrol. Over 80% of passengers and about 60% of freight are transported by road. With the increased economic growth and expendable income over the last two decades, demand has also increased for all transport services by road, rail, and air. Vehicle ownership has increased, with the number of private motor cars growing by 16%, two wheelers by 20%, and goods vehicles by 13%/yr from 1991 to 2003. The latest available statistics indicate that the total number of vehicles has increased more than threefold, from 1991 to 2007–2008 and projected to grow by 12–15% reaching 373 million in 2035 (Fig. 1). This growth is expected to fuel 5–8% in the demand for petroleum-based energy in India (GOI 2006b; MoP 2009)

In India, natural gas is currently a minor fuel in the overall energy mix, representing 10% of total primary energy consumption in 2008. Natural gas demand has been growing at the rate of about 6.5% during the last 10 yr. Industries such as power generation, fertilizer, and petrochemical production are shifting toward natural gas. Although recent discoveries are expected to boost gas production to bridge the gap, a growing share of gas requirements need to be met by imports.

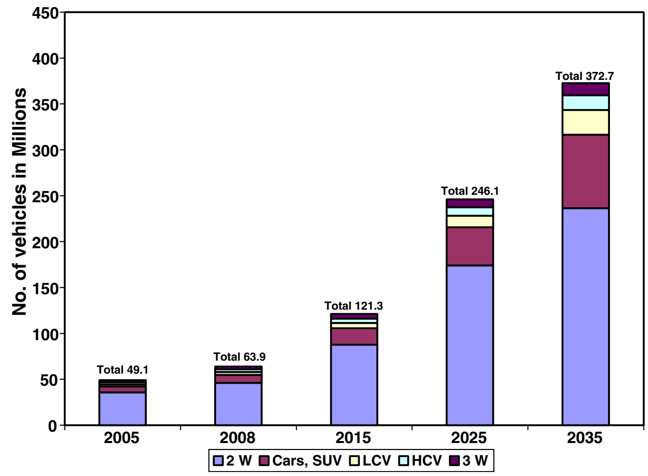



**Figure 1.** Projected growth of automobiles in India. *2W* motorcycles, *3W* 3 wheeler, *HCV* heavy duty commercial vehicle, *LCV* light duty commercial vehicle, *SUV* sport utility vehicle. Source: http://www.adb.org/Documents/Reports/Energy-Efficiency-Transport/chap01.pdf.

Today, India has one of the highest potentials for the effective use of renewable energy (Table 1). India is the world's fourth largest producer of wind power after Denmark, Germany, and Spain. There is a significant potential in India for generation of power from renewable energy sources such as small hydro (less than 25 MW), biomass, and solar energy. The country has an estimated small hydropower potential of about 150,000 MW. India produces 13,242 MW renewable energy excluding large hydropower (MNRE 2009) representing 9% of total electricity production. Other renewable energy technologies, including biomass, wind, solar, small hydro (less than 25 MW, bagasse and waste to energy are also growing.

Despite increasing dependence on commercial fuels, a sizeable quantum of energy requirements (40% of total), especially in the rural household sector, is met by noncommercial energy sources, which include fuel wood, crop residue, animal waste, and human and draft animal power. Regardless of the progress achieved after national independence, around 86% of rural households and more than 20% of urban households still rely primarily on traditional fuels to meet their cooking needs. Biomass is the domestic fuel used for cooking and consists of mainly of agricultural waste, gathered woods, and cow dung. Biomass is also used as industrial fuel by small cottage industries. The use of traditional fuels continues to cause health problems arising from indoor air pollution. India also has a 40-yr-old biogas program with 3.7 million installed plants providing energy requirements for the rural households; however, only half of these are in use.

**Table 1.** Renewable energy resources (Mtoe/yr)

| Resources | Present | Potential |
|---|---|---|
| Hydropower (MW) | 32,326 | 150,000 |
| Biomass | | |
| Wood | 140 | 620 |
| Biogas | 0.6 | 4 |
| | 0.1 | 15 |
| Biofuels | | |
| Biodiesel | | 20 |
| Ethanol | <1 | 10 |
| Solar | | |
| Photovoltaic | | 1,200 |
| Thermal | | 1,200 |
| Wind energy | <1 | 10 |
| Small hydropower | <1 | 5 |

Large segments of the population continue to have a low standard of living, and the task of providing clean and convenient energy for their essential needs, even when they cannot fully pay for it, is critical to their well-being (GOI 2006a).

Per capita consumption of energy in India is one of the lowest in the world, 439 kg oil equivalent (kgoe) per person, compared to 1,090 kgoe in China, 7,835 kgoe in USA, and world average of 1,688 kgoe in 2003 (GOI 2006a). It is expected to grow to 1,250 kgoe in 2032 which would be 74% of the global average in 2003. At the same time, India's dependence on imported energy has increased substantially over the years. Up from 17.85% of Total Primary Commercial Energy Supply (TPCES) in 1991, imports accounted for 30% of our TPCES in 2004–2005 (GOI 2006a). Due to limited domestic crude oil reserves, India meets about 70% of crude oil and petroleum products (diesel and aviation fuel) requirement through imports, which are expected to expand in coming years. The quantity of crude oil imported increased ninefold from (11.66 million tons) during 1970–1971 to (121 million tons) by 2007–2008. During the last 7 yr, India's oil import expenditure has increased fivefold because of the escalation of global oil prices (MoP 2009; Fig. 2). In addition, the economic cost of oil dependence is even greater because the government of India spends US $57.8 billion in subsidies: an amount more than 3% of country's GDP (Ringwald 2008). It is estimated that at a growth rate in demand of 2.9%/yr, India needs to import 6 million barrels/d crude oil in 2030. This would make India the world's third largest oil importer after the USA and China (GOI 2006a; IEA 2007b). Coal imports are likely to grow substantially over time. Hence, energy security has become a growing concern for India's energy policy.

## Policy Initiatives

To address these issues in an integrated manner during 2000–2006 period, the Planning Commission constituted a series of committees such as Hydrocarbon vision-2025, India vision-2020, and Integrated Energy Policy-2006 (GOI 2000a, b, 2006a) and prepared an integrated energy policy linked with sustainable development addressing all aspects of energy use and supply. The broad vision behind the energy policy was to reliably meet the demand for energy services of all sectors at competitive prices. In addition, essential energy needs of all households must be met even if that entails subsidies to vulnerable households. The demand must be met through safe, clean, and convenient forms of energy at the least cost in a technically efficient, economically viable, and environmentally sustainable manner.

Based on the committee reports, the Planning Commission projected the country's energy requirements until 2031–2032 based on various growth rates of GDP. To meet these requirements, India needs, at the very least, to increase its primary energy supply by three to four times and its electricity generation capacity/supply by five to six times of their 2003–2004 levels in 2031–2032 (Table 2). By 2031–2032, power generation capacity must increase to nearly 800,000 MW from the current capacity of around 160,000 MW inclusive of all plants in production. Similarly supply of coal, the dominant fuel in India's energy mix will need to expand to over 2 billion tons/annum based on domestic quality of coal (GOI 2006a).

Meeting this vision requires that India pursues all available fuel options and forms of energy, both conventional and nonconventional. IEA (2007b) estimated that from 2006 to 2030, India will need to invest the massive amount of US $1.25 trillion in the energy infrastructure, three fourths of which will be in the power sector: a huge challenge for meeting sustainable economic growth.

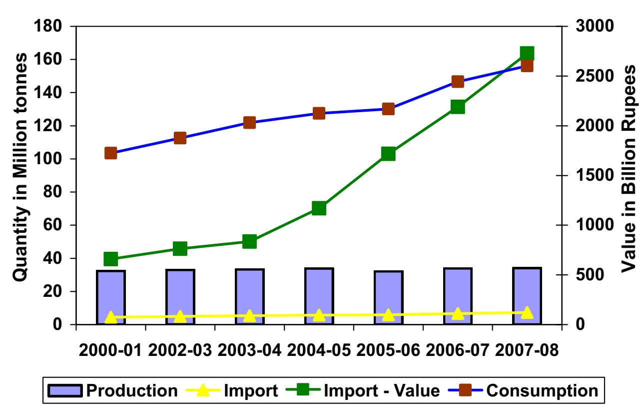



**Figure 2.** Crude oil production, consumption, and import trends in India.

**Table 2.** Projected primary commercial energy requirements at 8% GDP growth rate

| Year | Hydro | Nuclear | Coal | Oil | Natural gas | TPCES |
|---|---|---|---|---|---|---|
| 2011–2012 | 12 | 17 | 257 | 166 | 44 | 496 |
| 2016–2017 | 18 | 31 | 338 | 214 | 64 | 665 |
| 2021–2022 | 23 | 45 | 464 | 278 | 97 | 907 |
| 2026–2027 | 29 | 71 | 622 | 365 | 135 | 1,222 |
| 2031–2032 | 35 | 98 | 835 | 486 | 197 | 1,651 |
| CAGR—% | 5.9 | 11.2 | 5.9 | 5.1 | 7.2 | 6 |
| Per capita consumption 2032 (kgoe) | 24 | 67 | 569 | 331 | 134 | 1,124 |
| In 2004 (kgoe) | 6.5 | 4.6 | 157 | 111 | 27 | 306 |
| Ratio 2032/2004 | 3.7 | 14.6 | 3.6 | 2.9 | 5.2 | 3.7 |

A disturbing fact that emerges from these various scenarios is that even if India somehow succeeds in raising the contribution of renewable energy more than 40-fold by 2031–2032, the contribution of renewable energy to the overall energy mix will not go beyond 5.6% of total energy required in 2031–2032 (Table 3). The actual share of modern renewable energy in India's energy mix is significantly lower (about 2% of the total). This is based on the premise that India is neither a significant contributor to greenhouse gas emissions nor will it be so in the foreseeable future. Also, India has made environmental impact reports, called "green clearance", mandatory for most development projects.

However, the current growth in transport activity is a significant environmental concern given the fact that India's carbon emissions are growing at an average of 3.2% per annum, making it one of the top five global contributors to carbon emissions. Furthermore, at the present economic growth rate, India is set to become the third largest carbon dioxide emitter by 2015 (IEA 2007b). It is also estimated that the annual carbon dioxide emission could increase to 1 billion tons to 5.5 billion tons/yr by 2031–2032. There has been a per capita increase of carbon dioxide emissions in India from 2.6 to 3.6 tons, compared to 2004 levels of 20 tons in the USA and a global average of 4.5 tons. The Planning Commission in its integrated energy policy also indicated the carbon emission scenarios are significant (GOI 2006a). In addition, according to the calculation of Carbon Disclosed Project (CDP), the impact of climate change will be greater than in other countries and the cost of climate change in India could even be as high as 9–13% loss in GDP by 2100 (CDP 2007). These impacts will be experienced by a majority of the rural Indian population (60% or 700 million), who directly depend upon on climate sensitive sectors such as agriculture, forestry, and fisheries for their livelihood.

Although India's per capita emission of air pollutants remains low, the population size and the high density of automobiles in the urban areas produce some of the cities with the worst air quality. Hence, the government of India transport policy targets Euro III and Euro IV norms (GOI 2003) for the vehicles, which will require clean quality fuel. With the current planning of energy mix, it is not possible to mitigate projected carbon emissions because of heavy dependence on coal. This trend is not sustainable and India is bound to face serious international pressures to reduce carbon emissions, despite politically strong arguments such as the need for economic growth, and exceptions on account of a dense population and poverty. To create opportunities for growth and sustainable livelihood for its

**Table 3.** Range of utilization of different fuels in 2031–2032

| Resource | Supply sources (Mtoe) in 2031–2032 | Utilization (Mtoe) in 2004 |
|---|---|---|
| Oil | 463–493 | 116.00 |
| Natural gas | 114–224 | 27.65 |
| Coal | 573–1,082 | 184.35 |
| Hydro | 5–50 | <1 |
| Nuclear | 3–89 | <1 |
| Solar | 1–4 | <1 |
| Wind | 0–12 | <1 |
| Fuel wood | 0–69 | 115.44 |
| Ethanol | 0–4 | <1 |
| Biodiesel | 0–8 | <1 |

Source: GOI 2003, Planning Commission report.

citizens, balancing the economic growth and environmental demands requires a paradigm shift in the energy policy.

## Fuel Ethanol Overview

Ethanol is a biofuel produced from sugar and starch raw materials by fermentation and has been found to be an excellent substitute for petrol. In a large number of countries, ethanol obtained a predominant position among biofuels as a blending agent with petrol because of its oxygenation properties, energy balance, environmentally friendly nature, possible employment benefits in the rural sector, and contribution to energy security at the national level (GTZ-TERI 2007; Faaji et al. 2008; Zuurbier and van de Vooran 2008). Global production of fuel ethanol increased by 18% over 2006 to 46 billion liters in 2007, marking the sixth consecutive year of double-digit growth (Worldwatch Institute 2009). The USA became the leading fuel ethanol producer in 2007, producing over 24.5 billion liters and jumping ahead of longstanding leader Brazil. Brazil and the USA accounted for 95% of all ethanol production in 2007. Several important political, technological, and federal policies and incentives led to both countries becoming world leaders in the use of bioethanol. Other countries implementing fuel ethanol programs are Australia, Canada, China, Colombia, the Dominican Republic, France, Germany, India, Jamaica, Malawi, Poland, South Africa, Spain, Sweden, Thailand, and Zambia (Dufey 2006; DEFRA 2008; IEA 2008; Faaji et al. 2008).

## Biodiesel Overview

Biodiesel is technically defined as a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. It is produced by modification of oil through a chemical process of transesterification, neutralizing the free fatty acids, removing the glycerin, and creating an alcohol ester. There are several methods for carrying out this reaction including the common chemical batch process, supercritical processes, ultrasonic methods, and even microwave methods (Bruce et al. 2004; Janulis 2004). After this processing, biodiesel has combustion properties very similar to those of petroleum diesel and can be used as a direct motor fuel or supplement depending on the type and model of vehicle. A by-product of the transesterification process is the production of glycerol. For every 1 tonne of biodiesel that is manufactured, 100 kg of glycerol are produced (Gonsalves 2006; GTZ-TERI 2007; glycerol is presently used in cosmetics, soaps, pharmaceuticals, alkaline resins, and polyglycerols). A variety of oils can be used to produce biodiesel. These include oils from main crops such as rapeseed, soybean, mustard, flax, sunflower, palm oil, waste oils, animal fats, and nonedible crops such as jatropha and hemp. Sunflower and rapeseed are the raw materials used in Europe whereas soybean is used in USA. Thailand uses palm oil, and Ireland uses frying oil and animal fats (FAO 2008).

The world market for biodiesel has expanded rapidly in recent years. Large numbers of countries have implemented a broad range of laws that support biodiesel usage. Currently, a biodiesel mandate for use motor fuel has been set in 28 countries with various incentives and support (FAO 2008). Hence, biodiesel has steadily emerged from pilot plants to commercial production and marketing products with wide acceptance as a fuel for the diesel vehicle industry. Around 10 billion liters of biodiesel were produced in 2007, an 11-fold increase since 2000. Most biodiesel was produced in the EU (6 billion liters) followed by USA (2 billion liters), Indonesia (0.4 billion liters), and Malaysia (0.3 billion liters; FAO 2008). Various research studies, evaluations, tests, and certifications from a large number of countries confirmed biodiesel as clean alternative fuel having the potential to reduce carbon emission from transport vehicles (Gonsalves 2006). Biodiesel is considered a clean fuel since it has no aromatics and almost no sulfur and has about 10% to 11% built-in oxygen, which helps it to burn fully (GTZ-TERI 2007). Its higher octane number improves the ignition quality even when blended with petroleum diesel. Energy content of biodiesel is close to that of diesel. Fuel efficiency is the same as diesel. Fuel economy, power, and torque are proportional to the heating value of biodiesel or biodiesel blend. Due to these favorable properties, biodiesel can be used as fuel for diesel engines (as either, B5-a blend of 5% Bio-diesel in petrodiesel fuel or B20 or B100). USA uses B20 and B100 biodiesel; France uses B5 as mandatory in all diesel fuel (Martinot 2008).

In India, food security is a national priority and therefore, India cannot afford to use (or promote) either cereal grains for ethanol production or edible oil for biodiesel production as is done in other biofuel promoting regions (EU and USA). India is one of the leading importers of vegetable oil in the world as demand outstrips domestic production. Production of food grains like wheat, corn, and coarse cereals has been relatively stagnant in recent years, forcing India to import wheat in 2006 after being an exporter for several years. A recent spurt in global prices for cereals and vegetable oils have been an additional concern for the government, which does not want to aggravate the crisis by promoting the use of food commodities for biofuel. Hence, India's biofuel program is centered on bioalcohol from sugarcane molasses and biodiesel from nonedible oil crops such oil-bearing trees.

## Ethanol in India: Conflicting Interests

The processes by which ethanol can be produced are diverse as from sugarcane, molasses, sweet sorghum, wheat, corn, sugar beet, sweet sorghum, rice, cassava, and potato. Unlike Brazil, where ethanol is produced directly from sugar cane juice, and the USA, which uses corn for production, India produces ethanol from molasses, a by-product of sugar manufacturing. Alcohol is also a raw material for industrial use in the production of potable alcohol and chemicals. Hence, ethanol production in India has an intrinsic relationship and dependence with industry structure, government policies, and controls followed in sugar and other related industries.

The sugar industry in India is the second largest agricultural industry after cotton textiles and is located mainly in rural India. The sugar industry has a turnover of US $14 billion per annum and it contributes almost US $700 million to the central and state exchequer in additional taxes every year (KPMG 2007; MoCFA 2007). With more than 516 sugar mills operating in more than 18 states of the country, the Indian sugar industry has been a focal point for socioeconomic development in the rural areas. Around 249 sugar mills are in the cooperative sector and balance are in the private or public sector. Out of 516 operating units, the majority have small capacities (below 5,000 tonnes crushed/d): 64 are of medium size (above 5,000 tons crushes/d) and only eight units have large capacities (above 1,000 tons crushes/d; MoCFA 2009). About 50 million sugarcane farmers and a large number of agricultural laborers are involved in sugarcane cultivation and ancillary activities, constituting 12% of the rural population. In addition, the industry provides employment to about two million skilled or semiskilled workers and others mostly from the rural areas.

The sugar industry is a primary source of raw material for the alcohol industry in India, and sugarcane is the key raw material for the manufacture of sugar and alcohol. The sugarcane growing areas of India may be broadly classified into three regions based on climatic conditions, yield of cane, and sugar content. These regions are (a) the subtropical northern belts representing Uttar Pradesh, Uttaranchal, Bihar, Punjab, and Haryana; (b) the subtropical peninsular region representing Maharashtra, Gujarat, and Karnataka; and (c) the tropical Tamil Nadu, Andhra Pradesh, and Orissa (Table 4).

The sugarcane supply to mill is dependent on the cane production from a large number of small farmers because the mills cannot own land according to the Indian land ceiling act. The average size of farm holdings are less than 1 ha and only 25% are more than 4 ha. This means that a mill of 3,000 tons crushes/d must procure cane from 18,000 farmers (KPMG 2007). Cane cultivation and harvesting in India is manual and mechanization is mainly limited to plowing and transport. Availability of labor is becoming critical and mechanization of small farms will be a challenging task in the coming years. Another difficulty is that the crop cycle is limited to 2 or 3 yr because of extreme climatic conditions in most parts of India, compared to 6 to 7 yr cycles in other countries. This requires high flexibility of farmers to shift to other crops in the absence of profitability. The value chain of the sugar industry has significant variations from regions to regions in its profitability to farmers and millers, due to different levels of productivity of cane, cost structure, sugar recovery, and multiple and complex taxes and levies on sugar and its by-products (KPMG 2007; ISMA 2008).

In India, the sugar industry is beginning to diversify to an integrated complex with cogeneration of power, alcohol for industrial and fuel uses. The sugar industry is a green industry and largely self-sufficient in its energy needs because of the use of bagasse for power and steam. In fact, the sugar industry generates exportable surplus power through cogeneration and contributes to the reduction of the energy deficit. The realization from exportable power is dependent on long-term power purchase agreements with governments and power companies. The cogeneration also has proven revenue potential from CDM.

## Sugar Policy

Sugar is a controlled commodity in India under Essential Commodities Act 1955 and regulated across the value chain. The heavy regulations in the sector artificially impact the demand–supply forces resulting in market imbalance. Since 1993, the regulations have been progressively eased out. These include delicensing of the industry in 1998 and the removal of control on storage and distribution in 2002. However, central and state governments still have control over the sugar value chain from mandatory and state advisory cane price (statutory minimum price (SMP) and state advisory price (SAP)), mill capacity expansion, distance of operation, by-product use and transportation, levy and free sale (10:90) release mechanism and exports, and various forms of taxes at central and state level (KPMG 2007).

## Cyclical Sugarcane and Sugar Production

Since independence, the land area under cane cultivation, cane production, productivity, and sugar production have increased dramatically (Figs. 3 and 4). Regardless of increased growth in area and productivity, the production of sugarcane and sugar fluctuates considerably from year to

**Table 4.** Classification of sugarcane belts of India

| Region | State | Average yield tones/ha | Average recovery (%) | Average crushing days | Temperature | |
|---|---|---|---|---|---|---|
| | | | | | Min (°C) | Max (°C) |
| Subtropical—north | Bihar | 42.91 | 9.13 | 93.00 | 7.7 | 41.5 |
| | Uttar Pradesh | 57.57 | 9.62 | 134.42 | 3.6 | 42.6 |
| | Uttaranchal | 57.95 | 9.54 | 131.00 | 2.1 | 42.1 |
| | Punjab | 60.21 | 9.60 | 107.85 | 4.6 | 43.6 |
| | Haryana | 60.54 | 10.00 | 136.28 | 4.1 | 43.3 |
| Subtropical—central | Gujarat | 72.08 | 10.70 | 154.14 | 11.1 | 40.9 |
| | Maharashtra | 72.77 | 11.46 | 116.71 | 10.9 | 42.8 |
| | Karnataka | 83.74 | 10.56 | 141.85 | 14.4 | 41.5 |
| Tropical—south | Orissa | 59.01 | 9.33 | 72.42 | 11.5 | 41.2 |
| | Andhra Pradesh | 76.64 | 10.16 | 123.85 | 13.6 | 41.0 |
| | Tamil Nadu | 100.25 | 9.59 | 185.85 | 18.5 | 37.5 |

Source: Sugar data from Cooperative Sugar Journal, published by Indian Sugar Mills Association. Temperature data from www.indiawaterportal.org. Values are average of 2001–2002 to 2006–2007.

year in India (Fig. 3). Natural factors for this volatility include distribution of rainfall, climatic conditions of flood and droughts, pests and diseases, fluctuations, in prices of gur and khandasari (traditional Indian sugar products), and changes in returns from competing crops. Man-made factors are primarily government policies regarding sugarcane price, release mechanism, taxes, and export and import controls. Sugarcane prices are determined independently of sugar market prices and have been increasing year after year. The uptrend in the sugar cycle starts with timely cane payments by millers from the increased profits for sugar produced and sold in the markets. This will result in increased cane planting by farmers, bumper production of cane and factories to crush it, and produce more sugar, over supply in the market, decline in sugar prices, lower profitability for mills, and delayed payment to farmers. When there is a wide disparity due to high sugarcane price and low sugar prices in markets, millers are not able to make payments on time and arrears to farmers start mounting. The farmers are thus forced away from sugarcane cultivation to other crops and sugarcane and sugar production falls. This aggravates the cycle in a deficit situation, causing an increased diversion of cane to gur and khandasari and resulting in less availability of cane for white sugar manufacturing (Fig. 5). All these factors result again in reduced sugar production, higher sugar prices, turnaround of industry and timely cane payments, and then this vicious cycle continues. In the past, these cycles arose every 4 to 5 yr (Fig. 6). In recent years, these deficit/surplus gaps are becoming wider irrespective of stock positions, existing various control regimes, and policy interventions.

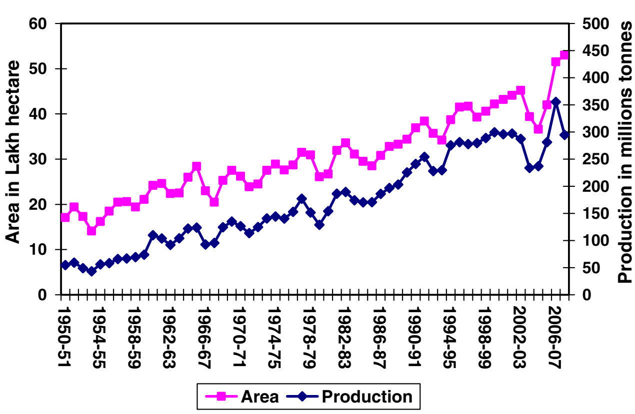



**Figure 3.** Indian sugarcane area and production—a cyclical trend. Source: Cooperative Sugar 40 (5), January 2009, NFCSF Ltd., New Delhi.

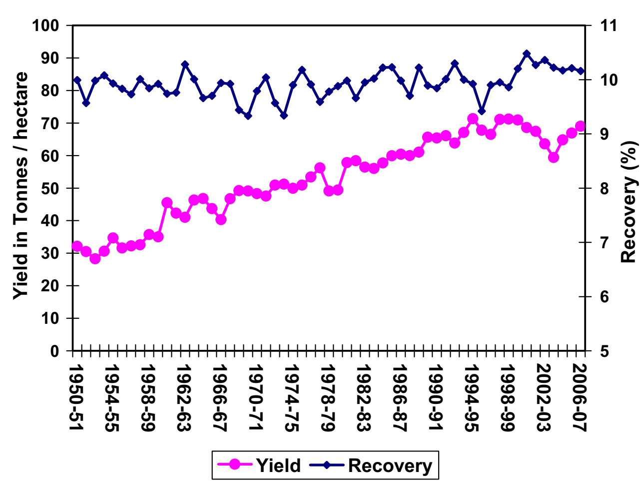



**Figure 4.** Indian cane yield and sugar recovery percentage. Source: Cooperative Sugar 40 (5), January 2009, NFCSF Ltd., New Delhi.

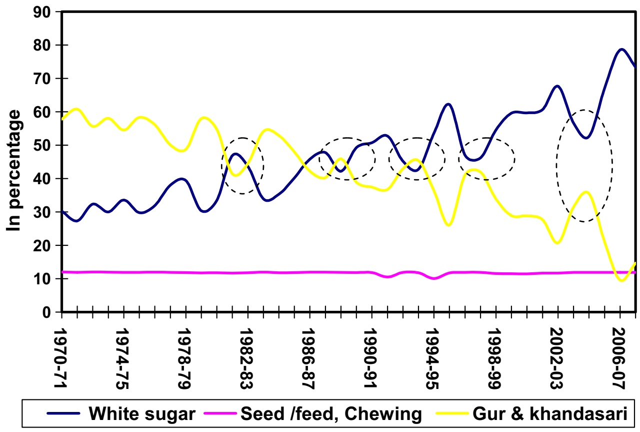



**Figure 5.** Sugarcane utilization trends for various purposes in percentage. Source: Cooperative Sugar 40 (5), January 2009, NFCSF Ltd. New Delhi.

However, consumption of sugar in India has been growing at a steady rate of 3% and is currently at 23.1 million tons, with per capita consumption at 18 kg (lower than world average of 22 kg; Fig. 6). Consumption trends continue to shift from household to industrial consumers. A nationwide survey conducted in 2007 estimated that 61% of sugar sold in the free market accounted for industrial and small business segments (KPMG 2007).

## Molasses and Alcohol Interdependence

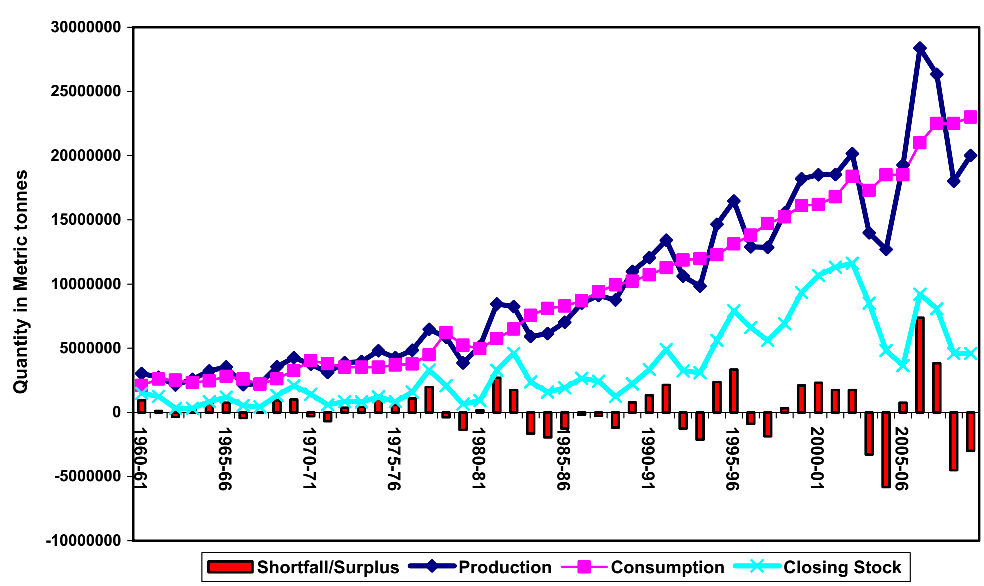
India has about 300 distilleries, with a production capacity of approximately 3.2 billion liters of rectified spirits (alcohol) per year, almost all of which is produced from sugar molasses. There has been a steady increase in the production of alcohol in the country, with the production doubling from 887.2 million liters in 1992–1993 to 1,654 million liters in 1999–2000 and was expected to triple to 2300 million liters by 2006–2007 (GOI 2006a).

The sugar industry is a major supplier of molasses for alcohol and ethanol producing units. There had been ups and downs in production of molasses and ethanol over the years as it is directly linked to molasses production from sugar and its cyclicality (Fig. 7). Surplus sugar results in increased production of molasses and depresses prices for molasses and alcohol. On the other hand, a shortfall of sugar production results in low molasses production and an increase in the price of molasses and alcohol. Main consumers of alcohol are potable and industrial segments. The industry is tightly controlled by various central and state rules, regulations, and taxes.

## Fuel Ethanol: A Turbulent Journey

Affected by the rising oil prices and increased imports of oil for transport, India commenced its bioalcohol transport fuel blending in 2001. In order to ascertain financial and operational aspects of blending 5% ethanol with petrol, government had launched three pilot projects: two in Maharashtra and one in Uttar Pradesh during 2001. Apart from these pilot projects, R and D studies were undertaken simultaneously to evaluate technocommercial feasibility and identify vehicle modification requirements, if any. Both pilot projects and R and D studies were successful and established blending potential of ethanol up to 5% with petrol and usage of ethanol-doped petrol in vehicles. Discussions were held with stakeholders at the central and the state level; Society for the Indian Automobile Manufacturers, the state governments, and an expert group were

**Figure 6.** Indian sugar production and consumption—vicious cycle. Source: ISMA 2008 and incorporating 2008–2009 data.



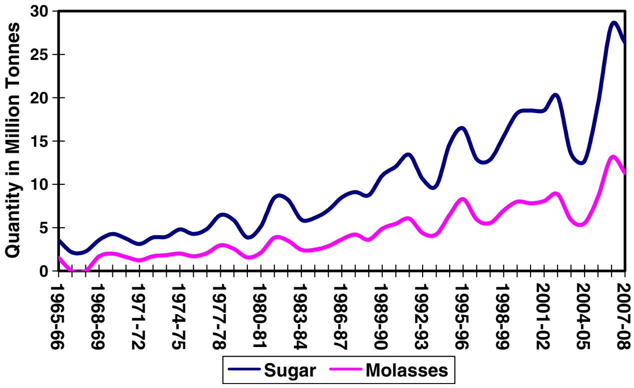



**Figure 7.** Indian sugar and molasses production—interdependence. Source: Cooperative Sugar 40 (5), January 2009, NFCSF Ltd., New Delhi.

set up an for examining various options of blending ethanol with petrol. Considering the logistical and financial advantages, this group has recommended blending of 5% ethanol with petrol at supply locations (terminals/depots) of oil companies. The second phase was aimed to cover the entire country and third phase ethanol blending to be increased to 10%. The availability of molasses and alcohol was estimated to be adequate to meet this requirement, after fully meeting the requirement of the chemical industry and potable sectors. In view of the surplus availability of alcohol, the central government has implemented with effect from January 1, 2003, 5% ethanol-doped petrol supply in the nine states (out of 29) and four contiguous union territories (out of six) as first phase (Gujarat, Andhra Pradesh, Haryana, Karnataka, Maharashtra, Punjab, Tamil Nadu, Uttar Pradesh, Damman and Diu, Goa, Dadra and Nagar Haveli, Chandigarh, Pondicherry).

In addition, during June 2002, the government commissioned a committee under Planning Commission with a mandate of identifying status of biofuels, its commercial use, storage, handling, development of quality standards, identification of prospective sources, cost benefits, R and D requirements, and measures for effective coordination of various ministries. The committee endorsed the initiative of government on the introduction of blending of 5% ethanol with gasoline and projected demand for petrol and diesel and the amount of ethanol and biodiesel required for 5%, 10%, and 20% blending. The committee also estimated demand and supply situation for ethanol until the 12th plan period (Table 5) for blending with 5% taking into consideration of requirements of potable and chemical industry.

Costing of ethanol using sugarcane–molasses ethanol route were also worked out taking into consideration of prevailing prices of molasses at that time and past trends (Rs. 1,000), efficiencies of production (220 l/ton). The ethanol costs were less than Rs. 9/l and quite competitive to that time imported cost of gasoline which was around Rs. 10–12/l (GOI 2003). The committee also took into consideration of past production and consumption trends of molasses, alcohol, and projected surplus alcohol production in the country (Table 6). It is also assessed that the area of 4.36 million hectares under sugar cane may expand to 4.96 million hectares in 2006–2007 yielding additional cane production of 50 million tons. This will provide an adequate base for ethanol for 10% blending even in the tenth plan period. Hence, the committee submitted the findings in April 2003 with following recommendations:

- The country must move toward the use of ethanol as substitute for gasoline.
- Production of molasses and distillery capacity can be expanded to meet 5–10% blend of ethanol.
- Ethanol may be manufactured using molasses or directly from sugar cane juice when sugarcane is surplus.
- Restrictions on movement of molasses and putting up ethanol manufacturing plants may be removed.
- Imported ethanol should be subjected to suitable duties.
- Buyback arrangement with oil companies will be arranged.

Several sugar mills geared up production and supply of ethanol by adding additional capacities (11 factories in Uttar Pradesh, seven units in Tamil Nadu, eight in Karnataka, four units in Andhra Pradesh). Similar steps have also been taken up by the cooperative sector units in Maharashtra, Punjab, and Uttar Pradesh. By the end of the 2004, it is estimated that about 300 million liters capacity would have been created for the production of anhydrous alcohol (Ethanol India 2009).

The 2003–2004 season droughts resulted in a lower sugarcane crop and sugar production (Figs. 3, 4, and 5) and consequently a decreased availability of molasses and increased molasses prices. The sugar output dropped to 13 million tons (normally 21 million tons), molasses production sunk to 5.9 million tons (normally 9 million tons), and the ethanol manufacturing level decreased to 1,518 million liters (normally 2,000 million liters; Fig. 5). The ethanol requirement for 5% blending in the nine states where blending mandatory was 363 million liters in 2003–2004, but the oil companies could only procure 196 million liters. In addition, most of the states have a labyrinth of rules and regulations (interstate movement, high excise duties, and storage charges) to control alcohol for the potable liquor industry. Due to large number of taxes and levies, ethanol blending became commercially unviable in most of the states. The results were that ethanol supplies to the oil companies came to a virtual halt in September 2004. To meet the shortfalls in the year 2004, India imported 447 million liters of ethanol

**Table 5.** Projected demand and supply of ethanol for 5% blending in petrol

| Year | Petrol demand (Mt) | Ethanol demand (ML) | Molasses production (Mt) | Ethanol production (ML) | | | Ethanol utilization (ML) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Molasses | Cane | Total | Potable | Industry | Balance |
| 2001–2002 | 7.07 | 416.14 | 8.77 | 1,775 | 0 | 1,775 | 648 | 600 | 527 |
| 2006–2007 | 10.07 | 592.72 | 11.36 | 2,300 | 1,485 | 3,785 | 765 | 711 | 2,309 |
| 2011–2012 | 12.85 | 756.36 | 11.36 | 2,300 | 1,485 | 3,785 | 887 | 844 | 2,054 |
| 2016–2017 | 16.4 | 965.30 | 11.36 | 2,300 | 1,485 | 3,785 | 1,028 | 1,003 | 1,754 |

Source: GOI 2003, Planning Commission report.

from Brazil. Recognizing the difficulties due to high ethanol prices and low availability, the government of India amended its 5% blending mandate with the notification that 5% ethanol blended petrol shall be supplied in identified areas if (a) the indigenous price of ethanol offered for ethanol blended program is comparable to that offered by the indigenous ethanol industry for alternative uses, (b) the indigenous delivery price of ethanol offered for the ethanol blended petrol program at a particular location is comparable to the import parity price of petrol at that location, and (c) there is adequate supply of ethanol (MoP 2004).

A new government expert committee was commissioned to develop an integrated energy policy to deal with all aspects and forms of energy. The committee reporting on molasses' scarcity differed from the previous committee on the potential of sugarcane ethanol for India. The relative merit of sugarcane ethanol and alternative technologies for ethanol development are still under discussion. In addition, it raises the issues of water scarcity, the lack of area for sugarcane, regional productivity drops, grain shortages, food security, and arguments that the availability of molasses-based alcohol from the sugar industry is unlikely to grow significantly over in coming years. Hence, the committee made the following major recommendations(GOI 2006a):

- Set import tariff on alcohol independent of use and at a level no greater than that for petroleum products.
- Do not mandate blending of ethanol with petrol and prices of ethanol at its economic value vis-à-vis petrol.
- To encourage alternate routes to ethanol, such production may be procured at the full trade parity price of petrol for 5–7 yr instead of being purchased at its true economic value based on calorific content duly adjusted for improved efficiency.
- Create incentives for cellulosic ethanol with investment credits

The bumper monsoon in the year 2005–2006 boosted sugarcane production, availability of molasses, and also increasing prices of petroleum products resulted in a renewed interest in the ethanol program. In August 2005, the government negotiated an agreement between the sugar industry and oil marketing companies to enable the purchase of ethanol, and the ethanol program restarted in a limited number of designated states and union territories. The government of India announced in September 2006 the second phase of the Ethanol Blending Program (EBP) because of the strength of sugar production in that time period. This mandates 5% blending of ethanol with petrol (gasoline) subject to commercial viability in the 20 states and eight union territories with effect from November 2006. Oil marketing companies floated open tenders for ethanol from the domestic producers. Subsequently, bids have been finalized and the EBP has started in about ten states.

**Table 6.** Molasses and alcohol production consumption trends (in million liters)

| Year | Molasses production | Alcohol production | Industrial use | Potable use | Other uses | Surplus availability |
|---|---|---|---|---|---|---|
| 1998–1999 | 7.00 | 1,411.8 | 534.4 | 5,840.0 | 55.2 | 238.2 |
| 1999–2000 | 8.02 | 1,654.0 | 518.9 | 622.7 | 576 | 455.8 |
| 2000–2001 | 8.33 | 1,685.9 | 529.3 | 635.1 | 588.0 | 462.7 |
| 2001–2002 | 8.77 | 1,775.2 | 5,398.0 | 647.8 | 59.9 | 527.7 |
| 2002–2003 | 9.23 | 1,869.7 | 550.5 | 660.7 | 61.0 | 597.5 |
| 2003–2004 | 9.73 | 1,969.2 | 578.0 | 693.7 | 70.0 | 627.5 |
| 2004–2005 | 10.24 | 2,074.5 | 606.9 | 728.3 | 73.5 | 665.8 |
| 2005–2006 | 10.79 | 2,187.0 | 619.0 | 746.5 | 77.2 | 742.3 |
| 2006–2007 | 11.36 | 2,300.4 | 631.4 | 765.2 | 81.0 | 822.8 |

Source: GOI 2003, Planning Commission report.

However, the EBP was not implemented in other states due to high state taxes, excise duties, and levies, which makes the ethanol supply for blending commercially unviable. Consequently, ethanol for blending with petrol in the Indian sugar year 2006–2007 (October–September) is reached at least 250 million liters against the target of 550 million liters.

The sugar industry offered that it could provide ethanol at Rs. 19/l ($0.38/l), which is at a lower cost than the product it would substitute, methyl tertiary butyl ether (MTBE), which costs Rs. 24–26/l ($0.49–0.53/litre) at that time. Petroleum companies purchased fuel grade ethanol from the sugar companies at rates ranging between Rs. 19.0 to 21.5 (47–53 cents)/l during 2006–2007. The cost of production of ethanol depends on the price of molasses, which fluctuates widely during the season. Industry sources estimate the average cost of production of ethanol to range from Rs. 16 to 18 (40–44 cents)/l at 2006 prices of molasses (Rs. 2,000–3,000). The 11th planning commission report (GOI 2007) also states that the economics of sugar production are crucially dependent on the production of by-product ethanol. After stabilization of 5% ethanol blending petrol sales extended to the country as a whole, the content of ethanol in petrol would be considered for increasing up to 10% by the middle of the 11th plan, subject to ethanol availability and commercial viability of blending.

## New Biofuel Policy on the Way

Rising prices of petroleum products in 2008 to more than US $100 per barrel and very high import bills of crude oil forced the government to reinitiate a national biofuel policy under the Ministry of New and Renewable Energy. The union cabinet approved the national policy on 11 September 2008 for setting up an empowered national biofuel coordination committee headed by the prime minister and a biofuel steering committee headed by the cabinet secretary (MNRE 2008). Draft policy was circulated for interministerial consultation and deliberations. The policy envisages the following:

- A target of blending bioethanol and biodiesel 20% by 2017
- Biodiesel production from nonedible oils in waste, degraded, or marginal lands
- Community-based biodiesel production
- Minimum support price for biodiesel and minimum purchase price for bioethanol
- Biodiesel and bioethanol may be brought under ambit of “Declared Goods” to ensure unrestricted movements
- No taxes and duties to be levied on biodiesel

The new policy is still in consultation phase and require approvals and parliament clearances. However, as the term of the present government will be ending in May 2009, the future of the biofuel policy is in question.

## Biodiesel India: Differing Policy Options

In India, biodiesel research, production, and marketing are in the early stages of development. Oilseeds and edible oils are two of the most sensitive essential commodities. India is one of the largest producers of oilseeds in the world and this sector occupies an important position in the agricultural economy and accounting for the estimated production of 282 lakh tons of oilseeds during the year 2007–2008 (Fig. 8). India contributes about 6% to 7% of the world oilseeds production. Climatic conditions enable India to produce wide range of traditional oil seed crops such as groundnut, mustard and rapeseed, sesame, safflower, linseed, niger seed, and castor. Soya bean and sunflower have also assumed importance in recent years. Coconut is the most important amongst the plantation crops. Efforts are being made to grow oil palm in Andhra Pradesh, Karnataka, Tamil Nadu in addition to Kerala and Andaman and Nicobar Islands. Among the nonconventional oils, rice bran oil and cottonseed oil are the most important. In addition, oilseeds of tree and forest origin are also a significant source of nonedible oils (NOVOD 2008).

Despite the production of diverse and large volume of oils, India is not self-sufficient in edible oils. In the early 1980s, India imported 20–40% of edible oil requirements. Finding this to be a huge drain on foreign exchange resources, the government launched the Oilseeds Technology Mission in 1986 leading to increase in oilseed production and reduction in imports to negligible levels. However, during the last two decades, the edible oil consumption has increased at a compound average growth rate of 4.25% from mere 4.959 million tons in 1986–1987 to 12.191 million tons in 2007–2008. Increased per capita

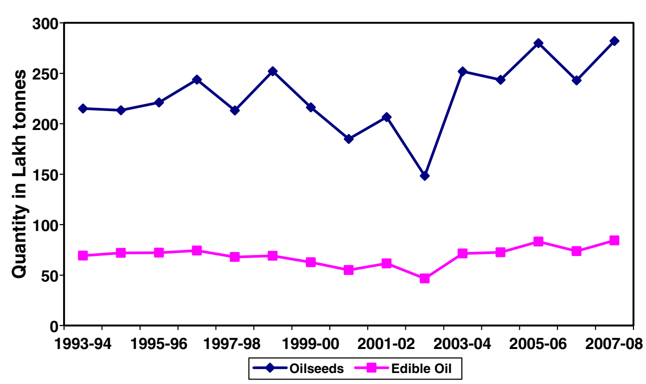



**Figure 8.** Indian oil seed and edible oil production. Source: Ministry of Agriculture, Production of oil seeds.

income has also increased per capita consumption of edible oils to 10.23 kg/yr in 2006–2007 from 6.43 kg/yr in 1986–1987. These led to nearly 50% of deficits, which was managed by importing palm oil from Indonesia and Malaysia soybean oil from Argentina and Brazil.

The edible oil consumption in the country is presently growing and likely to remain heavily dependent on imports. According to an estimate by National Council of Applied Economic Research (NCAER 2009), it is predicted that in the year 2015, the demand for edible oil in India would be 20 million tons per annum. Considering the present domestic edible oil supply of 12 million tons per annum, a shortfall of 7 million tons per annum is envisaged in the year 2015. To bridge this gap, an average growth rate of 15% per annum would be required in edible oil production in India. Edible oil production in India is growing at a compound annual growth rate (CAGR) of 4.26%. The situation might worsen if the country fails to maintain the growth in domestic vegetable oil production. Even maintaining the growth rate in production of vegetable oils will not be an easy task, especially when there is increasing competition among the different crops for the cultivable land and irrigation. In the event of failure to achieve the required growth rate, India would continue to spend large sums on the importation of edible oil. In addition, the demand for vegetable oil is becoming linked to the price of petroleum and to the geopolitical complexities of the crude petroleum market.

The edible oil industry of India comprises of 50,000 expellers, 600 solvent extraction plants, 300 vegetable oil refineries, and 175 hydrogenation plants. The edible oil sector occupies a distinct position in Indian economy as it provides job to millions of rural people, achieves on an average a domestic turnover of US $10 billion per annum, and earns foreign exchange of US $90 million per annum from export of by-products of oil. Domestic cost of edible oils is higher than petroleum products. The domestic consumption demand, stagnant growth in production, and foreign exchange requirements of import make edible oil an unviable option for biodiesel in India. Hence, the Indian government decided to explore alternate source for biodiesel development in India.

## Biodiesel: A Journey Without Direction

India has a vast untapped potential of nonedible oil-bearing plant species distributed throughout the country: 300 species of trees have been reported to produce oil-bearing seeds (Subramanian et al. 2005). All of them are naturally grown wild species which have not yet been cultivated and harvested systematically for oil production. Seventy-five plant species have been identified (Azam and Nahar 2005) with 30% or more oil content in their seeds or kernels. According to a survey conducted in 2002, 12 species have been selected for its importance of present industrial usage and abundance in distribution. These 12 species of trees identified are *Azadirachta indica, Pongamia glabra, Calophylluum ionophyllum, Hevea braziliensis, Madhuca indica, Shorea robusta, Mesua ferra, Mallotus philippines, Garcinia indica, Ricinus communis, Jatropha curcas and Salvadora*. There are billions of these trees distributed all over India. Collection and processing mechanism of these tree seeds are not yet fully developed. Local people collect small percentage of these seeds (10%) and trade for oil and cake, and the remainder of the seeds go uncollected. Their seeds, oil, and by-products are increasingly being used in modern industry for cosmetics, varnishes and paints, lubricants, resins, adhesive, dyes and inks, explosives, cellophane, pesticides, and pharmaceuticals (GTZ-TERI 2007). It is estimated that the potential availability of tree borne seed oils in India amounts to about 1 million tons/yr; the most abundant oil sources are sal (180,000 tons), mahua (180,000 tons), neem (100,000 tons), and karanja (55,000 tons).

The national and state research laboratories have been investigating the potential of these tree seed oils as a biofuel. Among these, *Jatropha curcas*, *Pongamia pinnata*, *Calophyllum inophyllum*, and *Heveia brasiliensis* have been investigated in detail for suitability for Indian conditions and also to meet the automobile blending requirements. There are different advantages to the different species. While jatropha is a native species of South America, pongamia is of Indian origin. Pongamia tree is traditionally planted in several states in road sides, avenues, national highways, and parks and therefore is well known publicly. This tree is not only used for oil but also for animal feed, manure, firewood, and medical purposes. The government of India's biofuels committee submitted a report on biofuels in April 2003, in which it found that *J. curcas* is the most suitable for the biodiesel purpose in India because of following advantages:

- The estimated oil yield per hectare for *Jatropha* is among the highest among tree-borne oil seeds. With an average seed production 3.75 tons/ha, oil content of 30–35% and oil yield of 1,200 kg/ha estimated compared to 375 kg/ha per for soybeans in the USA and 1,000 kg/ha for rapeseed in Europe
- Ability to grow in areas of low rainfall (200 mm/yr), on low fertility, marginal, degraded, fallow, and waste lands
- Relatively easy to collect, plant, and grow without fencing requirements
- Potential use of by-products for manure and biogas generation

- Opportunity to intercrop, integrate with existing social forestry and poverty alleviation programs that deal with land improvement
- Conformation from pilot studies as alternate clean fuel for automotives from India and other parts of world

It is also estimated with a plant density of 2,500 trees/ha can provide an average seed yield of 1.5 kg/tree. A 1-ha plantation can produce an average of 3.75 tons/ha of seed, corresponding yield of 1.2 tons of oil/ha and 2.5 tons of cake. It is estimated that by the end of 11th plan (2011–2012) period that 13.38 million tons of biodiesel for 20% blending will be required, which in turn will require over about 11.2 million hectares of land for jatropha. Cultivation of jatropha was expected to create employment for the rural population.

## Potential Availability of Land

India has much underused or unused lands which need to be deforested to prevent degradation. *Jatropha* plantation was intended to rehabilitate these lands, by improving their water retention capacity, stabilizing the soil, and especially for helping the poor. The chain of activities from raising nurseries, planting, maintaining, primary processing, and oil extraction are labor intensive and expected to generate employment opportunities on a large scale, particularly for the rural landless and help them to escape poverty. Hence, 13.4 million hectares of land conversion to jatropha was proposed under various land categories such as forestry management (3 million hectares), hedge plantations (3 million hectares), absentee landlords (2 million hectares), forestry (2.4 million hectares), and public lands park (1 million hectares) and on waste land (2 million hectares). Accordingly, a national mission on biodiesel was proposed with necessary government support to demonstrate the viability of the program in two phases.

Phase I consists of a demonstration project to be implemented by the year 2006–2007 in six "micro-missions" including plantation, procurement of seed and extraction of oil, processing of seed oil into biodiesel (transesterification), blending and marketing, and research and development. This phase was aimed at cultivating 400,000 ha of jatropha installation of a 80,000 tons/yr transesterification plant to produce 0.5 million tons of biodiesel, 10.52 tons compost from the press cake, and the generation of 127.6 million work days in plantation (cumulative basis) for rural poor. The phase II was planned as a self-sustaining expansion of the program leading to the production of biodiesel to meet 20% of the country's diesel requirements by 2011–2012. It plans to accomplish this through accelerating the momentum achieved in the demonstration project, establishing jatropha plantations throughout the country.

The government planned to act as the principle mover ensuring the necessary resources and components, with involvement from all stakeholders. This will involve 400,000 ha of plantations in compact districts, each with an area of 50,000 to 60,000 ha with facilities established for all the activities involved in forward and backward linkages. The Ministry of Forests and Environment and the National Oilseed and Vegetable Oil Development (NOVOD) Board were identified to serve as responsible agencies for the cultivation in the forest and nonforest areas, respectively, by providing the necessary information and financial assistance. Support mechanisms under the National Employment Guarantee Schemes include Comprehensive Land Development Program, Drought Prone Area Program, Watershed Development Fund, and National Food for Work Program. The financial requirement of the demonstration project until 2007–2008 was estimated up to Rs. 14960 million. This includes a government contribution of Rs. 13600 million towards plantation, Rs. 680 million towards administrative expenses and Rs. 680 million towards R & D. In addition to these a mix of entrepreneurs' own contribution of Rs. 160 million (margin money), a subsidy from the government of Rs. 480 million, and a loan of Rs. 960 million from the National Bank of Agricultural and Rural Development in the ratio of 10:30:60. The transesterification unit will be a commercial venture, estimated at Rs. 750 million. The implementation part of the project has divided into four sectors: (1) plantation, production, marketing and trade and research and development, and various stakeholders from concerned central ministries, departments, and research institutes; (2) state departments and universities; (3) petroleum companies and distributors; and (4) private enterprises, nongovernment organizations, and farmers' organizations.

## Federal Initiative Progress

*Seed development.* NOVOD has established national network on jatropha and karanja in 2004 toward development of high-yielding varieties. The network consists of 42 public research institutions and state agricultural universities. Department of biotechnology initiated a "micro-mission" on production and demonstration of quality planting material of jatropha. Work is also in progress on the development of high oil-yielding varieties of jatropha by Department of Biotechnology, Aditya Biotech Research Centre (Raipur), the Indira Gandhi Agriculture University (Raipur), and the Bhabha Atomic Research Centre (Trombay).

*Plantation.* Agronomic research is under way on jatropha and pongamia in The National Afforestation and Eco-development Board under the guidance of the Ministry of

Environment and Forests, The National Oilseed and Vegetable Oil Development Board under the guidance of the Ministry of Agriculture, and The Central Salt and Marine Chemicals Research Institute (Bhavnagar).

*Transesterification study.* Production of esters from *Madhuca indica*, *Shorea robusta*, *Pongamia glabra*, *Mesua ferra*, *Mallotus philippines*, *Garcinia indica*, *J. curcas*, and *Salvadora* are in progress at Punjab Agricultural University; Indian Institute of Petroleum (IIP), Dehradun; CSMCRI, Bhavnagar; and NBRI Lucknow (CSMCRI, Bhavnagar; NBRI Lucknow; Indian Institute of Chemical Technology; Indian Institute of Technology, Delhi and Madras). Indian Oil Corporation research and development are working on jatropha, karanj oil, mahua oil, and *Salvadora* oil. Alternate enzymatic esterification on neem, mahua, and linseed is also progressing at Mahindra and Mahindra Ltd.

*Pilot plant study.* Pilot plants on transesterification with jatropha oil has been carried out by Indian Oil Corporation (research and development), Faridabad; the Indian Institute of Technology, Delhi; the Punjab Harbinsons Biotech, Agricultural University, Ludhiana; the Indian Institute of Chemicals Technology, Hyderabad; the IIP, Dehradun; the Indian Institute of Science, Bangalore; and Southern Railways, Chennai.

*NGOs.* Organizations *viz.*, Uthan (Allahabad), Sutra (Karnataka); the Institute of Agriculture and Environment (Jind, Haryana); the Bharatiya Agro Industries Foundation Development (Pune, Maharastra); Pan Horti Consultants (Coimbatore); Classic Jatropha Oil (Coimbatore); and Renulakshmi Agro Industries (Coimbatore) are involved in the promotion and creating awareness on biofuel.

*Trials.* Bharat Petroleum Corporation Limited test marketed through its retail outlets 5% of diesel blends of jatropha and pongamia oil. Railways organize trial runs between Amritsar and Delhi (Shatabdi Express) using blended diesel. Daimler Chrysler, Mahindra and Mahindra Co., and Bombay Electric Supply and Transport tested the blended fuel in Mercedes Cars, Tractors, and Public transport buses, respectively.

## State Initiatives

Many states have initiated biodiesel programs based on the central policy directives or their own. Two hundred districts in 19 potential states have been identified on the basis of availability of wasteland, rural poverty ratio, below poverty line census, and agroclimatic conditions suitable for jatropha cultivation over a period of 3 yr. Each district planned to be treated as a block and under each block, a 15,000-ha jatropha plantation is planned to be undertaken through farmers (GOI 2003; DIE 2008). Details of progress are summarized in Table 7.

## Commercial Initiatives

Large number of small and medium private enterprises was also invested in plantations as well as commercial production of biodiesel; however, the market for biodiesel has not yet emerged on a commercial scale. The current status of their activities is summarized in Table 8. In October 2005, the Ministry of Petroleum and Natural Gas initiated a biodiesel purchase policy with effect from January 2006. According to the policy, oil marketing companies are to purchase biodiesel in 20 purchase centers in 12 states (DIE 2008). As per the government notification, biodiesel has been completely exempted from the excise duty.

Recently, the Global Exchange for Social Investment (GEXSI 2008a, b) has conducted a detailed survey of status of Indian jatropha plantations. They report that India jatropha plantations fall into one of three types of ownership: private, public, and public–private partnerships with 31%, 31%, and 38% respectively. The total area under plantation estimated to be of 497,881 ha of which 84,000 ha is in Chhattisgarh, 33,000 ha is in Rajasthan, 20,277 ha is in Tamil Nadu, 16,715 ha is in Andhra Pradesh, 350 acres is in Uttaranchal, and 328 ha is in Haryana. Most of these crops are grown in nonirrigated land and 60% are planted in wastelands. It is also projected that India will have 1,179,760 ha of crop in 2010 and 1,861,833 ha in 2015. Recently concluded another study by German development institute (DIE 2008) confirmed that the biodiesel sector in India is different from elsewhere in the world. Biodiesel production is restricted to nonedible oil plants and not related to the price increase of edible oils. The focus is on nonintensive agricultural lands minimizing the competition between fuel and food. Biodiesel activity in rural areas can improve the food security as it provides additional income opportunities to the rural poor. The report also indicated that the biodiesel program address the five important development challenges such as energy supply, reduction of carbon dioxide emission, rural employment, rural energy securities, and protection of natural resources.

## Constraints

The critical factors limiting the successful fuel alcohol program in India are restrictive government policies, availability of molasses, and price. All these factors are

**Table 7.** Details of progress on biofuel initiatives in various states of India

| No. | Name of state | Status of activities |
|---|---|---|
| 1 | Andhra Pradesh | Promotion of pongamia and simaruba with an objective to achieve 100,000 acres of biodiesel plantations in 13 districts was initiated in order to make productive use of degraded land. Forest department is planning to enter into a public private partnership with private company for ensuring buy back agreements. For example, a formal agreement was entered with Reliance Industries for jatropha planting. The company has selected 200 acres of land at Kakinada to grow jatropha. Government has reduced the value added tax for biodiesel to 4% and state road transport corporation was planned to run 10% of its fleet on 5% blending of biodiesel (APGO 2006) |
| 2 | Bihar | Plantations have been initiated in districts namely, Araria, Aurangabad, Banka, Betiah (West Champaran), Bhagalpur, Gaya, Jahanabad, Jamui, Kaimur, Latehar, Muzzaffarpur, Munger, and Nawada |
| 3 | Chhattisgarh | Chhattisgarh Biofuel Development Authority has been set up for promotion of biofuel. 210 million jatropha saplings were raised for planting in the year 2005 and 2006 and planted on 84,000 ha of farmer's and government fallow land. Pilot demonstration plantation was established on 100 ha in government fallow land in each district. A small transesterification plant was installed for biodiesel production at Raipur. Biodiesel-based power generators for rural electrification in a cluster of 50 remote villages were also installed. As a part of the government plan to electrify all villages by 2012, 400 villages are planned to electrify through jatropha based biodiesel funded by Village Energy Security Program of MNRE. State-of-art laboratory was set up in association with a local NGO, for testing of oils and biodiesel, etc. As a demonstration, chief minister continued to use biodiesel-blended fuel in his official vehicle. Government notification issued for allotting government revenue fallow land on lease to private investors to undertake Jatropha/Karanj plantation and also to setup biodiesel plant |
| 4 | Jharkhand | Plantations have been initiated in 19 districts namely Bokaro, Chatra, Daltenganj, Devgarh, Dhanbad, Dumka, Garhwa, Godda, Giridih, Gumla, Hazaribag, Jamshedpur, Koderma, Pakur, Palamu, Ranchi, Sahibganj, Singbhum (east and west) |
| 5 | Gujarat | Plantations have initiated in 10 districts. Ahmednagar district more than 1,000 farmers are working with Govind Gramin Vikas Pratishthan for jatropha planting an area of 2,500 acres. To date, more than 2 million jatropha plants have been planted in the target area of the five villages of Vankute, Dhoki, Dhotre, Dhavalpuri, and Gajdipoor |
| 6 | Goa | Plantations have been initiated in Panaji, Padi, Ponda, and Sanguelim districts |
| 7 | Himachal Pradesh | Plantations have been initiated in Bilaspur, Nahan, Parvanu, Solan, and Unna districts |
| 8 | Haryana | Plantations have been initiated in 11 districts namely, Ambala, Bhiwani, Faridabad, Gurgaon, Hisar, Jind, Jhajjar, Mohindergarh, Punchkula, Rewari, and Rohtak |
| 9 | Karnataka | A biofuel policy has been drafted by state government. Plantation has been initiated in 15 districts. Farmers in semiarid regions of Karnataka are also planting jatropha. Since 2002, Labland Biodiesel, a Mysore-based private limited company, is active in biodiesel and jatropha development |
| 10 | Kerala | Plantations have been initiated in Kottayam, Quilon, Trichur, and Thiruvananthapuram districts |
| 11 | Madhya Pradesh | Plantations have been initiated in 20 districts, namely Betul, Chhindwara, Guna, Hoshingabad, Jabalpur, Khandwa, Mand Saur, Mandla, Nimar, Ratlam, Raisena, Rewa, Shahdol, Shajapur, Shivpuri, Sagar, Satna, Shahdol, Tikamgarh, Ujjain, and Vidisha |
| 12 | Maharashtra | 200 ha plantations were raised in Nasik and Aurangabad districts. In July 2006, Pune Municipal Corporation demonstrated biodiesel blended fuel in over 100 public buses. In September 2007, the Hindustan Petroleum Corporation Limited partnership with the Maharashtra State Farming Corporation Ltd. for a jatropha-based biodiesel venture |
| 13 | Orissa | Plantations have been initiated in 13 districts namely Bolangir, Cuttack, Dhenkanal, Ganiam, Gajapati, Jajapur, Koraput, Keonjhar, Kalahandi, Nowrangpur, Nawapra, Phulbani, and Puri |
| 14 | Punjab | Plantations have been initiated in 5 districts namely, Ferozpur, Gurdaspur, Hoshiarpur, Patiala, and Sangrur |
| 15 | Rajasthan | Plantations have been initiated in Udaipur, Kota, Sikar, Banswara, Chittor, and Churu districts |
| 16 | Tamil Nadu | The government has been promoting development of jatropha through large scale entrepreneurs. To support contract farming of jatropha in 20,000 ha, government allocated Rs. 400 million through primary Agriculture Cooperative Banks. The government has abolished purchase tax on Jatropha. Currently entrepreneurs established 1,000 acres area under jatropha against the target of 20,000 ha |
| 17 | Uttarakhand | A biodiesel board has been established to coordinate jatropha cultivation. Board also coordinate seed procurement, extraction, and transesterification. Along with MNRE government planned to electrify 500 villages with biodiesel |

interlinked upon the historic control regimes and policies imposed on the sugar, molasses, and ethanol industry. There are several ministries involved in policymaking, regulation, promotion, and development for the biofuels sector. The ministry of food and consumer affairs controls sugar and molasses production. The ethanol for industrial use is controlled by ministry of industries and chemicals. The potable alcohol segment is controlled and managed by various state policies. The ministry of renewable energy has the overall policymaking role for promotion and development of biofuels. The ministry of petroleum and natural gas has the responsibility of marketing biofuels as well as the development, implementation of pricing, and procurement policy. The ministry of agriculture handles research and development for production of sugar, ethanol, and biofuel feedstock crops. The state governments control the licensing of new sugar factories and distilleries and their expansion. In addition, the state government controls the allotment of cane in their state and the distance of operation. The central government sets the policy regarding ethanol blending, but the state governments control the movement of molasses and often restrict molasses transport over state boundaries. The state governments also impose excise taxes on potable alcohol sales, a lucrative source of revenue. Foreign liquor imports are taxed at 150% or more, thus affording domestic potable alcohol the highest protection. The dynamics and complexity of managing the control regimes, regulations, and policies on fuel ethanol make it practically impossible for its sustainable production at present. The availability of molasses depends on cane area, cane yield, cane diverted to gur and khandasari, cane price, and sugar produced. Additionally, cane area and sugarcane production are subjected to the vicious cyclicality leading to shortages and surplus. Hence, molasses prices continue to fluctuate. Historical trend of cyclicality indicates that deficits/surplus gaps are widening compared to previous cycles. The surplus deficits of molasses expected to continue in coming years, unless government controls are removed. Recently, the ministry of food and consumer affairs amended the sugarcane control order allowing the direct use of sugarcane juice for sugar and ethanol production. Depressed crude oil prices and the increased market price of sugar led to lack of enthusiasm from the investors toward this choice.

The manufacturing cost of ethanol depends upon the price of molasses, taxes, and duties imposed by state and central government. The molasses price also depends on the cane price. The SMP of cane is regulated by central government over which state government announces the SAP. Hence, wide variation exists in cane and molasses price from state to state. The fuel ethanol market price depends upon the international crude oil price and various subsidies offered. Ethanol pricing in India is also complicated by differences in excise duty and sales tax across states. Central government is trying to rationalize ethanol sales tax across the country. The oil industry, however, is seeking parity between ethanol and the price of gasoline on an ex-refinery or import basis. India's petroleum ministry announced that it would appoint a Tariff Commission to fix an appropriate price for ethanol sourced from sugar mills. The sugar industry is seeking the parity in price with MTBE which alcohol substitutes as an oxygenating fuel. More significantly perhaps, there are still substantial differences in the profitability of potable alcohol in contrast to fuel alcohol in several states. Hence, alcohol-based biofuels production and use are neither encouraging nor remunerative as an automotive fuel.

In addition to the inconsistent government policies, availability of land, choice of crop, its yield, and the market price are the critical impediments encountered during the implementation program. Even though the government prepared an extensive plan in 2003, implementation of the program suffered widely because of the change in priorities and lack of effective coordination. The involvement of large number of agencies without responsibility and accountability made it very difficult to manage and coordinate. The multiple stake holders with conflicting objectives created incoherent views and confusion at all levels of implementation. In addition, various state governments initiated its own programs and policies either aligned with the central government or independently.

The project document identified 11.2 million hectares of land with specific categories for plantation. The quality and ownership of the land intended for the plantation continues to be under dispute. Many of the lands described in the plan are held by state government and managed by collaborative groups or own by selective community, such as *panchayats*. India's experience suggests collective ownership has been very difficult to manage for large scale commercial production. Even for private lands, the present land holding laws and tenancy act as stumbling blocks for large scale plantations. The expectation of jatropha, a nonnative plant, providing high yields even on marginal and dry lands without inputs such as irrigation, fertilizers, and pesticide has not been materialized. This was mainly due to the lack of research data, amenability of jatropha for large scale commercial plantation, and its inconsistent yield. Hence, the productivity and economic viability of this crop in India continued to be in question. Therefore, without the government subsidies, most of the farmers do not consider jatropha cultivation rewarding. As the focus and incentives was mainly on jatropha, the native available potential oil seed bearing tress were neglected for research and commercial exploitation. The present price of biodiesel produced from jatropha is not competitive with conventional diesel at current market price. Conventional diesel is

**Table 8.** Current status of commercial biodiesel production in India

| No. | Organization/institution | Technology/raw material | Capacity |
|---|---|---|---|
| 1 | Southern Online Biotechnologies (P) Ltd.,[z] in Andhra Pradesh with Chemical Construction International Ltd., New Delhi[y] | The technology for the unit will be provided by Lurgi Life Science Engineering, Germany, along with their local partner, Chemical Constructions national Private Limited, New Delhi. Both oil expelling and transesterification units. Raw material supply—*Pongamia*, *Jatropha* and other raw materials like acid oils, distilled fatty acids, animal fatty acids and nonedible vegetable oils | Initial capacity of 30 tonnes of biodiesel/d, which is expandable to 100 tonnes/d. Current availability of seeds in the state is less than 4,000 tons |
| 2 | Maharashtra Energy Development Agency and Mint Biofuels, Pune[x] | Karanja oil-based biofuel | Initially had a capacity of 100 l/d, scaled up to 400 l/d |
| 3 | Gujarat Oelo Chem Limited (GOCL)[w] | From vegetable-based feedstock | Supplying to Indian Oil Corporation |
| 4 | Kochi Refineries Ltd. (KRL)[v] | From rubber seed oil | Capacity of 100 l/d |
| 5 | TeamSustain Ltd., Kochi, a division of US-based Dewcon Instruments Inc.[u] | Discussion in progress | |
| 6 | Shirke Biohealthcare Pvt. Ltd, Hinjewadi, Pune[t] | From *Jatropha* plant | To process 5,000 l |
| 7 | Jain Irrigation System Ltd[s] | Large-scale transesterification biodiesel plant with *Jatropha* | Capacity of 150,000 tons/d in Chattisgarh by 2008 |
| 8 | Nova Bio Fuels Pvt. Ltd[r] | Transesterification biodiesel plant with *Jatropha* of Rs. 200 million | Capacity of 30 tons/d in Panipat in 2006 |
| 9 | Naturol Bioenergy Limited, Andhra Pradesh[q]—a joint venture with Energea Gmbh (Austria) and Fe Clean Energy (United States), Kakinada | 100% export-oriented unit to blend of palm oil, rapeseed, jatropha, pongamia, and vegetable oil. Shipping biodiesel to the EU for blending the alternative fuel into gasoline and diesel | 100,000 tonnes of biodiesel annually. 120,000 ha for *Jatropha* cultivation |
| 10 | Savoia Biodiesel plant, Ganapathipalayam, Tamil Nadu[p] | Transesterification biodiesel plant with *Jatropha* | |
| 11 | KTK German Bio Energies India[o] | Rubber seeds | Commercial production of biofuel in 2006 |
| 12 | Mint Biofuels, Pune[n] | Pongamia seed based | 400 l/d and 5,000 tonne of fuel/d |
| 13 | Sagar Jatropha Oil Extractions Private Limited, Vijayawada[m] | Jatropha oil extraction unit of Rs. 100 million | Jatropha oil is mixed with diesel to produce biodiesel |
| 14 | D1-Mohan Bio Oils Limited[l] (a joint venture of Mohan Breweries and Distilleries and U.K.based D1 Oils Plc) | One lakh hectares under jatropha cultivation in Tamil Nadu | 24 tonnes/d capacity |
| 15 | Classic Jatropha Oil (India) Ltd., Coimbatore[k] | Promoting cultivation of *Jatropha* in Tamil Nadu | |
| 16 | Bharat Renewable Energy and the government-owned Hindustan Petroleum[j] | 40,000 ha of *Jatropha* cultivation | Million metric tons of biodiesel by 2015 |
| 17 | Cleancities Biodiesel, Visakhapatnam[i] | Blend of palm oil, jatropha oil and soya oil | Capacity of 250,000 tonnes |
| 18 | Emami Group, Kolkata[h] | Blending of waste cooking oil of Rs. 150 crores | |

**Table 8** (continued)

| No. | Organization/institution | Technology/raw material | Capacity |
|---|---|---|---|
| 19 | Alagarh Industries in Sivakasi (Tamil Nadu)[g] | | 5 tonnes/d capacity |
| 20 | D1-BP Fuel Crops, based in the UK, is a 50:50 Joint Venture between BP and D1 Oils[f] | Feedstock *Jatropha* and other nonedible oil seeds | |
| 21 | Newcastle-based D1 Oil Plc, along with Labland Biotech[e] | Developed 10,000 ha of jatropha in India | |
| 22 | Aatmiya Biofuels Pvt Ltd, Gujarat[d] | | Commercialized by March 2005 and now producing 1,000 l/d |

[z] http://www.sol.net.in/bio_index.php cited 10 Nov 2008.

[y] http://cdm.unfccc.int/UserManagement/FileStorage/FS_686206579 cited 12 Dec 2008.

[x] http://www.mahaurja.com/ cited 10 Nov 2008.

[w] http://www.gujaratoleochem.com/product1.htm cited 12 Dec 2008.

[v] http://www.bharatpetroleum.com/refineries/refinerykochi_overview.asp?from=ref cited 12 Dec 2008.

[u] http://www.teamsustain.com/g_home.html cited 10 Nov 2008.

[t] http://www.shirkebiofuels.com/biodiesel.htm cited on 10 Feb 2009.

[s] http://www.jains.com/jatropha/Jatropha%20cultivation.htm cited 12 Dec 2008.

[r] http://novabiofuels.com/knowbiofuel.html cited 10 Nov 2008.

[q] http://www.naturol-bio.com/ cited 10 Feb 2009.

[p] http://www.savoiapower.com/biodiesel.html cited 10 Feb 2009.

[o] http://ecoworld.com/features/2006/04/06/indias-biodiesel-scene/ cited 12 Dec 2008.

[n] http://www.mintbiofuels.com/expanse.html cited 10 Feb 2009.

[m] http://www.tech2transfer.com/pdf/Article.pdf cited 10 Feb 2009.

[l] http://www.d1plc.com/globalIndia.php cited 12 Dec 2008.

[k] http://www.svlele.com/biodiesel_in_india.htm cited 10 Feb 2009.

[j] www.cleantech.com cited 12 Dec 2008.

[i] http://www.cleancities.in/ cited 09 Jan 2009.

[h] http://www.emamigroup.com/index.php cited 10 Feb 2009.

[g] http://www.unctad.org/en/docs/ditcted20066_en.pdf cited 09 Jan 2009.

[f] http://www.d1bpfuelcrops.com/ cited 10 Feb 2009.

[e] http://resourceguide.biospectrumasia.com/CompanyDetails.aspx?id=26 cited 10 Feb 2009.

[d] http://ecoworld.com/features/2006/04/06/indias-biodiesel-scene/ cited 09 Jan 2009.

heavily subsidized and present production cost of jatropha oil is higher than the market price. In addition, committed subsidies, minimum support prices, and exemption from taxes are yet to be implemented.

## The Way Forward

India's choice of feedstock for biofuel differs from rest of the world. Sugarcane–molasses-based biofuel and nonedible oil seed-based biodiesel make it an ideal fit for economic development, energy security, employment generation, poverty alleviation, and carbon dioxide mitigation without affecting the food supply. As the sugarcane industry is one of the largest rural industries, the bioethanol program is expected to improve rural agricultural income and generate additional employment for people associated directly or indirectly with the sugar industry. It also provides to opportunity to over come cyclicality of sugarcane, sugar, molasses, and alcohol production. Sustainable production enables market prices of sugar, molasses, and ethanol to stabilize and reduce drastic volatility experienced in past. Also, the wide fluctuations in the price of molasses, which is the main determining factor in the cost of fuel ethanol, can be brought under control. Even if sugar prices are depressed occasionally, factories can divert some of the sugarcane juice to ethanol production, thus bringing extra income, ensuring better and timely payment to the farmers. These will also encourage farmers to discontinue distress crop shifting to alternate crops every 2 to 3 yr. Steady market prices will increase attractiveness of biofuel ethanol business and drive much needed investments into the rural agriculture sector. Additional investments in farm mechanizations, drip irrigations and fertigations can bring substantial yield improvements leading to increased cane productions without an increase in dedicated land. Such an initiative provides additional benefits of carbon credits because of less energy use per unit area. However, the government needs to reform restrictive policies and controls to encourage sugar, molasses, ethanol, and fuel ethanol production, such as the deregulation of sugar and lifting ban on cross movements of molasses. Additional development of a consistent and coherent national policy, covering entire value chain from sugarcane to all its products, will ensure effective coordination and level playing field to all its stakeholders. There is also an urgent need to invest in long term research in second, third, and fourth generation biofuel technologies.

Biodiesel also requires similar policies dealing with its development integrating with its stake holders. There is a need to provide incentives for biodiesel programs until economic viability and profitability. To enable to compete with highly subsidized and volatile imported diesel, tax incentives and minimum support prices may be provided. To alleviate the existing problems, government needs to bring confidence building measure to its all stakeholders. Public and private partnerships needs to be encouraged in the development of plantations and production. Investments in research on native tree oil-bearing plants need to be carried out with long-term commitments for selection, large scale production, and commercial use.

A well-structured, centralized, coherent, and consistent biofuel policy at the national and state level is the immediate need of the hour. The sugarcane-based fuel ethanol and biodiesel from nonedible tree oils are continued to be ideal choices for India until new generation feed stock and technologies are developed. However, the new policy will have to strike a delicate balance of achieving the socioeconomic goals, food security, unemployment, energy security, and environment quality. India needs a leadership that is committed, coherent, and consistent with long-term vision to enable biofuel journey to reach its desired destination.

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