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REVIEW

Promoting biofuels: the case of ethanol blending initiative in India

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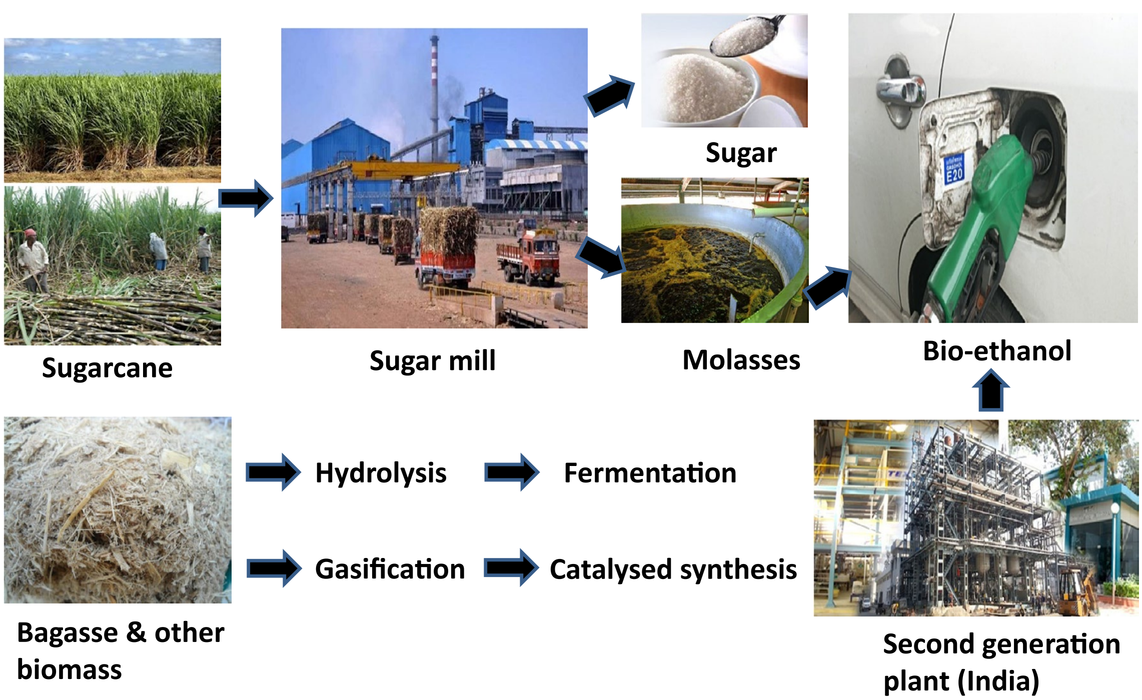
Abstract

In India, a gradual shift from fossil fuels to renewable fuels is considered necessary in view of growing energy demands of road transportation sector and also addressing the environmental concerns. The national biofuel policies of the country mandate increased use of ethanol blended petrol. However, the present main raw material supply source is closely linked to the cyclical nature of sugarcane harvests and its prices. Further, there are limits as at present ethanol is only derived through the molasses route. Second-generation ethanol production utilizing lingo-cellulose wastes from sugarcane (unutilized bagasse and sugarcane trash) and other agricultural wastes has the potential to bridge the supply gaps. The pilot-scale studies initiated in 2009 have shown that such a conversion is economically viable, and conversion cost of sugarcane bagasse has come down from ₹ 68 (US$ 0.97) to ₹ 16.5 (US$ 0.24) per litre during 2011–2016. An analysis of ethanol blend initiative in Indian context that highlights the present scenario, future projections, emerging trends, technologies, policies and institutional framework required for improved availability of ethanol for road the transport sector is presented. It is realized that a dynamic policy that rationalizes taxation framework and accommodates the agricultural shifts is actually needed.

Graphical abstract



Keywords Distilleries · Ethanol blends · Lingo-cellulose wastes · Molasses · Sugarcane

Extended author information available on the last page of the article

Introduction

The concerns about the fossil fuels for their non-renewable nature and adverse environmental effects have led to a great deal of interest in biofuels world over. Bioethanol, a prosperous renewable energy carrier mainly produced from biomass fermentation, provides a promising method for hydrogen production through ethanol reforming and has a promise for its future fuel cell applications (Ni et al. 2007; Nanqui et al. 2011; Lukajhs et al. 2018; Kumar et al. 2018).

At present it may not be feasible to replace fossil fuels by the biofuels, greater use of biofuels is a step towards environmental conservation. Even a partial transition from oil to biofuels can stabilize the energy markets in a significant way without affecting food security (Farrell et al. 2006; Balat and Balat 2009; REPN 2016). India's interest in improving its energy security is on account of its rapidly growing dependence on imported oil, over 84.5% of its requirement. As the country is one of the fastest growing economies, it is projected as the third largest consumer of transportation fuel in 2020, after the USA and China (Gunatilake et al. 2011). In India, the growth in energy consumption is estimated as 6.5% per annum and petroleum reserves are on a decline (Swain 2014).

Globally, more adoption of electrical vehicles (EV) in coming years is expected to reduce dependence on crude oil by 2040–2050. By 2040, global sale of EV is projected to the order of 41 million, representing 35% of new light duty vehicle sales, almost 90 times of the equivalent figure for 2015. Thus, 13 million barrels per day of crude oil is likely to be replaced by electricity (2700 TWh) (Diego and Poxon 2006). In India, automotive industry has a great potential for growth on demographic and economic considerations. The predicted increase in India's working-age population is likely to help stimulate the burgeoning market for private vehicles. However, gradual legislative move towards greener fuel (bioethanol, etc.) and electrical vehicles (EVs) is game changing. The automotive manufacturers are placing greater thrusts in dual-fuel technologies than battery-powered alternatives because of cost considerations and also lack of necessary support infrastructure such as recharge stations. (KPMG 2010). Presently, the EV sale in India is less than 1% of total vehicle sale. With support and policies of the Indian government, the situation will definitely improve, but various estimates of automobile industry suggest that such sales are likely to remain at 4–11% by 2050 (Sharma et al. 2016). So in foreseeable future, heavy dependence on conventional fuels will continue and biofuels will help in augmentation of fuel supply that is more environment friendly.

Across the world, several crops like wheat, sugar beet, corn, maize and sugarcane have already emerged as the major feedstocks for ethyl alcohol production. In southern hemisphere, bioethanol industries mainly use sugarcane, while in northern hemisphere it is cereal grains and sugar beet. Bioethanol has emerged as a renewable energy resource and has already been introduced on a large scale in several countries like Brazil and the USA (RFA 2015). The estimates suggest that around 33% of the energy needs of Europe and USA for different transportation purposes will be through conversion of biomass to biofuels by 2030 (Gonealves et al. 2015; Puri et al. 2012). However, all these feedstocks have a direct competition with food sector (Ravindranath et al. 2011; Sharma et al. 2016). The long-term productivity and sustainability of energy crops, changing diet patterns, population growth, global markets for food and animal feed, advances in biomass conversion technology and growing demands of water and fertilizers for other non-energy uses of land and climate change are likely to favour allocation of land for biofuels in future (Rosillo-calle 2012).

India has already adopted the policy of ethanol blending in gasoline in order to reduce vehicular emissions and import burdens (GoI 2009). A great opportunity, therefore, lies in promoting use of ethanol as an automotive fuel. The main feedstock for ethanol in India is sugarcane through molasses, a by-product in the conversion of sugarcane juice to sugar. Although the practice of ethanol blending started in India in 2001, the national policy on biofuels came into existence in 2009 with the aim of selling petrol blended with minimum 5% ethanol with provisions to its increase in future (GoI 2009; Pohit et al. 2009). However, in reality, the targets were not achieved. Therefore, it is very important to develop an appropriate action-oriented policy framework that promotes and regulates ethanol production and its utilization as a biofuel.

Sugarcane is one of the important cash crops in this country, and there are many opportunities to utilize this resource for more ethanol production in view of technological advances and the infrastructure available at the sugar mills. This policy perspective is in the context of India that describes the present status of ethanol blending in vehicular transport, technologies and existing policies. Outline about an integrated policy framework that includes appropriate institutional mechanisms is described.

Ethanol as transport fuel

Although ethanol has been used as an alternative transport fuel as early as 1894, it was only after the oil crisis of 1970s, interest in ethanol increased because of economic as well as environmental considerations (Kintisch 2008; Balat and Balat 2009). It adds extra oxygen to petrol which helps in reducing of air pollution and harmful emissions (carbon dioxide, carbon monoxide, un-burnt hydrocarbons, etc.) in tailpipe exhaust (Alleman et al. 2015). It is considered less toxic and is more effective in reducing emissions when compared to methyl tertiary butyl ether (MTBE), a preferred oxygenate. Now it is replacing hydrocarbon octane sources such as MTBE and aromatics like benzene (RFA 2016). A comparison of the characteristics of MTBE and ethanol (EFOA 2002; EESI 2015) is shown in Table 1. It is evident that ethanol vaporizes faster and is highly miscible in groundwater. However, it degrades faster, preventing groundwater contamination.

With a global increase in the use of flex-fuel vehicles (FFVs), ethanol is being used in greater proportions by the consumers with access to E85 and other flex fuels. With options up to E85 being more widely available at fuel stations in the USA, bioethanol has increasingly begun to gain traction as a mainstream fuel option for consumers (Guarieiro 2013; RFA 2016). Also, it represents a sustainable source of energy. Toady a variety of grades of ethanol blended gasoline are used globally. The common low ethanol blends are E 5 to E 25 (containing 5% to 25% ethanol). High ethanol blends like E 85 (contain 85% ethanol) and flex fuel (ethanol ranges from 51% in winters to 83% in summers) are also available (RFA 2015). The gasoline vehicles in a particular country are designed accordingly. The governments of USA and Brazil support such blending programme with enormous subsidies (Gunatilake et al. 2011).

International scenario

Globally, about 10 million ha of land that is less than 1% of world's arable land is used for ethanol. The USA (through maize) and Brazil (through sugarcane) account for over 80% of ethanol production (Zuurbier and Vooren 2008). In Brazil, the use of ethanol blended petrol started in vehicles as early as the 1920s but gained momentum after the oil shock of the 1970s. Now, this country offers the consumers a choice to use ethanol on competitive prices with added environmental benefits. The production of ethanol increased to 28.28 billion l in 2015–16 over 27.5 billion litres during 2013–14 (Voegele 2015). Since 2003, Brazil's emissions of carbon dioxide reduced by more than 300 million tons that is equivalent to planting and maintaining 2.1 billion trees for 20 years (Miryala and Satana 2016). One of the reasons for such a success is that presently about 58% of sugarcane is diverted purely for ethanol production in Brazil. It could be even higher in coming years on account of need to have cash flow for the production units, drop in global sugar prices and changes that have occurred in that country's domestic fuel ethanol market. Another trend is although the ethanol production is increasing, the exports (now about 1 billion litres only) are declining (Voegele 2015). Most of sugarcane ethanol in Brazil is based on first-generation technology, and there are currently two commercial plants producing cellulosic ethanol in Brazil: one from the GranBio group and the other one from Raizen, with production capacity of 82 and 40 million litres, respectively (Sugarcane.org 2016). Many factors and policies like (1) ideal climatic conditions for sugarcane crop, (2) cheap labour, (3) huge subsidies, (4) fully integrated industrial processing of sugarcane as a feedstock for sugar and ethanol, (5) laws forcing the oil marketing companies (OMCs) to blend ethanol, (6) stringent environmental laws, (7) flexibility to growers to divert sugarcane towards sugar or ethanol depending on the profitability (Amaral et al. 2008; Voegele 2015) contibute towards promotion and adoption of ethanol blends.

Situation in India

In India, ethanol is mainly produced from molasses through fermentation process. The enzymes from yeast change simple sugars into ethanol and carbon dioxide. About 90% of ethanol production is contributed by the sugar mills in India (GoI 2015a, b, c, d). The consideration of sugar industry for ethanol production is based on national policy, low costs involved, high efficiency and ease of fermentation. About one tonne of sugarcane produces 85–100 kg of sugar and 40 kg of molasses (Tsiropoulos et al. 2014). There are mainly three grades of molasses produced from the sugar industry based on content of total reducing sugar (TRS)—A

Table 1 A comparison of the characteristics of MTEB and ethanol. (*Source*: EFOA 2002; EESI 2015)

Attributes	Details	MTEB	Ethanol
Water solubility (mg/l)	Dissolving potential in water	43,000–54,300	Miscible
Partition coefficient (PoC)	Tendency to absorb soil particles from water	1.0–1.1	0.20–1.21
Vapour pressure	Ability to vaporize	245–256	49–56.5
Henry's constant (Kh)	Volatilization from ground water into soil gas	0.023–0.21	0.00021–0.00026
Biodegradability	Capability of the soil and ground water microbes to break down a component (petrol hydrocarbons and alcohol are relatively biodegraded; ether oxygenates take more time)	1.09	1.04
Octane number (research and motor)	Anti-knocking property of a fuel	117–121; 99–103	120–135; 100–106

grade (50% or above TRS); B grade (45–50% TRS); C grade (40–45% TRS). B grade is mostly used for ethanol production in India (Pohit et al. 2009). The diversion for fuel use takes place after meeting the requirements for industrial and potable purposes (Sindelar and Aradhey 2015). The other possible alternate raw materials to a limited extent could be sweet sorghum and maize (Reddy et al. 2005).

Ethanol production

Ethanol is a key by-product for integrated sugar mills in India. The sugarcane area has increased by nearly 2.5 to 3 times after independence of India (1950–51) (Pohit et al. 2009; GoI 2016a, b; Sugarcane.org 2016). However, there is a trend of stagnation in area expansion after 2013–14 (Fig. 1). At present, India is the fourth largest producer of ethanol (installed capacity 2.58 billion l; average production 2.21 billion l) (Fig. 2) in the world and the second largest in Asia (Chauhan and Dixit 2012; ISMA 2016). The main raw material for the distilleries in the country is sugarcane molasses, and use of starchy material is very limited. Although there are many sugar factories (around 526 operative mills) in the country, the mills have lower capacities in contrast to other sugar-growing countries where more emphasis is towards consolidation and larger capacity (KPMG 2007; Nande 2016).

Analysis of long-term data on area under sugarcane acreage and sugar production indicates a cyclic pattern, increasing for 3 to 4 years in a cycle of 5–7 years that leads to lower sugar prices and arrear payment to farmers increase (Ray et al. 2012; ISMA 2016). The acreage goes in next 2 to 3 years and sugar prices increase. Such variations largely determine the cost of ethanol production as well. Policy-based interventions, therefore, assume significance to overcome such scenarios (KPMG 2007; Ray et al. 2012). During 2017–18, high ethanol producing states were Uttar Pradesh

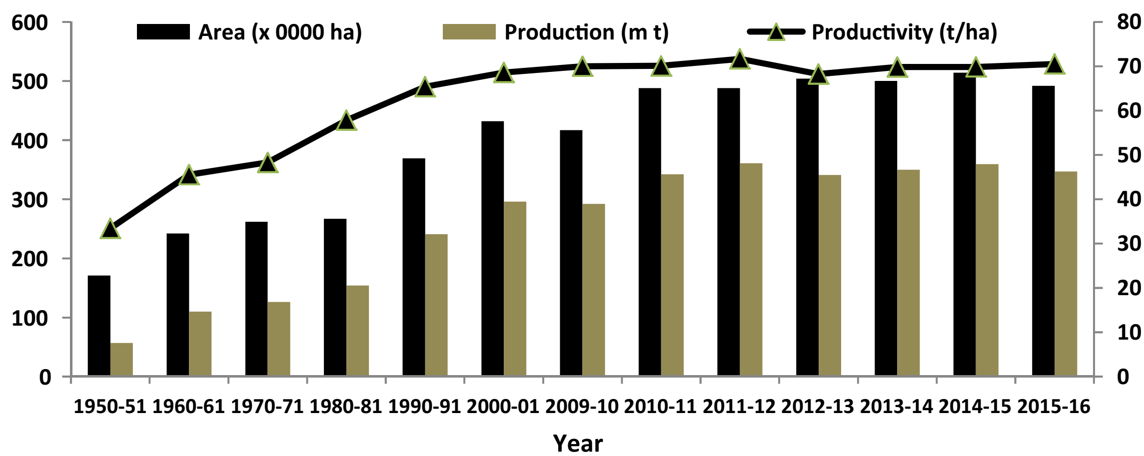
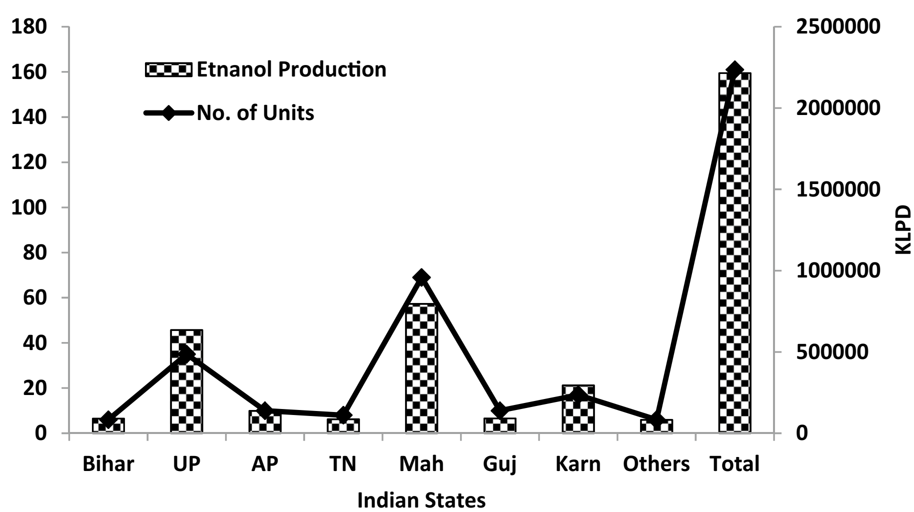


Fig. 1 Sugarcane area, its production and productivity in India since its independence

Fig. 2 Current annual capacity of ethanol production in different states of India (2015–16) Note: [1]KLPD = kilo litres per day; KLPA = kilo litres per annum; [2]annual capacity on the basis of number of days allowed by respective pollution control boards. Compiled from multiple sources (Chauhan and Dixit 2012; ISMA 2016)



(658 million l) and Maharashtra (606 million l). Other states include Karnataka (312 million l), Andhra Pradesh (148 million l), Tamil Nadu (96 million l) and Gujarat (79 million l).

Demands and supply scenario

The actual production of sugarcane molasses and alcohol in the country is presented in Table 2. The availability of ethanol for blending purposes is only about 20–30% of the statutory requirements in the recent years. The trend of petrol consumption and ethanol blends for the last few years is shown in Fig. 3. Projected demand of ethanol in near future for its blending with petrol at various levels in India is depicted in Table 3. The advance estimates suggest that domestic ethanol production will decline by 8% in the calendar year 2017 on account of second consecutive year of decreased sugarcane acreage and fuel ethanol will be little less than 2% national blending rate (Slelte and Aradhey 2016).

As the sugar mill's capacity is not enough to supply the required ethanol for E10 targets, the government is looking for second-generation ethanol production. The oil marketing companies (OMCs) like Indian Oil Corporation (IOC), Bharat Petroleum Corporation (BPCL), etc., are steadily working in placing orders for second ethanol plants. Also, some sugar companies are increasing their ethanol capacities to benefit from E10 blending.

Table 2 Production of molasses and alcohol in India (2009–2016)

Years	Molasses (× 000 t)	Alcohol (million l)
2009	8.4	1073
2010	11	1522
2011	11.8	1681
2012	11.7	2154
2013	11	2057
2014	12.7	2002
2015	11.3	2292
2016	11.2	1850

Table 3 Projected demands of ethanol (in million litres) in near future for blending purposes in India. (*Source*: CSTEP 2016)

Years	Petrol	E5	E10	E15	E20
2018	33,280	1664	3328	4992	6656
2019	36,075	1804	3608	5411	7215
2020	39,042	1952	3904	5856	7808
2021	42,191	2110	4219	6329	8438

Major pathways and feedstocks for ethanol conversion

There are two major pathways for conversion to ethanol (Fig. 4). In the former one, enzymatic hydrolysis or acid hydrolysis is followed by fermentation to produce alcohol, while the second one is a thermochemical process where biomass is gasified and the syngas is converted into ethanol and other co-products through a catalytic process.

The estimated theoretical yield in the former process is 415 l t^{-1} (if lignin is not converted), whereas in the latter process, it is about 640 l t^{-1} (if lignin is converted). However, the present experimental achievable yields are only in the range from 47 to 62% of the theoretical yields (Bharadwaj et al. 2007; El-Naggar et al. 2014; Galbe and Zacchi 2007; Somerville et al. 2010; Wi et al. 2015). The reasons for low recovery are many, viz. resistant nature of biomass to breakdown; the variety of sugars which are released when the hemicellulose and cellulose polymers are broken and the need to find or genetically engineer organisms to efficiently

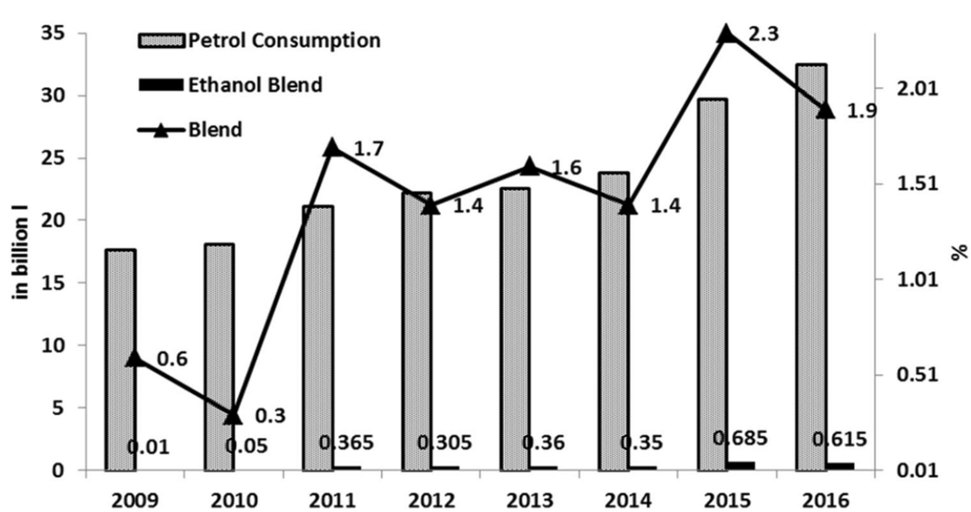


Fig. 3 Pattern of petrol consumption and ethanol blending in India (2009–16)

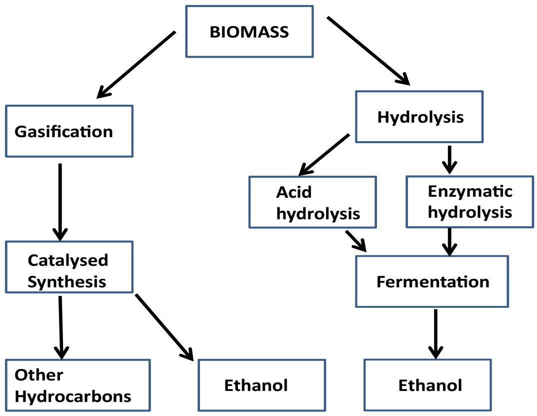


Fig. 4 Outline of second-generation ethanol production from biomass

ferment these sugars; costs for collection and storage of low density ligno-cellulose materials, etc. (Cardona and Sanchez 2006; Garima et al. 2016). Recent advances in genetically engineered microorganisms are encouraging for higher alcohol tolerance and conversion efficiency. Thus, by combining such advanced systems supported by intensive additional research to eliminate current bottlenecks, conversion yield to about 92% of the theoretical yields may be achieved and second-generation bioethanol could surpass the traditional first-generation processes (Kang et al. 2014).

The feedstocks for first-generation (1G) ethanol are molasses and sugar. The second-generation (2G) biofuels can be manufactured from lingo-cellulosic biomass or woody crops, agricultural residues or waste like rice and wheat straw and cotton stalk (Singh et al. 2016) (Table 4).

More ethanol may be extracted via B-heavy molasses route to get higher yield of ethanol per ton of sugarcane. Presently, ethanol is derived from molasses after the third stage of sugar extraction, yielding 230–250 lt per MT of molasses. The B-H molasses may yield 300 lt per MT of molasses as in this route sugar production is stopped after the second stage. This route may make more availability of ethanol for blending purposes, on the one hand, and solve the issue of oversupply of sugar during the years of overproduction of sugarcane. However, at present, there is no policy in place to extract ethanol from B-heavy molasses. Also, the existing distilleries may require some modifications to process such molasses.

Achieving the targets

At present, the position of India in global biofuel map is not very significant, but the country has the political will to expand it many folds. So far the blending rate is around 4% (2017–18) of the total consumption in the country. However, indications are that it may reach 7–8% in near future mainly on account of better price offered by the OMCs (GoI 2018). Sugarcane is just enough for meeting demands of sugar, and diversion of sugar or cane juice towards ethanol production is neither affordable nor permitted in the country. The route through molasses has its own limits. The possibilities of commercial adoption of second-generation technologies in coming years are the hope (Badger 2002; Balan 2014). Already some beginning is there in India. Some potential feeds in context of sugarcane include bagasse and sugarcane trash. While most of the bagasse is effectively used by the Indian sugar mills in generating process heat and electricity, most of sugarcane trash may find its role in producing ethanol. The projected estimates suggest that if around 10–25% of the unutilized bagasse and about 34 million tonne sugarcane trash (at current levels) are effectively put to use for ethanol production (Wright and Aradhey 2016) using second-generation technology, it may be possible to meet national blend requirement at 10% level (Table 5). This assumption is based on the present sugarcane acreage and productivity and also requirements of other industries. With a little increase in area and improvement in productivity by 10–12%, it may be possible to almost meet the 15% blend requirement. The pilot-scale studies initiated in 2009 have shown that such a conversion is economically viable; conversion cost of sugarcane bagasse has come down from ₹ 68 (US$ 0.97) to ₹ 16.5 (US$ 0.24) per litre during 2011–2016 (Sheth 2016). There are reports of production of biohydrogen from sugarcane bagasse by integrating dark

Table 4 Availability of major feedstocks for ethanol production in India

Technology	Organic substrate	Raw material
First generation	Sugary (glucose, fructose, sucrose)	Molasses
		B-H molasses
		Sugarcane juice
		Sweet sorghum (stalk) juice
	Starch	Grains (corn, sorghum, rice, wheat, millet)
		Cassava
Second generation	Cellulose and hemicellulose	Ligno-cellulose biomass (bagasse, sugarcane trash, corn cobs, rice straw, etc.)
	Complex mixed organics	Pet coke and municipal organic wastes

Table 5 Projected likely availability of ethanol (other than sugarcane molasses) through application of second-generation technology in India—a futuristic vision

Assumptions	Bagasse	Cane trash
Sugarcane production (2015–16): 347 million t	–	–
Sugarcane used (70% of production) by sugar mills: 243 million t	–	–
Bagasse fresh weight (30% of sugarcane) in million t	73	–
Bagasse dry weight (50% of fresh weight) in million t	37	–
Cane trash fresh weight (10% of sugarcane) in million t	–	24
Cane trash dry weight (25% of fresh weight) in million t	–	18
Ethanol production estimation	–	–
Theoretical yield (l t^{-1})	415	315
Experimental yield (l t^{-1})	260	220
Ethanol production in different scenarios	–	–
10% availability	950	400
20% availability	1900	800
25% availability	2375	1000
50% availability	–	2000
75% availability	–	3000

Projection based on our analysis based on information from multiple sources (Badger 2002; Balan 2014; Singh et al. 2016; Wright and Aradhey 2016)

and photo-fermentation (Rai et al. 2013) and improvement of gaseous energy recovery by dark fermentation followed by biomethanation (Kumari and Das 2015).

However, in order to meet ethanol blending at the rate of 20% or above, other resources like rice stalk and husks, wheat stalk and husks, maize stalks and cobs, cotton stalks and husks and a number of other crop/forest residues in the country may be utilized. Estimates suggest that availability of such biomass residues is of the order of 125–183 billion tonnes in India and if converted into ethanol, availability of ethanol will be in the range from 34 to 50 billion litres (Shinoj et al. 2011; Basavaraj et al. 2012). The other important areas in future could be conversion of organic waste material (cooking oil, etc.) which can be used as an automotive fuel; pretreated industrial wastes (Prabakar et al. 2018); animal manure and organic household wastes into biogas; and with special strains of algae into ethanol. Such an approach also helps to diminish waste management problems (McKendry 2002; TERI 2015). In India, second-generation ethanol production from agricultural/forest residues (capacity 10 t of biomass per day) on pilot basis has started very recently (DBT 2016).

At present, first-generation ethanol as a biofuel is being promoted by several nations and the commercial viability of next-generation biofuel like lingo-cellulose biomass is under investigation. Such a technology has the advantage of limiting the direct competition between food and energy security. In view of serious limitations of production threshold of first-generation biofuel manufacture, the second-generation biofuel technologies are gaining importance. Although the second-generation fuels are considered more sustainable and environment friendly, technological development in this area needs standardization for attaining popularity (Rifffat et al. 2016). In a country like India where ethanol production is based almost wholly on molasses, a byproduct of sugar manufacturing; exploring possibilities of ethanol production using other feedstocks like cellulose and lignocellulose materials is an important area (Saon Ray 2011). Besides sugar-rich biomass primarily from sugarcane (some sugar beet), starch-rich biomass from grains, sorghum, cassava, etc., and cellulose-rich biomass from straw residues, corn cobs and stalks, grass, paper, etc., qualify for second-generation ethanol programme in India.

Policy implications

The important milestone(s) in the history of ethanol blending in India is depicted in Table 6. The concerns of energy security and environmental issues encouraged the Government of India to expand domestic biofuel industry since 2001.

In 2003, the first phase of Ethanol Blended Petrol Programme (EBPP) was launched, mandating 5% blending of ethanol in nine major sugarcane-growing states and four union territories. However, due to unavailability of ethanol in desired quantity, mandatory requirement was made optional in 2004. Subsequently in 2006, through EBPP II its scope was enlarged in 20 states and 8 union territories, except a few north-east states and Jammu and Kashmir. The requirement of ethanol at that time for this target was 1.05 billion litres against the supply of 440 million litres. Also, the directives were issued to oil marketing companies (OMCs) to have a target of 10% blending in most

Table 6 Important milestones in the history of ethanol blending in India

Years	Milestone
2001	Launch of three pilot projects at Miraj and Manmad in Maharashtra and Bareilly in Uttar Pradesh to examine the feasibility of ethanol blending
2003	Launch of Ethanol Blended Petrol (EBP) Programme for sale of 5% ethanol blended petrol in 9 states and 4 union territories
2006	Relaunch of EBP Programme in 20 states and 4 union territories
2009	Release of national biofuels policy
2010	Provisional ad hoc procurement price of ethanol set at ₹ 27 (US $ 0.38) per litre
2012	Cabinet Committee on Economic Affairs (CCEA) decides purchase price of ethanol would be decided between the OMCs and the suppliers of ethanol
2014	Price of ethanol fixed depending upon the distance of sugar mill from the depot/installation of the OMCs
2015	Central excise duty levied on ethanol supplied for blending with petrol exempted
2016	Central excise duty exemption removed. Price of ethanol revised to ₹ 39 (US $ 0.55) per litre for the 2016–17 sugar season
2017	New biofuel policy launched in 2017 with greater emphasis on second-generation ethanol production. Price of ethanol revised to ₹ 40.85 (US $ 0.58) per litre for the 2016–17 sugar season
2018	Gazette notification of National Biofuel Policy 2018. Present price of ethanol is revised to ₹ 43.70 (US $ 0.62) (from C molasses) and ₹ 47.49 (US $ 0.68) (from B molasses)

parts of India as soon as possible. The national policy on biofuels came into existence in 2009 with the objective to consume greener fuel via blending and setting the targets at 10 and 20% by 2017 and 2021, respectively (GoI 2009; Pohit et al. 2009; CSTEP 2016). The general policy barriers in sustainable marketing of biofuels in Indian context have been described by Srarvanann et al. (2018). In this section, we discuss the issues related to bioethanol, the major biofuel used in the country that is derived from sugarcane.

Although there are no quantitative restrictions on imports of biofuels, high duties make imports economically unviable. Similarly, government do not provide any financial assistance for biofuel exports (Gunatilake et al. 2011). During years of low sugar production and consequent shortage of molasses, alcohol is imported mainly for industrial and potable liquor production (CSTEP 2016).

Very recently, the country has announced a new bioethanol policy that aims to spur investments to the tune of ₹ 50,000 million (US $ 715 million) for setting up projects with a total production capacity of 1 billion litre of ethanol every year. The capacity installation may go higher if there is saving in budget amount for financial support. The policy is aimed at cutting down the country's huge energy import dependence (Energy World 2017).

The scheme envisages setting up integrated bioethanol projects using lingo-cellulosic biomass and other renewable feedstock. Under this scheme, viability gap funding (VGF) is to be provided subject to a maximum of 20% of project cost or ₹ 50 million (US $ 0.71 million) for every 1 million summed to the biorefinery name plate capacity will be provided to make the projects commercially viable. Maximum VGF disbursement of ₹ 1500 million (US $ 22 million) is envisaged.

The framework

The present institutional framework in India to execute the EBPP is spread over many establishments of diverse nature, viz. government, industry and research organizations. Six ministries of central government and one apex planning body, NITI Aayog, are involved. They include Ministry of Petroleum and Natural Gas (MPNG), Ministry of New and Renewable Energy (MNRE), Ministry of Road Transport and Highways (MRTH), Ministry of Agriculture and Farmers' Welfare (MAFW), Ministry of Environment and Forests (MEF) and Ministry of Consumer Affairs, Food and Public Distribution (MCAFPD). Various state governments have also role in respect of their state policy. The industry part includes Society of Indian Automobile Manufacturers (SIAM), Indian Sugar Mills Association (ISMA) and several oil marketing companies (OMCs). There are three major research organizations, viz. Sugarcane Breeding Institute (SBI), Indian Institute of Sugarcane Research (IISR) and The Energy Research Institute (TERI), that are connected in some or the other way with EBPP. Several state government research stations and universities also undertake studies in context of ethanol blending. The role of such multiple organizations in specific aspects of EBPP is depicted in Fig. 5.

It is evident that there is a lack of an integrated approach that limits the potential of EBP in the country (Basavaraj et al. 2012; GoI 2014). So the policy frame work should be consolidated in a way that objectives of various stakeholders are in line. Since agriculture is a state subject in India, the national and state objectives should complement each other for the EBPP.

In order to realize the advantages in context of ethanol blending in the country, a clear and consistent framework is necessary in implementation of programmes. The support

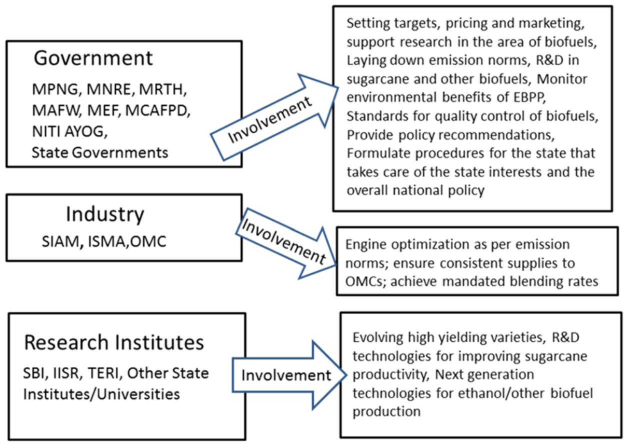


Fig. 5 Role of various organizations in ethanol blending programmes in India

from automobile industry for necessary engine modification for their compatibility with > E10 is important. Adoption of successful international experiences in light of prevailing emphasis on biofuels in the country is relevant. As there are many agencies involved in ethanol blending programme in the country, identification of a nodal agency will be desirable.

The recommendations need be based on in-depth quantitative and qualitative analysis. Identification of existing hurdles in programme implementation and approaches that have overcome such hurdles in other countries will be useful. Short-term focus on flexibility in procurement and production processes and a long-term plan of supporting expansion of domestic capacities and a mechanism of fair pricing for domestic suppliers are considered vital.

A well-formulated and integrated policy framework is the basic requirement for improving ethanol blending scenario in the country that accommodates certain key points like (1) EBPP is closely linked to agricultural policy and agricultural markets; (2) demand for ethanol from other sectors (non-blending) will continue to grow; (3) the nature of problems faced by the sector is often interlinked, such that they reinforce one another; (4) the centrally coordinated approach retains a limited flexibility at the state level. Therefore, meeting the EBP targets will require revamping of its production and procurement policies and practices, which limit access to raw material essential for blending (CSTEP 2016; Naylor et al. 2007; TERI 2015).

While the present price of ₹ 43.70 (US $ 0.62) for ethanol delivered at OMC depot is attractive for sugar mill given that average retail price of petrol is on a little higher side (GoI 2015a), however, any procedural delay in EBP could encourage them to divert ethanol to chemical and potable industries. Additionally, mills could divert molasses as cattle feed or for exports if their prices are competitive (Sindelar and Aradhey 2015; Slelte and Aradhey 2016). Now, most of the sugar companies in India are well integrated and diversified into distillery, ethanol and power. The biofuel policy of government has provided a good opportunity to the sugar mills to implement forward integration (CSTEP 2016; GoI 2015a, b, c, 2016a; KPMG 2007).

The road map

An ideal road map will envisage support coming in from public sector for next-generation ethanol production and stabilization of the existing value chain. The focus on a flexible logistics for transportation and storage of ethanol for blending, addressing issues in interstate movement of ethanol, vigorous creation of market for hybrid and flex-fuel vehicles by the automobile manufacturers and a desirable shift in favour of biofuels among the consumers are important.

A dynamic pricing mechanism that is linked to market conditions is required in context of biofuels and ethanol as the current pricing mechanism of ethanol for blending results in supply shortfalls. Price setting should account for shifts in agricultural markets, transportation and transaction costs. Rationalization of the taxation framework for blending is also required.

The road map for achieving the EBP targets should be planned for short-term (up to 2 years) and medium-to-long-term (2–5 and 5–7 years) basis (Table 7). The short-term areas include (1) encouraging increased production of ethanol from intermediate (B molasses); (2) rationalization of excise duty on ethanol; (3) concessional loans for distilleries supplying to OMCs; (4) interest-free loans to standalone mills to establish distilleries; (5) adopt improved sugarcane cultivation technologies and water management; (6) setting procurement targets for OMCs and production targets for suppliers; (7) single-window online certification system for interstate ethanol movement. Similarly, the medium-to-long-term targets should include (1) scaling up the next-generation technologies and fix targets to meet the growing demands; (2) developing indigenous vehicle manufacturing that support higher blends; (3) easing the regulatory provisions to ensure competitiveness with the global markets; (4) using GIS-enabled decision management system for location, transport and storage decisions.

Recently, the Government of India has revised national policy on biofuels 2018 (GoI 2018) on considerations of required funding, forex savings and OMC capex (Table 8). Success of such measures is expected to lead a structural change in Indian sugar industry change, making it comparatively non-cyclical as well. Several other initiatives are now in operation to boost the ethanol blending and save the import bill on crude imports. This includes introducing new vehicles supporting higher blending, and even on cent percent ethanol. It is now realized that if there is a stable

Table 7 Foreseeable road map for EBP in context of India

Category	Timeline		
	Short term (0–2 years)	Medium term (2–5 years)	Long term (5–7 years)
Technology	Shortlisting of technologies for second-generation ethanol production that are adopted by states	Pilot-scale projects coming up	Scale up next-generation technologies and reduction in dependence of agricultural markets
	Standardize ethanol blend wall for existing vehicular technologies	R&D investments on sugarcane crop in context of ethanol production	
	Phase out MTBE usage and investments in technology at refineries, etc.	Allow ethanol production from B grade molasses as well	Incentivize usage of FFVs and shifting preferences of vehicle users
	New vehicular technologies to utilize higher blending rates	Pilot testing of FFVs and hybrid vehicles	Developing indigenous manufacturing capabilities
Markets	Target setting for OMCs (procurement) and suppliers (production) Ease in procurement by non-sugarcane producing states Stable pricing system for domestic markets	Implementing a fair price mechanism across the value chain of EBP Offering advanced choices by supporting EFVs and developing compatible facilities at petrol pumps	Simplifying the regulatory provisions to ensure competitiveness with international markets
Logistics	Analysis of existing transport/storage/mandate capacity, etc. Offering flexibility to petrol pumps to procure ethanol straight from nearby distilleries Developing an online single-window certification system for interstate ethanol movement	Explore alternate and efficient transport modes as well, like railways and inland water transport	Develop and use GIS-enabled techniques for location, transport and storage decisions for better efficiency
Financial	Rationalization of excise duty on ethanol Timely payment to sugarcane farmers Concessional loans for distilleries supplying to OMCs and interest-free debt for standalone mills to establish distilleries	Some hedging options against price fluctuations of imported ethanol Duty exemptions on ethanol supplied for EBP	
Policy	Utilize the platform 'Make in India' for efficient ethanol production		

Table 8 The key elements of Indian national policy on biofuels (2018). (*Source*: GoI 2018)

The elements	Description	Remarks
	Funding of ₹5000 crore (US$ 72 million) for 2G ethanol biorefineries over 6 years (with additional tax incentives; higher purchase price compared to 1G fuel)	Steps are similar to that of Brazilian government to support growth of ethanol biofuel market
Forex savings	10 million litre of E10 would save ₹ 280 million of forex (US$ 4 million)	At the current supply of ~ 1500 million litre of ethanol (2017–18), it will help to save ₹ 42,000 million of forex (US$ 600 million)
OMC capex	100 KLPD biorefinery is expected to cost ₹ 8000 million (US$ 115 million). Currently, OMCs are in process of setting up twelve such 2G biorefineries with an total investment of ₹10,0000 million (US$ 1430 million)	This will lead to capacity addition of ~ 1200 KLPD

ethanol demand with stable prices, it will stabilize the sugar industry to great extent. Also, if there will be stable on-time export of sugar during times of overproduction, it can help stabilize the sugar prices.

With recent rise in crude prices, it makes more sense to increase the blending of fuel with biofuels and to save on higher crude prices. Blending ethanol with petrol raises the octane number of petrol. The standard octane number of petrol in India is 91. The costs of additives required to achieve this rating is already built into price of petrol. The splash blending (without changing the octane level at refinery) actually increases the costing by ₹ 1.60 (US$ 0.022) per litre of petrol. Thus, implementing E10 blend mandate is expected to translate into a savings of ₹ 2.60–2.90 (US$ 0.037–0.041) per litre of petrol. However, in the very unlikely scenario where crude oil prices dropping significantly from the current levels, ethanol blending will not be as remunerative but will address the environmental concerns. In the current scenario of overproduction of sugar in India and internationally, such initiatives offer a win–win situation to produce as much of ethanol as possible and simultaneously lower the production of sugar.

Conclusion

The demographic and economic growth in India is putting a great pressure on energy requirements of the road transport sector. Since 2009, significant initiatives have been taken for improving ethanol blending ratios in India. However, maintaining adequate supplies has become very challenging. However, this country is in a unique position to meet its blend requirement as sugarcane a major crop. There is availability of vase agricultural (ligno-cellulose fibres) residues or wastes and necessary infrastrucure in form of sugar mills and other distilleries to convert them into fermentable sugar. Significant progress has been made in innovation of enzymes for hydrolysis of various types of biomass from pilot to demonstration, now even commercial facility. There is positive momentum in the country, and a few pilot project cellulose ethanol plant supported by government as well as few private sector facilities has come up. Transforming all sugar mills into energy hubs for second-generation alcohol production utilizing sugarcane bagasse, trash and other available biomass in a well-designed and an integrated manner will gear up ethanol availability in the country.

However, much more is needed in form of a stable and coherent policy framework for speeding up such initiatives. The analysis in this paper suggests that the aspects related to biomass collection, storage, transport and supply to plants at reasonable prices, infrastructure such as pipelines, etc., private/public co-financing, loan guarantees, etc., will require in-depth analysis and institutional support. Investments in sugarcane research on improving crop yields and its water usage in combination with appropriate measures to tap potential of lingo-cellulose wastes from sugarcane and other agricultural residues will definitely bring a significant positive change in ethanol blending scenario in India.

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