

Gunatilake , Herath; Abeygunawardena, Piya

Working Paper

Energy Security, Food Security, and Economics of Sugarcane Bioethanol in India

ADB Economics Working Paper Series, No. 255

Provided in Cooperation with:

Asian Development Bank (ADB), Manila

Suggested Citation: Gunatilake , Herath; Abeygunawardena, Piya (2011) : Energy Security, Food Security, and Economics of Sugarcane Bioethanol in India, ADB Economics Working Paper Series, No. 255, Asian Development Bank (ADB), Manila, <https://hdl.handle.net/11540/2038>

This Version is available at:

<https://hdl.handle.net/10419/109398>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<http://creativecommons.org/licenses/by/3.0/igo>

ADB Economics Working Paper Series



Energy Security, Food Security, and Economics of Sugarcane Bioethanol in India

Herath Gunatilake and Piya Abeygunawardena
No. 255 | April 2011



ADB Economics Working Paper Series No. 255

Energy Security, Food Security, and Economics of Sugarcane Bioethanol in India

Herath Gunatilake and Piya Abeygunawardena
April 2011

Herath Gunatilake is Principal Energy Economist at the South Asia Department, Asian Development Bank. Piya Abeygunawardena is a Professor at Texas A&M University. The authors accept responsibility for any errors in the paper.

Asian Development Bank

Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org/economics

©2011 by Asian Development Bank
April 2011
ISSN 1655-5252
Publication Stock No. WPS113615

The views expressed in this paper
are those of the author(s) and do not
necessarily reflect the views or policies
of the Asian Development Bank.

The ADB Economics Working Paper Series is a forum for stimulating discussion and eliciting feedback on ongoing and recently completed research and policy studies undertaken by the Asian Development Bank (ADB) staff, consultants, or resource persons. The series deals with key economic and development problems, particularly those facing the Asia and Pacific region; as well as conceptual, analytical, or methodological issues relating to project/program economic analysis, and statistical data and measurement. The series aims to enhance the knowledge on Asia's development and policy challenges; strengthen analytical rigor and quality of ADB's country partnership strategies, and its subregional and country operations; and improve the quality and availability of statistical data and development indicators for monitoring development effectiveness.

The ADB Economics Working Paper Series is a quick-disseminating, informal publication whose titles could subsequently be revised for publication as articles in professional journals or chapters in books. The series is maintained by the Economics and Research Department.

Contents

Abstract	v
I. Introduction	1
II. Biofuel Policy and the Bioethanol Program	5
III. Natural Resources and Technological Constraints	7
A. Land Requirement	7
B. Technological Constraints	11
IV. Cost–Benefit Analysis	14
A. Methods and Data	14
B. Economic Feasibility of Molasses Bioethanol	18
C. Economic Feasibility of Sugarcane Juice Bioethanol	21
D. Economic Feasibility of Alternative Feedstock	23
V. Second-Generation Biofuels	24
VI. Concluding Remarks	26
Appendix	28
References	29

Abstract

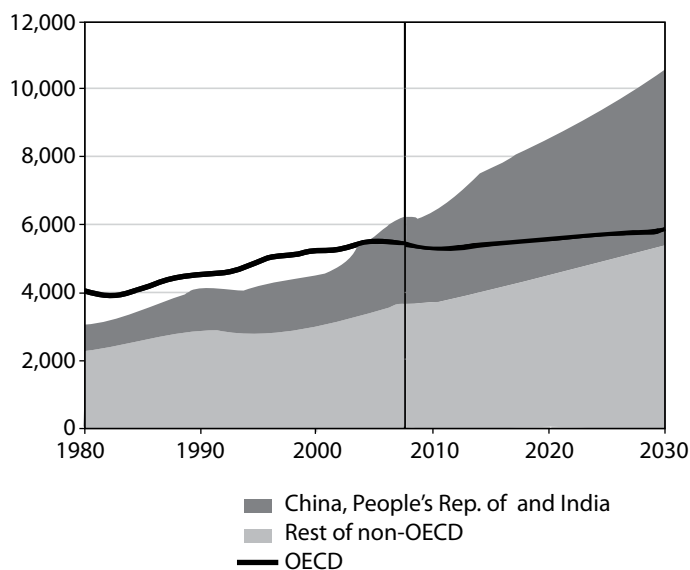
Energy security has been an important global policy issue for more than 4 decades. Transport biofuels like bioethanol have been receiving increased attention in recent years as a solution to heavy dependence on imported petroleum fuels, which brings destabilizing price effects on the economy and causes serious environmental problems like climate change. India's biofuel policy proposes an ambitious target of replacing 20% of petrol by blending bioethanol by 2017. This paper examines the economic feasibility of sugarcane bioethanol in India while considering food security as a competing policy priority. The analyses show that 20% blending of bioethanol cannot be achieved without affecting food production in India at the current level of productivity. Moreover, the cost of sugarcane bioethanol production exceeds the social benefits, hence use of sugarcane bioethanol cannot be justified on economic grounds. Molasses, a by-products of sugar manufacturing, can support up to 5% blending on bioethanol without compromising food production while improving social welfare. Given that first-generation bioethanol has limited scope in the country, India's ambitions to enhance energy security should rely on second-generation bioethanol technologies, which require improvements to become commercially viable.

I. Introduction

Energy security has been an important global policy issue for more than 4 decades. Global energy markets have relied heavily on fossil fuels like oil, natural gas, and coal, which provide almost 80% of the world's supply of primary energy needs (IEA 2007). Being nonrenewables, however, they have brought with them global destabilizing price shocks. The extensive worldwide use of fossil fuels has not only threatened energy security but has resulted in serious environmental concerns, particularly climate change. One of the key challenges facing the developing world is how to meet its growing energy needs and sustain economic growth without contributing to climate change. Cleaner renewable sources of energy are the ultimate solution to the global energy crisis, and biofuels, which are renewable energy sources, have been receiving increased attention in recent years.

The reference scenario of the *World Energy Outlook* is that global primary energy demand is likely to increase by as much as 40% by 2030 with oil, coal, and gas continuing to dominate the energy mix for the next quarter century. Most of the demand for energy will be driven by nonmember countries of the Organisation for Economic Co-operation and Development, which are likely to account for over 90% of this increase (Figure 1). The People's Republic of China and India are expected to take up roughly 53% of this incremental demand. As both countries have limited indigenous energy resources, they will increasingly compete for a larger share of the world's energy supplies.

Figure 1: World Primary Energy Demand



OECD = Organisation for Economic Co-operation and Development.
Source: International Energy Authority (2007).

The situation with crude oil is even grimmer. Global oil supplies are likely to take a hit due to the attainment of the “peak oil” in the early part of the 21st century. This will result in a gradual decline in production with no new major fields being discovered on land, and new reserves being located in deep water or remote areas, entailing high costs of production. With the attainment of “peak oil” and the increased concentration of global crude reserves in just a few countries, energy security is likely to remain a major concern. Prices are likely to rise dramatically once again, adversely affecting the economies of vulnerable nations. Although the global financial crisis led to a dramatic drop in crude oil prices (British Petroleum 2009), it was only a temporary phenomenon, and energy prices particularly oil have already risen from a low of under \$40 per barrel (bbl) in December 2008 to more than \$100/bbl in April 2011. Further rises in energy prices will adversely affect economic growth and poverty reduction efforts in developing countries, forcing them to search for alternative sources of energy to sustain economic growth. This paper investigates the economic feasibility of using sugarcane bioethanol as an alternative transport fuel in India.

India is an energy-deficit nation having one of the lowest levels of per capita consumption of energy globally. According to the Integrated Energy Policy of India, its per capita energy consumption was 439 kilograms of oil equivalent (KGOE) in 2003, which was much lower than that in developed countries and the global average of 1,688 KGOE (Government of India 2003). Table 1 shows the country’s proven oil reserves are estimated to be about 775 million tons (t). With limited reserves, India’s indigenous production was around 33.51 million tons in 2008–2009 and consumption was around 161.7 million tons (MoPNG 2008). India does not have the ability to meet the country’s growing demand for energy from indigenous sources even in the short term. As a result, the country is increasingly becoming dependent on imported crude oil. Figure 2 shows the future global energy import scenario predicted by the International Energy Authority.

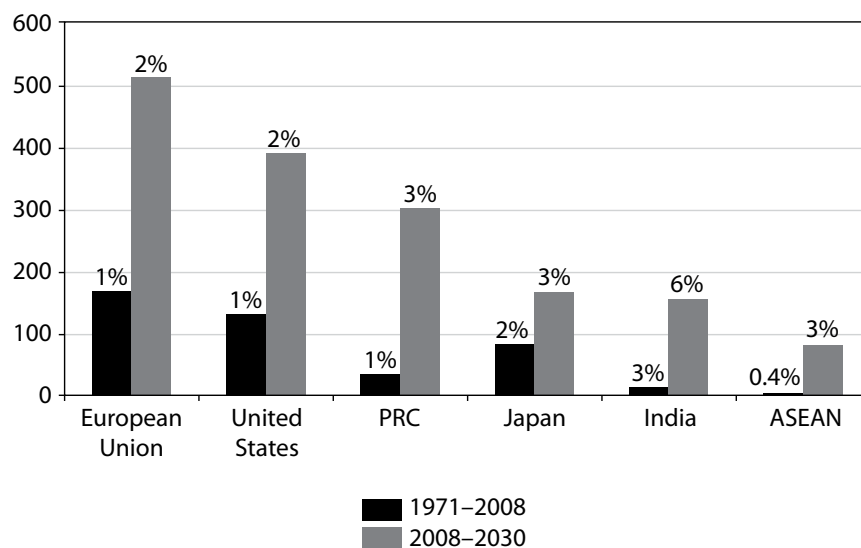
Table 1: Proven Reserves, Present Production and Present Levels of Imports of Coal, Oil, and Gas

Type	Proven Reserves	Present Production	Present Imports
Oil (MMT)	775	33.5	128.2
Gas (BCM)	1,074	32.85	8.06*
Coal (billion tons)	267.2	0.525	0.035

BCM = billion cubic meters, MMT = million metric tons.

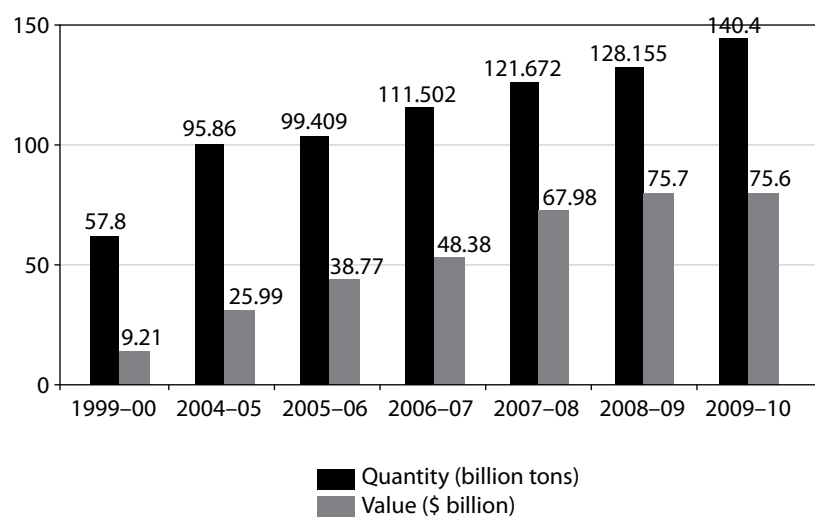
* Million tons of LNG # Data for 2008–2010.

Source: Ministry of Petroleum and Natural Gas (2009).

Figure 2: Average Annual Net Imports of Oil and Gas as a Percentage of GDP, 2008 (\$ billion)

ASEAN = Association of Southeast Asian Nations, GDP = gross domestic product.
Source: International Energy Authority (2007).

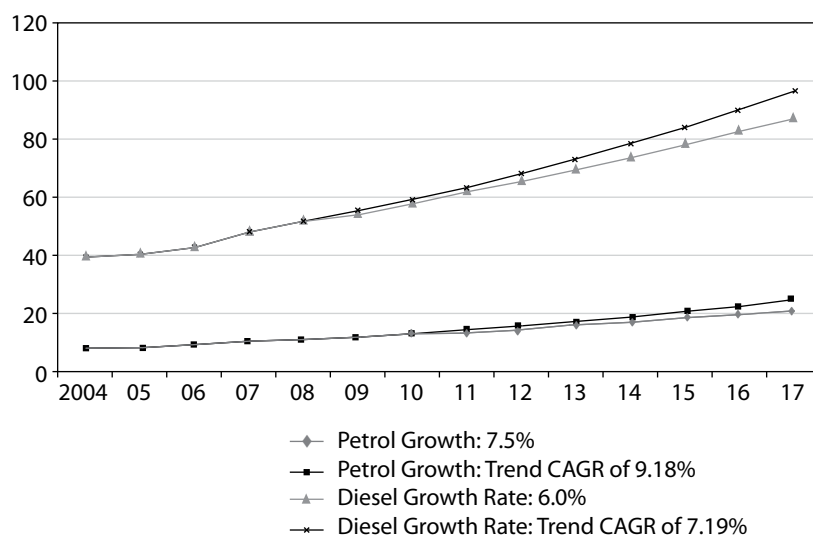
India has been a net importer of liquid fuels whose volume and value have risen in the past few years as highlighted by Figure 3. The import of crude oil has risen from 57.8 million tons (\$9.21 billion) in 1999–2000 to approximately 140.4 million tons (\$75.6 billion) in 2009–2010, accounting for about 81% of total oil consumption in the country. With the country entering a more energy-intensive phase of development, demand for liquid transportation fuels will dramatically rise in the future.

Figure 3: Volume and Value of Imports of Crude Oil by India, 1999–2009

Source: Ministry of Petroleum and Natural Gas (2009).

Petrol and diesel consumption have been rising rapidly over the past few years. For example, diesel consumption grew at a cumulative average growth rate (CAGR) of 7.19% between 2004–2005 and 2009–2010, compared to 6% over the past decade (Ministry of Petroleum and Natural Gas 2009). Petrol consumption grew at a CAGR of 9.18 % in the last 5 years and 7.5% in the last decade. Conservative estimates based on growth in the last decade indicate petrol consumption is likely to rise to 21.59 million tons and diesel to 87.3 million tons by 2017–2018 (Figure 4).

Figure 4: Predicted Growth in Petrol and Diesel Consumption



CGAR = cumulative average growth rate.

Source: Ministry of Petroleum and Natural Gas (2009).

With increasing global demand and global energy prices likely to increase in the medium to long term, higher oil imports by India could adversely affect the country's balance of payments and future development. This outlook for energy in India forces it to intensify its efforts to search for alternate fuel options. In this context, biofuels may offer an attractive option for meeting part of India's energy needs. India has been taking various initiatives to introduce biofuels. Bioethanol blending of 5% was made mandatory 7 years ago. It met with partial success in 2007–2009 because only about 2% bioethanol blending was achieved. Although the industrial capacity for producing bioethanol has increased in the country, the bioethanol program faced a temporary setback owing to a number of reasons including the decline in oil prices in 2008–2009.

II. Biofuel Policy and the Bioethanol Program

In light of rising oil prices and increased dependence on imported oil, India established an bioethanol pilot program in 2001. The program consisted of three 5% ethanol blending (E5) pilots in Maharashtra and Uttar Pradesh and research and development (R&D) studies investigating the technical feasibility of bioethanol use (Gopinathan and Sudhakaran 2009). The pilot projects were successful and in September 2002, the Ministry of Petroleum and Natural Gas mandated an E5 blending target for nine states and four Union Territories, effective 1 January 2003.

The 5% target was established after consultations with key stakeholders at the state and central government levels, including the Society for Indian Automobile Manufacturers and major sugar manufacturers (Gopinathan and Sudhakaran 2009). It was assumed that there were adequate surplus supplies of molasses and alcohol in the country to meet the initial 5% target as well as to possibly scale up the target to 10% nationwide (Gopinathan and Sudhakaran 2009). Under the program, India's oil marketing companies (OMCs) were responsible for purchasing and blending bioethanol. In April 2003, India further strengthened its bioethanol program when the Planning Commission released a report on biofuels (Government of India 2003). The report analyzed various blending targets, price, and feedstock availability scenarios and issued the following recommendations to advance India's bioethanol program:

- (i) The country must move toward the use of bioethanol as a substitute for gasoline.
- (ii) Production of molasses and distillery capacity can be expanded to meet 5%–10% blends of bioethanol.
- (iii) Bioethanol may be manufactured using molasses as the primary feedstock supplemented by sugarcane juice when there is an excess supply of sugarcane.
- (iv) Restrictions on the movement of molasses and establishing bioethanol manufacturing plants may be removed.
- (v) Imported bioethanol should be subjected to suitable duties.
- (vi) Buyback arrangements with oil marketing companies will be arranged.
- (vii) Financial incentives should be provided to establish new, state-of-the-art distilleries.

- (viii) R&D programs should be established to research alternative feedstock including sugarbeet, corn, potatoes, grain, and straw.

At the time the initial policy was established, India was endowed with surplus sugar supplies. However, severe droughts in 2003 and 2004 reduced sugar supplies by over 60% from historic averages and molasses supplies by about 53%. Further, bioethanol was subject to various central and state alcohol taxes and levies, which created challenges for moving bioethanol around the country (Gopinathan and Sudhakaran 2009). This diminished bioethanol supplies, and as a result, India had to import 447 million liters of bioethanol from Brazil in 2004 to meet the E5 blending target. In October 2004, India amended the E5 mandate requiring E5 blends only when adequate bioethanol supplies were available and when the domestic price of bioethanol was comparable to the import parity price of petrol.¹

India continued importing bioethanol to meet its blending targets and became the largest importer of Brazilian bioethanol in 2005 importing 411 million liters from Brazil, which accounted for approximately 9% of the global bioethanol trade. However, transporting bioethanol across states remained difficult. As a result, the majority of the imported bioethanol was used for chemical manufacturing rather than for fuel blending (Government of India 2006). Therefore, the government recommended a further scale-back in the bioethanol program outlined in its Integrated Energy Policy (IEP) in August 2006. The IEP contained the following recommendations for the bioethanol program (Government of India 2006, 95–6):

- (i) Set the import tariff on bioethanol, independent of use, at a level no greater than the price of petroleum products.
- (ii) Require, not mandate, OMCs to blend 5% bioethanol.
- (iii) Price bioethanol at its economic cost in relation to petrol but not higher than its import parity price.
- (iv) Allow for 5–7 year forward contract purchases at the parity price of petrol.
- (v) Consider waiving all or part of the excise taxes and levies charged on blended petrol.
- (vi) Provide incentives for research on cellulosic bioethanol.

The Ministry of Petroleum and Natural Gas, however, strengthened and expanded its Bioethanol Blending Program (EBP) in September 2006. The EBP mandated E5 blends,

¹ Gopinathan and Sudhakaran (2009), referencing *Basic Statistics* of the Ministry of Petroleum and Natural Gas (2004).

effective 1 November 2006 in 20 states and four Union Territories, subject to commercial viability (MoPNG 2007). India experienced a surplus in sugar production during the 2005–2006 season, which most likely facilitated the new policy decision. As a result of the policy, 10 states had enacted the EBP by 2007.

The 11th Five-Year Plan (2007–2012) recommended increasing bioethanol blending mandates to 10% once E5 blends were put in place across the country (Government of India 2007). The Planning Commission recommended this increase to occur around 2010. In September 2007, the Cabinet Committee on Economic Affairs (2007) implemented E5 blends across the country² and recommended E10 blends (blending up to 10%) where feasible, effective October 2007. The E10 blending target remains in effect and will be scaled up to 20% blends (E20) by 2017, as proposed by the country's recently enacted National Policy on Biofuels. This comprehensive policy has provisions for a variety of policy mechanisms such as subsidies, preferential financing, fiscal incentives, research and development support, and international cooperation. The policy implementation will be coordinated by the Ministry of New and Renewable Energy. The policy is not feedstock-specific but maintains the government position that energy crops should not have any adverse impact on the food sector.

III. Natural Resources and Technological Constraints

The biofuel policy of India thus has an indicative target of 20% blending of bioethanol by 2017. This section of the paper assesses the feasibility of achieving this target using a simple natural resource accounting approach. It first reviews land availability considering the food security implications of diverting sugarcane land or any other type of arable land for bioethanol production. It then considers other constraints along the supply chain of sugarcane bioethanol. Land requirement and other constraints for two alternative bioethanol crops—tropical sugar beet (TSB) and sweet sorghum (SS)—are also analyzed.

A. Land Requirement

Currently bioethanol is produced from molasses,³ which is a by-product of the manufacture of sugar. Cane juice can also be used for producing bioethanol without going through the sugar production process. The resource requirements for bioethanol would depend on the current consumption of petrol and the trend in growth. Petrol consumption has been experiencing rapid growth, especially in the last few years, with a trend CAGR of 7.5% in the past decade.⁴ Based on this trend, it is expected that petrol consumption

² The policy excludes the areas of, among others, the Northeastern States and the Island Territories.

³ Certain parts of the sugar in sugarcane cannot be granulated and that portion in the process of sugar production becomes a by-product, which can be fermented to produce bioethanol.

⁴ Based on data from the MoPNG website (MoPNG 2009).

would be around 21.6 million tons by 2017. To achieve the target of 20% blend of bioethanol with petrol in 2017, the bioethanol requirement is estimated to be about 5.76 million kiloliters (KL).

By far the dominant feedstock for the production of bioethanol has been molasses, the production of which has been fluctuating due to the cyclical nature of the sugar industry. On a decades-based average, India produces about 8.4 t of molasses per year. However, this is expected to increase to 17.6 mt by 2017 and will support 11.64 % of blending with petrol, if fully used as transport fuel. The use of the total quantity of molasses for bioethanol is unlikely because of its more lucrative alternate uses such as potable alcohol and industrial alcohol. Thus, molasses alone does not provide a viable option for achieving the target of 20% blending in 2017.

Since the price of molasses rises dramatically in lean years, while the OMCs have fixed prices for 3 years, the EBP ceases to function as the prices offered or contracted by OMCs are unremunerative to the bioethanol producers. Sugarcane juice is an alternative choice as a feedstock, the use of which in surplus years is recommended in the biofuel policy. Average Indian sugar yields have fluctuated between 65 t/ha and 71 t/ha. The area under sugarcane planting has also varied, from 4.22 million ha in 1999–2000 to 5.15 million ha in 2006–2007, falling back to 4.4 million ha in 2008–2009. Sugar consumption was estimated at 16.2 mt in 2000–2001 and has been increasing at a CAGR of about 4% in the past decade to about 23 mt by 2008–2009. At this rate, it is expected to increase to 34.2 mt by 2017. Production has increased from 18.52 mt in 2000–2001 to 26.36 mt in 2007–2008 with the exception of 2006–2007, which had the all-time highest production of 28.3 mt. Looking across these fluctuations, sugar production has been growing at a CAGR of about 4.5% over the past decade due to the increase in area farmed.

For the purpose of assessing land resource requirements, we consider the following scenarios. In these scenarios we use the average Indian yield of sugarcane at about 70 tons/ha, which should give an average yield of about 4.9 KL/ ha of bioethanol.

1. Scenario 1

This scenario assumes that all molasses is used for bioethanol production and the balance is obtained from sugarcane. If the average molasses production remains at 8.4 t (the average between 2000–2009), bioethanol production would be 1.89 million KL. To meet the required balance for bioethanol, 0.79 million ha of sugarcane land would be required. However, if sugar production continues to grow at a CAGR of 4.5%, molasses production is expected to increase to 17.6 mt by 2017, and this will support 11.64% of blending with petrol, if fully used as transport fuel. The balance area of sugarcane required would be 0.35 million ha to meet the 20% blending requirement. This scenario is unlikely because the use of all available molasses for bioethanol for transport is not feasible, given the attractive alternative demands for molasses.

2. Scenario 2

This scenario assumes the use of sugarcane juice to produce the total requirement of bioethanol for 20% blending. In such a scenario, the area of land required to produce 5.76 million KL of bioethanol would be 1.18 million ha by the year 2017. Here the land requirement is assessed assuming no productivity growth in sugarcane farming. Under such circumstances the use of sugarcane from 1.18 million ha for production of bioethanol will result in a reduction of sugar production of 8.23 mt/year. Assuming this amount of raw sugar were to be imported at \$350/t it would cost about 126.6 billion rupees (Rs) or \$2.88 billion/year.

3. Scenario 3

This scenario assumes sugarcane productivity growth. Here, a CAGR of 4% in sugarcane yield increases is assumed. With this assumed growth, the bioethanol yield should be 6.97 KL/ ha by 2017. The area of land required to produce 5.76 million KL of bioethanol would be 0.83 million ha by 2017, if only cane juice is used to produce the total quantity of bioethanol required. In this scenario about 5.79 million tons (t) of sugar has to be imported at the cost of Rs 91.19 billion/year.

The above discussed scenarios should be considered in the context of India's fixed amount of arable lands already under cultivation. From the above it can be observed that 20% blending of bioethanol cannot be achieved without diversion of current sugarcane lands or displacement of other croplands to produce sugarcane. In one of the plausible scenarios, sugar production has to be displaced and an equivalent quantity of sugar imported. In another scenario, irrigable crop lands such as wheat or rice have to be converted to sugar to meet the 20% requirement. In both cases bioethanol production cannot be increased without reducing some food crop production.

With the Government of India's stand that energy crops should be developed without affecting food crop production, bioethanol blending at 20% will require a significant increase in agricultural productivity, in particular sugarcane. Such a productivity increase may release some arable land to produce sugarcane for bioethanol production without reducing food. However, the situation is more complex with a growing population and increasing rural incomes. Population increases as well as rural income increases lead to higher food consumption. India had experienced unprecedented food price inflation in 2010, highlighting the social implication of food shortages and price hikes. Given the fixed arable land resources, which are already in production, any allocation of arable land to energy crop production will adversely affect the production of food in India. Therefore, it may be wise for the country to confine itself to molasses-based bioethanol production for transportation needs.

The Indian sugar industry is cyclical by nature. Production was 18.5 mt in 2000–2001, 28.3 mt in 2006–2007, and estimated at 14.6 mt in 2008–2009. For 2009–2010 it is forecast to be 18.5 mt. The cyclical nature of the sugar industry is well known and is due to huge excess or glut of sugar in some years followed by some years of shortage accompanied by wide price fluctuations. One idea is to use the excess sugar in surplus years for bioethanol production without affecting the food sector. For example, India produced 28.3 mt in 2006–2007 against a domestic requirement of 21 mt. This approach will have the added advantage of stabilizing sugar prices. While this idea seems sound, there is a major constraint that may make it difficult to use surplus sugar for bioethanol production: the increased bioethanol-producing capacity that would be used only once in about 5–7 years may not be economical to maintain. Sugarcane is available for only about 5–7 months in a year. If other feedstocks such as TSB or SS can be produced in a planned manner to use the excess capacity of bioethanol production in lean months, the sugar-based bioethanol industry may be able to avoid excess capacity issues. However, as discussed below the other bioethanol crops will also affect food production.

Other feedstock crops such as TSB and SS can be successfully cultivated in India. If rainfall is sufficient,⁵ SS can be grown without irrigation particularly during the monsoon season (*kharif*). It can also be grown as a crop in the second harvest (*rabi*) season with lower irrigation needs than that of sugarcane. However, experience has shown that the combined average yield of SS for two crops is lower (about 40 t/ha/yr) than for sugarcane, even with the additional yield of 3 tons of sorghum grain. The expected yield of alcohol is low, at about 55 liters/ton. Therefore, the land requirement would be higher than that of sugarcane for any equivalent production of bioethanol. If the total amount of the bioethanol for 20% blending in 2017 is coming from SS, the land requirement would be about 2.6 million ha. The SS will be grown on arable lands and diversion of 2.6 million ha of arable lands for SS production will adversely impact the food sector.

TSB is a 6-month crop and normally one crop can be taken per year with a yield of 65 t/ha and a bioethanol yield of 70 liters/ton. Under the equivalent scenario, TSB bioethanol production to meet the 20% blending requirement, about 1.26 million ha of arable land is required. The land requirements for both SS and TSB are larger than that of sugarcane but land would be available for 6 months each year for other crops. TSB and SS are not commercially established like sugarcane and their cost competitiveness, in comparison to sugarcane-based bioethanol, is not fully understood.

⁵ Sweet sorghum requires about 4,000 cubic meters of water per hectare per season.

B. Technological Constraints

The worldwide impetus for promoting biofuels has led to an increased focus on technology development and R&D. Biofuels have been classified as “first-generation” and “second-generation” on the basis of the nature of the feedstock used. First-generation biofuels are usually derived from sugars, grains, or seeds; often the edible portion of the plant. Although global biofuel production using first-generation technologies has increased rapidly over the last decade, key concerns are being raised about their long-term sustainability mainly due to their likely impact on food security. This has led to the development of second-generation biofuel technologies. Second-generation biofuels are produced from the nonedible lingo-cellulose biomass, i.e., nonedible residues of forests and agriculture, energy crops, and organic municipal solid waste. The use of these feedstock would significantly increase the availability of biofuels and are projected to make them cheaper as the technology matures. These biofuels would not affect food security and have a smaller carbon footprint than the first-generation fuels. However these biofuels are still in the development stage and are rarely being produced on a large scale globally.

India is among the top five bioethanol producers in the world. Until now almost all of India’s capacity for bioethanol has been from molasses. Recently, a few Indian companies have taken the first tentative steps to produce bioethanol using alternate feedstock like sugarcane juice, SS, and TSB. India started its bioethanol blending program in January 2003 and adequate capacity (1.7 billion liters/year) has been installed for meeting the requirements of E10. The technology for the production of bioethanol from molasses is well established, as there are almost 350 distilleries in India. The technology for bioethanol production in India is becoming increasingly sophisticated as companies located in India are now providing technology and supplying energy-efficient plants all over the world.

1. Molasses

The key technological constraint for production of bioethanol from molasses has been the effluent, which has a high organic content. Effluents can be used as a fertilizer together with irrigation, but cannot be used throughout the year. Another option is bio-composting, which uses biomass and by-products from sugar mills. The limitation of this option is the inability to produce bio-compost in the monsoon season. However, with concentration using reverse membrane technology or evaporation and incineration in boilers, the limitations can be overcome.

2. Tropical Sugar Beet

TSB has been introduced recently in India and the TSB technology is still maturing. The main technological constraints include poor sugar extraction, long crop cycle (6 months)

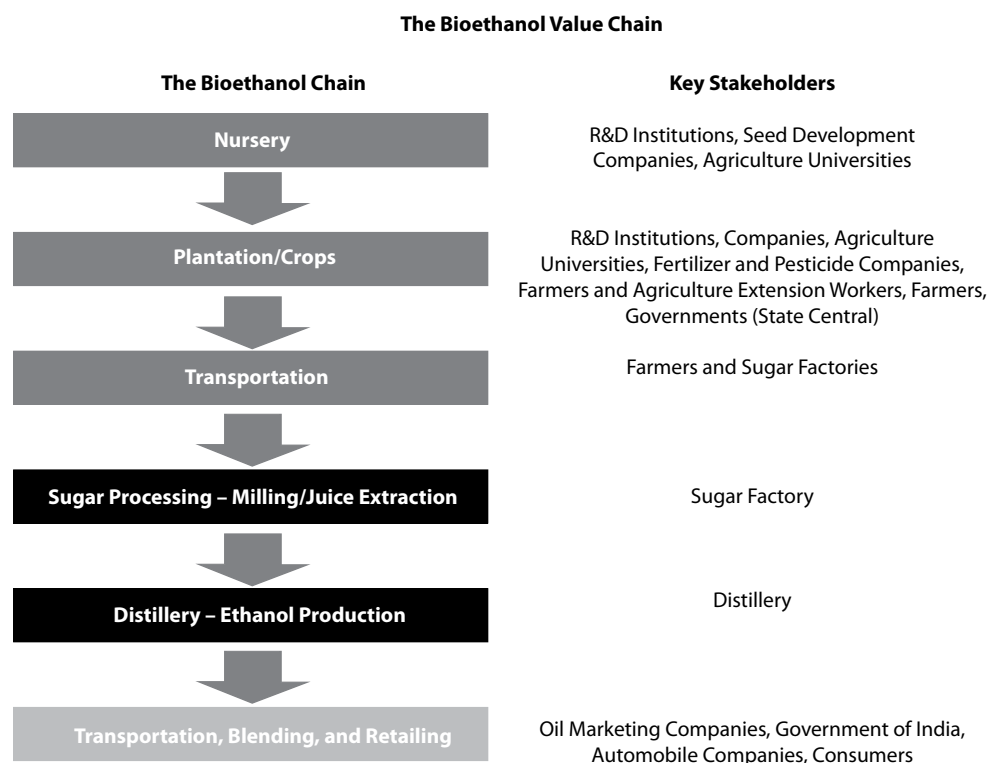
that allows only one crop each year, and the perishability of the crop and the need to extract sugar within a short period after harvesting. Seasonal harvests come to the processing mills within a short period of time and these mills can be operated only for a few months each year. Without using other supplementary feedstocks to operate the plant for a longer period, this may make processing units financially unattractive.

3. Sweet Sorghum

Sweet sorghum is a sugar-rich stalk similar to sugarcane and is touted as a “smart biofuel crop”. It is supposed to have wide adaptability, rapid growth, high sugar accumulation, and biomass production potential. In addition, SS is believed to be water- and fertilizer-efficient, has a short crop cycle of 4 months, and has the additional availability of co-products such as grain. There have been some technological problems related to the extraction of juice from the stalk in existing sugar mills. The main constraints are the low SS yield, the requirement to extract juice and ferment within a short period of time, and the financial nonviability of juice extraction plants.

Figure 5 describes the bioethanol supply chain together with the key stakeholders. The main activities of the bioethanol supply chain consists of R&D for the cultivation of feedstock, plantations, and their management; harvesting, storage, and transportation of feedstock; and processing, storage, transportation, blending, and retailing of bioethanol.

Figure 5: Supply Chain and Key Stakeholders



Source: Compiled by authors.

The critical bottlenecks impacting on the development of the bioethanol value chain to meet the national goal of 20% blending in petrol by 2017 are shown Table 2. In terms of technological constraints, the bioethanol supply chain is well established in India and does not face any major constraint.

Table 2: Supply Chain Bottlenecks for Bioethanol

Supply Chain Segments	Major Bottlenecks		
	Sugarcane	Tropical Sugar Beet	Sweet Sorghum
Nursery	• Lack of appropriate high-yielding varieties suitable for different regions		
Plantation or Crops	<ul style="list-style-type: none">• Cyclical production due to variation in yields and area under cultivation• Low prices• Poor commercial practices by sugar mills• Lack of investment and mechanization	<ul style="list-style-type: none">• Lack of commercialization	
Transportation	• High cost of transport from producer to markets		
Milling/Juice Extraction	<ul style="list-style-type: none">• No significant issues	<ul style="list-style-type: none">• Commercialization yet to be achieved <p>Milling units not financially sustainable, especially due to limited operating periods (1-2 months annually)</p>	
Processing or Distilling	<ul style="list-style-type: none">• No significant issues		
Blending or Retailing	<ul style="list-style-type: none">• Long-term, inflexible price contracts by oil marketing companies• Nonremunerative prices for bioethanol• Resistance to direct retailing by oil marketing companies• Inappropriate regulations• Lack of support by automobile companies for higher bioethanol fuel blends		

Source: Compiled by authors.

The bioethanol supply chain will interact with the petrol supply chains. Petroleum products in India are produced to technical specifications at the refinery and transported to various warehouses, also called oil depots, by means of tanker trucks or by railways or product pipelines. At the depot, the volume of the product is measured and unloaded into large tanks. When the unblended diesel or petrol is to be supplied, the product is filled in measured quantities into tanker trucks and then transported to retail establishments where it is unloaded into underground tanks. The diesel or petrol is finally supplied through a dispenser to a consumer's vehicle.

For petrol blended with bioethanol, certain additional steps are required. The bioethanol is dispatched from the bioethanol producing plant to the depot in tankers. The quality is checked and the quantity measured and unloaded into the bioethanol tanks. From these tanks it can be blended with petroleum. During the blending stage, additives such as corrosion inhibitors or pour point depressants, which improve the properties of the blend can be mixed in. The process of dispatching it to the retail petrol pump is the same as the one described for unblended petrol. But in the case of blended products, special

precautions are taken to clean the tanks and remove water. The facility costs for adding bioethanol to the petroleum plants include additional storage tanks for the bioethanol and the metering systems. In addition, special precaution has to be taken so that water does not enter the system: in order to avoid moisture from the air being picked up by the bioethanol, special moisture traps need to be installed.

In the case of vehicles using bioethanol blends, some types of rubber fittings and gaskets may have to be changed frequently as they deteriorate faster in contact with blended fuel than with traditional petroleum products. In addition, the control unit or the carburetor in the car has to be adjusted so that the air–fuel ratio can be maintained for good vehicle efficiency and efficient operation. Bioethanol blending beyond 10% requires changes in the vehicle fleet. This is one of the constraints to expanding bioethanol use for transport.

India has been blending bioethanol in petrol since 2003 and the fuel supply chain has been well established starting from the dispatch by bioethanol producers to the blending by oil marketing companies and dispensing at the gas stations or petrol pumps. The costs for establishing this infrastructure have been borne by the oil marketing companies. The blending of bioethanol in India is well established and there is little need for enhanced integration with the fossil fuel supply chain. The investments in developing the fuel supply chain from the depot onwards are in common with fossil fuels and have been already undertaken by the OMCs.

The final issue is that of the pricing of blended gasoline. Bioethanol has a lower amount of energy content per liter compared to that of petrol. The calorific value of bioethanol is 30 megajoules per kilogram (MJ/Kg) or 7,170 thousand calories per kilogram whereas the equivalent value of petrol is 44.8–46.9MJ/Kg or 10,707–11,209 Kcal/kg. Blended petrol should provide lesser mileage per liter compared to petrol. Therefore, blended petrol should be priced lower than pure petrol. At a lower percentage of blending, the price difference may be small. However at higher levels of blending, lower prices should be offered to consumers. This has been the practice in Brazil and the United States. This type of differential pricing system requires additional adjustments in petroleum retailing outlets.

IV. Cost–Benefit Analysis

A. Methods and Data

The data used for the analysis was taken from public sources. Limited field investigations were undertaken to supplement and verify the data. Where applicable, the publicly collected data was crosschecked with the limited data collected from field investigations.

When doubts concerning the accuracy of data arose, the more conservative values were used. The economic life of project-related facilities was assumed at 25 years. If any facility's life span was expected to go beyond a 20-year period, a salvage value was added to the economic feasibility model. However, such salvage values gave only a marginal change in the net present values (NPV). Therefore, the salvage values were not incorporated in the analysis.

The first step consisted of assessing the financial viability of bioethanol production.⁶ This assessment produced part of the database for the cost–benefit analysis. Financial analysis of bioethanol was carried out considering regional differences (three regions in India—north, south, and west India) and scale of operations (1, 5, and 10 ha and above). Sugarcane production and bioethanol production were assessed separately. Across the country the economics of producing sugarcane is different in terms of costs as well as productivity. Regional differences and in soil and climatic conditions result in different costs for growing sugarcane. National averages were used in the cost–benefit analysis. Table 3 presents the average financial costs of producing bioethanol from the two methods.

Table 3: Financial Cost of Bioethanol Production from Molasses and Sugarcane

Item	Molasses Bioethanol (Rs/liter)	Sugarcane Bioethanol (Rs/liter)
Cost of feedstock	12.55	16.73
Steam	3.00	3.50
Electricity	1.63	3.25
Chemicals	0.25	0.35
Operating cost	0.75	0.75
Manpower cost	0.44	0.59
Administrative and overhead	0.19	0.22
Repair and maintenance	0.15	0.22
Marketing and other expenses	1.00	1.00
Total	19.96	26.61

Rs = rupees.

Source: Authors' estimates.

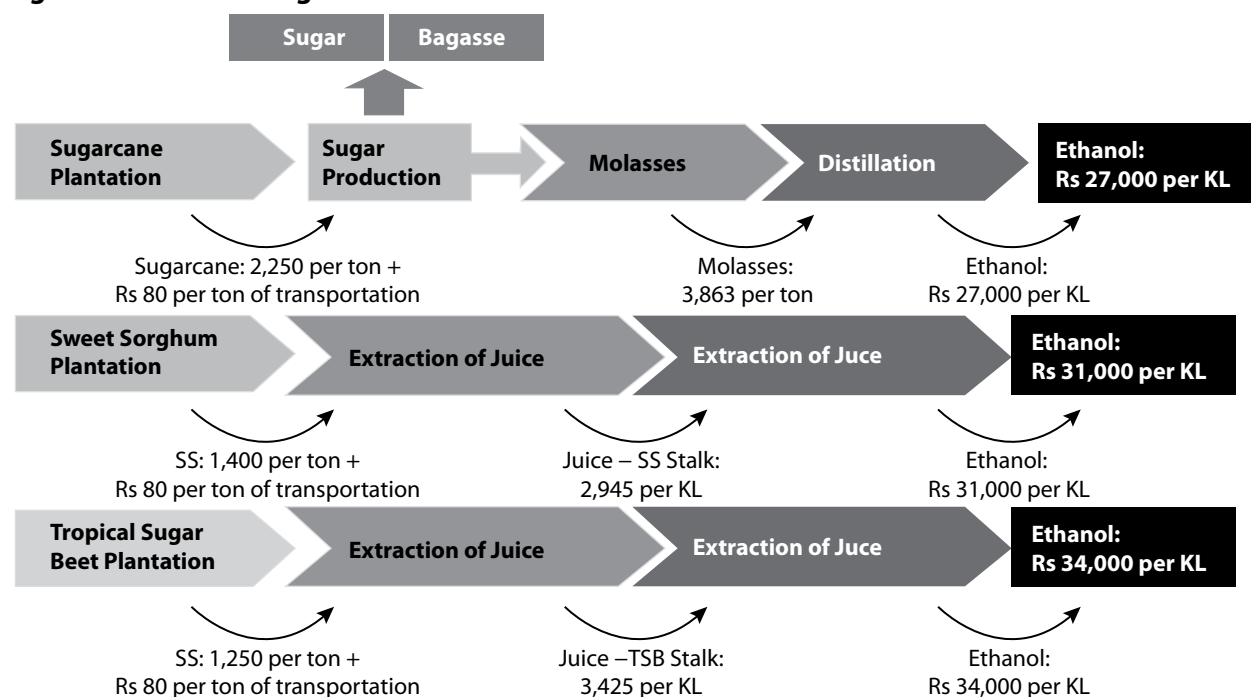
Although bioethanol conversion technology using alternative feedstock is similar to that of sugarcane, there are few commercially viable production plants established in India. The financial analyses were undertaken for two bioethanol techniques: (i) bioethanol production using molasses, and (ii) bioethanol production using direct sugarcane. In India, bioethanol is mainly produced using molasses. To attain financial viability, most of the sugar mills have integrated bioethanol units (distilleries). Typically, these modular distilleries are set up with a capacity of 50–100 kiloliters per day (KLPD). In addition to the molasses route, bioethanol can directly be produced through sugarcane. The

⁶ The results of the financial analysis are not discussed here to preserve the flow of the paper. See ADB (2011) for the details.

unavailability of sugarcane throughout the year makes the production of bioethanol only from sugarcane commercially nonviable.

Figure 6 presents the price structure across the value chain of producing bioethanol from molasses and alternative sources. With the present productivity and cost scenarios, the financial analysis shows that the price of bioethanol produced by molasses should be Rs 27/liter, to provide sufficient financial returns to each and every stakeholder across the value chain. Note that the required price estimated here is indicative and considers only the costs from the producer's side and assumes 16%–18% returns. In addition to the costs, the benefits or the consumer's willingness to buy blended petrol should also be considered.

Figure 6: Price Building Model of Bioethanol



KL = kiloliter, Rs = rupees, SS = sweet sorghum, TSB = tropical sugar beet.
Source: Prepared by authors.

The financial analysis models for bioethanol production and processing in India were aggregated and expanded to develop economic feasibility analysis models. The analysis was undertaken at the national level and the results highlight the overall welfare implications of bioethanol production and use. In aggregating the different costs and benefits along the supply chain, the 20% blending target was used to define the scale of bioethanol production in India. In other words the national bioethanol project was defined based on the 20% blending target. A detailed cost–benefit analysis of various

environmental implications of the bioethanol sector was not considered in the economic feasibility analysis presented in this paper mainly because of data limitations. Only the benefits of carbon emission reduction were incorporated.

All economic costs and benefits are valued at 2010 prices and are expressed in domestic currency, the Indian rupee. Tradable commodities were valued at the border price. Nontradable commodities were valued through shadow prices using a standard conversion factor of 0.93, with the following specific conversion factors: 1.0 for equipment, 1.5 for steel, 0.76 for cement, 0.82 for timber, 2.0 for skilled labor, and 0.67 for unskilled labor. These conversion factors were taken from previous ADB project preparatory documents and from other published data.

The economic feasibility analysis for bioethanol has focused on three feedstocks: sugarcane, sweet sorghum, and tropical sugar beet. Benefits were estimated as the resource cost savings equivalent to the shadow value of gasoline minus the economic value of sugar. The same principle applies for the costs. In the case of sugarcane, costs were derived by considering the incremental cost of bioethanol processing from molasses or cane juice. In all these cases, costs and benefits have been considered on an *incremental basis*. The rationale for using the incremental approach originates from the *without-project* situation. Given that India's fixed arable land is already under cultivation, bioethanol production cannot be undertaken without displacing some other crops. When the sugarcane that is used to produce sugar is diverted to produce bioethanol, there is an opportunity cost for the lost sugar production. The incremental approach allows the analyst to properly incorporate this cost in the cost–benefit analysis.

In the case of bioethanol production from cane juice, a better understanding is needed about the “with” and “without” project models. In the case of without-project, sugar is produced and molasses comes as a by-product, and the analysis assumes that the molasses is used for bioethanol production. Let us assume that under the without-project scenario:

$$\text{Total cost of sugar production} = C_s$$

$$\text{Cost of bioethanol production} = C_{me}$$

$$\text{Benefits of sugar} = B_s$$

$$\text{Benefit of bioethanol} = B_{me}$$

$$\text{Net benefit without project, } NB_1 = (B_s + B_{me}) - (C_s + C_{me})$$

Under the with-project scenario, sugar will not be produced, hence no molasses is produced, and all the cane juice will be used for bioethanol production. Let us assume:

Total cost of bioethanol production = C_e

Total benefit of bioethanol = B_e

Net benefit with the project $NB_2 = B_e - C_e$

Since the net benefit without the project (NB_1) is the opportunity cost of producing bioethanol from cane juice, the incremental net benefit (NB_{INC}) will be:

$$NB_{INC} = NB_2 - NB_1 = \{B_e - C_e\} - \{(B_s + B_{me}) - (C_s + C_{me})\}$$

The above incremental net benefit is the benefit of producing bioethanol from sugarcane juice.

B. Economic Feasibility of Molasses Bioethanol

As discussed earlier, there are two possibilities for meeting the 20% target of bioethanol: (i) divert existing sugar land to produce bioethanol, or (ii) set aside an additional 1.18 million ha of land for sugarcane-based bioethanol production. In the second case, some other irrigable croplands such as wheat or rice should be converted to sugarcane. Since which croplands will be converted cannot be determined with any accuracy, the analysis of sugarcane-based bioethanol considers only the first option. For other crops such as SS and TSB, an alternative crop (e.g., wheat or maize) was assumed to replace each initial feedstock in estimating the incremental costs and benefits. For example, if maize is the alternative crop for SS, benefits were assessed as the economic value of replaced gasoline minus the economic value of maize. Incremental costs are the cost differences between SS bioethanol production and maize cultivation.

Petrol consumption would be around 21.6 million tons by 2017 and a 20% bioethanol blend target would mean 5.76 million KL per year. The bioethanol project assumes that this amount of bioethanol will be produced by 2017 with a gradual increase from 2010. Bioethanol production up to 2.88 million KL (50%) was assumed to be accomplished using only molasses. The total quantity of molasses currently produced in India is about 8.4 million t/yr. This amount is not adequate to meet the 20% blending requirement. At the current rate of growth, by 2017 the total molasses quantity will be 17.6 million tons and the use of the full amount will make it possible to blend 11.64%. The analysis assumes that 10% bioethanol blending will be achieved by production of 2.88 million KL of bioethanol from molasses.⁷ The molasses bioethanol conversion rate used in the analysis is 0.22 KL of bioethanol for 1 ton of molasses.

⁷ Given the current production of molasses and demand for industrial and potable alcohol, 10% bioethanol for transport is unlikely. However, assumed scale does not affect the conclusions and it allows incorporation of opportunity cost of diversion of industrial and potable alcohol for transportation.

Bioethanol is used for three purposes in India: as transport fuel, for industrial use, and as potable alcohol. There is limited information on the quantity of alcohol used for industrial use or human consumption. According to one of the available estimates,⁸ about 70% of bioethanol produced in India is currently used as potable alcohol and for industrial uses. Given the recent increase in the price of bioethanol, it is assumed in the economic model that about 50% of the total will be used for blending. Molasses bioethanol is a by-product of sugar production but it has a market and therefore it has an opportunity cost.

The total gross benefit of bioethanol is estimated as resource cost savings because every liter of bioethanol displaces 0.67 liter of petrol. The market price of petrol as of March 2010 was Rs 47.43/liter. This includes Rs 14.78 of excise duty and educational levy. On top of these taxes, another value-added tax is levied on petrol at the supply point. The value-added taxes vary from state to state. In the present calculation, the Rs 7.90 (20%) rate applied in Delhi was used. Altogether the total tax will be about Rs 22.68/liter. If oil companies incur a loss, the government pays the balance to the OMCs, which is known as underrecovery. As of March 2010 underrecovery was Rs 4.18/liter. Deducting the taxes from the market price and adding the subsidy (underrecovery) the shadow price was estimated at Rs 28.84/liter. These calculations provide the shadow price coefficient of 0.6, which was used in estimating the benefit of bioethanol.

Appendix Table 1 shows the cost–benefit stream of molasses-based bioethanol. Table 4 provides a summary of the results of cost–benefit analysis. Note that since the net benefit stream is positive throughout the economic internal rate of return estimate was not possible and the economic feasibility assessment is based on the NPV. The base case provides an NPV of Rs 25,229 million at the Government of India's official social discount rate of 12%. This indicates molasses-based bioethanol production generates social benefits in excess of costs, and so improves social welfare. The base case result is stable against a change in the discount rate.

Table 4: Results of the Economic Analysis of Molasses-Based Bioethanol

Scenario	NPV (Rs million)		
	10% Discount Rate	12% Discount Rate	15% Discount Rate
Base case	29612.43	25228.93	20375.33
Base case + opportunity cost of industrial/potable bioethanol	-77390.49	-65934.45	-53249.83
Base case + CDM benefits	32348.03	27360.53	21872.75
Costs increase by 20%	-52216.04	-44486.55	-35928.13
Gasoline prices increase by 15%	95425.64	81299.88	65659.22
Gasoline prices increase by 25%	139301.12	118680.51	95848.48
Gasoline prices increase by 40%	205114.33	174751.46	141132.37

CDM = clean development mechanism, NPV = net present value.

Source: Authors' estimates.

⁸ The Indian Chemical Council (2010) estimates total bioethanol production in India to be 3.4 million KL of which 41% and 29% are used as potable alcohol and in the industrial sector, respectively. The remaining 30% is available for blending with petrol.

If the 20% blending of bioethanol by 2017 is achieved, then the avoided carbon is estimated to be 6.56 million tons of carbon dioxide equivalent (tCO₂e) per annum, based on an estimate made by Ministry of Science and Technology (Department of Biotechnology et al. 2010). According to this study, the net energy balance per kiloliter of bioethanol from molasses is 19.11GJ and the net energy ratio is 4.57. The net carbon balance (in terms of avoided carbon emissions) per kiloliter of bioethanol produced through this route is 1.14 tons of carbon dioxide equivalent (tCO₂e). If the potential reductions are carried forward for clean development mechanism (CDM) registration at an estimated rate of \$5 per tCO₂e, the projected revenue earning potential is about Rs 1,476 million per annum from bioethanol. However eligibility for this benefit depends on the mandatory blending requirement. If 20% blending is made mandatory, only the carbon reduction over and above the 20% requirement will be eligible for CDM benefits. Therefore, realization of this benefit is unlikely. However, as part of the sensitivity analysis, the CDM benefits are incorporated, and the results show that adding the CDM benefit increases the NPV.

As a part of the sensitivity analysis, the potential opportunity cost was deducted from the benefits. It is assumed that the industrial or potable use of bioethanol will be displaced by using it as a transport fuel, and that only about 20%⁹ of the current quantity of industrial bioethanol would be displaced for transport bioethanol. This opportunity cost was estimated at Rs 25 per liter, which is the current average price of industrial bioethanol. The results show negative NPV, indicating molasses-based bioethanol is economically feasible only if incremental production (over and above industrial and potable alcohol) is used as a transport fuel. If any of the other current uses are displaced, the use of bioethanol as a transport fuel is not socially desirable. Switching value analysis shows that 6% of the industrial/potable bioethanol displacement is sufficient to make negative NPV. Oil prices should increase by about 20% to offset the negative impact of opportunity cost of industrial/potable alcohol. Note here that the analysis makes very conservative assumptions regarding the opportunity costs for molasses-based bioethanol. The clear message is that India should try to use only the excess bioethanol for transportation. Diverting industrial or potable alcohol will not benefit the country.

A 20% increase in cost will make molasses-based bioethanol economically infeasible: the bioethanol industry is quite sensitive to cost escalations. The major cost in the bioethanol industry is that the cost of molasses and cyclical fluctuations in sugar production make the price of molasses higher in some years, bringing some instability to the industry. The benefit of bioethanol depends on the price of oil. As shown in Table 4, the NPV increases as the price of oil goes up. Given that the price of oil will continue to increase in the future, the molasses-based bioethanol industry most likely will provide higher net benefits than those indicated by the base case.

⁹ This is based on the composition of current use of molasses bioethanol.

C. Economic Feasibility of Sugarcane Juice Bioethanol

In the above model it was assumed that molasses-based bioethanol will provide half of the bioethanol for 20% blending requirements.¹⁰ In the overall (national) model, the other half is assumed to come from sugarcane juice. Here, sugarcane juice is assumed to be directly used for bioethanol production without going through the sugar production process.

In the sugarcane juice-based model, bioethanol production reaches 2.88 million KL (half the 20% blending requirement) in 2017 with a gradual increase from 2013. One ton of sugarcane produces 100 kg of sugar and 45 kg of molasses, which contains about 25 kg of fermentable sugar. One kilogram of fermentable sugar produces about 0.56 liter of bioethanol. Therefore, the total quantity of bioethanol from 1 ton of cane is about 70 liters. Ten tons of sugarcane produce 1 ton of sugar. Therefore, 1 ton of sugar produces 0.7 KL of bioethanol. These parameters were used in the sugarcane based bioethanol model. In addition, the cost of the production of sugar was estimated to be Rs 23,723 per ton and the market value was estimated to be Rs 30,000 per ton. The cost–benefit stream of the without-project scenario is given in Appendix Table 2.

In the without-project model, the total quantity of bioethanol produced from molasses is used for industrial and potable alcohol purposes and its value was estimated at Rs 25/ liter. Table 5 shows the results of the without-project model. This model gives a NPV of Rs 137,654 million at the 12% discount rate indicating sugar production together with bioethanol for industrial and other purposes is economically attractive. Sugar production shows cyclical fluctuations and prices drop in excess production years. The net benefits under the without-project scenario are quite stable to price drops and cost escalations, but a drop in the price of sugar to Rs 23,000 (23% drop in price) makes sugar plus bioethanol production economically infeasible. Overall, the results show that the without-project scenario is economically quite attractive.

Table 5: Results of Economic Analysis for Sugarcane-Based Bioethanol—Without-Project Scenario

Scenario	NPV (Rs. Million)		
	10% Discount Rate	12% Discount Rate	15% Discount Rate
Base case	202,324.92	166,126.56	126,601.42
Sugar prices decrease by 20%	58,268.13	47,843.26	36,460.31
Total costs increase by 20%	43,709.93	35,889.70	27,350.75
Bioethanol prices decrease by 20%	185,518.29	152,326.84	116,084.96

NPV = net present value.

Source: Authors' estimates.

¹⁰ In reality, the molasses-based bioethanol contribution can be as low as 5% depending on the total production and alternative uses. However this assumption does not affect the policy direction.

Appendix Table 3 shows the cost and benefit stream of the sugarcane juice-based bioethanol model. As is evident from the table, the net benefits (NB_2) of sugarcane-based bioethanol are negative. This is because the shadow value of bioethanol at current prices is lower than the cost of production. This clearly demonstrates that the use of sugarcane for bioethanol production is not economically feasible. Once the opportunity cost of sugarcane-based bioethanol—displaced sugar and molasses-based bioethanol—is incorporated into the model, the negative benefits (NB_{INC}) or the economic losses become larger. The economic feasibility of sugarcane-based bioethanol should be determined based on the last column of Table 6. The negative values indicate it is not worthwhile to convert sugarcane juice to bioethanol.

The results clearly show that converting sugarcane juice to bioethanol is not socially desirable. Adding CDM benefits or a decline in the sugar and industrial bioethanol price does not change the basic conclusion. An increase in petrol price by about 25% makes the conversion of sugarcane to bioethanol feasible but once the opportunity costs are added, NPV remains negative. This situation does not change even if petrol prices increase by 40%. Therefore, converting sugarcane to bioethanol will not be economically feasible even in the future with higher oil prices. Cyclical drops in sugarcane prices will only have a marginal impact on the economic feasibility of sugarcane juice-based bioethanol because opportunity costs are very large compared to the cost of production of bioethanol. About a 40% drop in the sugar prices is required to make sugarcane juice-based bioethanol economically viable. Even in surplus years, that type of a drop is highly unlikely.

Table 6: Results of the Economic Analysis of Sugarcane Juice-Based Bioethanol

Scenario	NPV (Rs million)	
	Without Opportunity Cost, NB_2 (12% discount rate)	With Opportunity Cost, NB_{INC} (12% discount rate)
Base case	-687,48.42	-234,874.98
Base case + CDM benefits	-65,211.57	-231,338.13
Sugar and industrial bioethanol prices decrease by 20%	N/A	-201,649.67
Sugar prices decrease by 40%	N/A	1,691.62
Gasoline prices increase by 15%	-26,310.14	-192,436.71
Gasoline prices increase by 25%	1,982.04	-164,144.52
Gasoline prices increase by 40%	44,420.31	-121,706.25

CDM = clean development mechanism, NPV = net present value, Rs = rupees.

Source: Authors' estimates.

The results clearly show that the cost of bioethanol production using sugarcane juice exceeds the social benefits; hence there is no economic rationale for expanding bioethanol production using sugarcane juice. Consequently, there is no justification for a promotional program or any government support for sugarcane juice-based bioethanol

production in India. In contrast to these results, the molasses-based bioethanol model is economically attractive provided that only excess bioethanol is used for transportation. If sugar production increases at around 4% to meet growing demand, there will be some excess molasses for bioethanol blending. However, potable alcohol and industrial alcohol demands are also increasing. Therefore, how much excess alcohol is available for blending is highly uncertain. As the results clearly show, diversion of industrial and potable alcohol is not socially desirable and only excess alcohol should be used for blending. Blending of molasses-based bioethanol is not only economically feasible but also does not have adverse food security implications. Moreover, molasses-based bioethanol blending will have a stabilizing effect on the sugar industry that shows a cyclical behavior.

D. Economic Feasibility of Alternative Feedstock

This section assesses the economic feasibility of two alternate bioethanol feedstocks. Today, there is no SS or TSB production on a commercial scale in India. However, research trials have been undertaken by agencies including the International Crops Research Institute for the Semi-Arid Tropics. The two basic financial models were built upon data from those trials, and this database was used for economic analysis with necessary modifications. Sweet sorghum can be cultivated under harsh conditions, but still it will have to compete with rainfed food or feed crops such as corn or millet. Tropical sugar beet generally requires more water and other soil nutrients to produce an economically attractive yield. So, the opportunity cost of TSB would be higher than SS because it replaces more profitable crops like legumes, onions, or high-value vegetables. So for both crops we have assumed a positive opportunity cost in calculating economic indicators. The results are given in Tables 7 and 8.

Table 7: Results of the Economic Analysis of Sweet Sorghum-Based Bioethanol

Scenario	NPV (Rs million)	
	Without Opportunity Cost, NB2 (12% discount rate)	With Opportunity Cost, NBINC (12% discount rate)
Base case	4,487.67	-40,027.60
Base case + CDM benefits	6,619.27	-37,895.95
Opportunity costs decrease by 20%	N/A	-31,124.51
Gasoline prices increase by 15%	195,216.06	150,700.84
Gasoline prices increase by 25%	212,191.37	167,676.15
Gasoline prices increase by 40%	237,654.33	193,139.11

CDM = clean development mechanism, N/A = not available, NPV = net present value, Rs = rupees.

Source: Authors' estimates.

In the base case, without the opportunity costs, the NPV is positive. When CDM benefits are included, the NPV is even more attractive. However, when the opportunity costs are included with the base case, the NPV becomes negative. Note that economic decisions

should be made on the results of the model with the opportunity cost. The results basically show bioethanol-based using SS is not economically feasible at current oil prices. However, when gasoline prices increase, in all cases the NPV becomes positive (or economically viable), with or without considering the opportunity costs. Gasoline prices must increase by at least 15% for SS to become a part of India's biofuel industry with justifiable economic benefits. Regardless of oil prices, SS for fuel is competing with food crops; hence promotion of SS for fuel may conflict with the government policy of not compromising food crop security for promoting energy crops.

Table 8: Results of the Economic Analysis of Tropical Sugar Beet Juice-Based Bioethanol

Scenario	NPV (Rs million)	
	Without Opportunity Cost, NB2 (12% discount rate)	With Opportunity Cost, NBINC (12% discount rate)
Base case	2,991.78	-24,402.20
Base case + CDM benefits	5,123.38	-22,270.60
Opportunity costs decrease by 20%	N/A	-18,923.41
Gasoline prices increase by 15%	130,144.04	102,750.06
Gasoline prices increase by 25%	141,460.91	114,066.93
Gasoline prices increase by 40%	158,436.22	131,042.24

CDM = clean development mechanism, N/A = not available, NPV = net present value, Rs = rupees.
Source: Authors' estimates.

Just as in the case of SS, opportunity costs cause the NPV to become negative in the case of TSB. However, increases in gasoline prices likewise cause TSB to become economically viable. Just as with SS, gasoline prices must increase by at least 15% for TSB to become a part of India's biofuel industry with adequate economic benefits. Even at higher prices, TSB still competes for the agricultural resources, despite being economically attractive.

V. Second-Generation Biofuels

Biofuels can be classified as first-generation and second-generation on the basis of the nature of the feedstock used. First-generation biofuels are usually derived from sugars, grains, or seeds, often the edible portion of the plant. In India, as discussed above, this first-generation biofuels have limited scope as their economic feasibility results are not promising, except for molasses-based bioethanol. Although global biofuel production in the form of first-generation biofuels has increased rapidly over the last decade, there are concerns about their long-term sustainability especially due to their impact on food security—they compete with food crops for land, water, and other resources.

This has encouraged the development of second-generation biofuels, often produced from nonedible biomass, for instance, forest and farm residues or municipal solid waste. The use of these feedstocks would significantly increase the availability of biofuels.

Second-generation biofuels are, however, still in the development stage and are rarely being produced on a large scale. Some examples include:

- (i) Cellulosic ethanol: The feedstock is nonfood forestry or farm biomass, including twigs, sawdust, and grass. The cost of the enzymes that break down the cellulose has been a problem, but significant cost reductions have been reported.
- (ii) Syngas: Produced from a variety of feedstocks, including agricultural waste, but historically from coal; syngas is an intermediary product composed of carbon monoxide and hydrogen that can be converted into ethanol.
- (iii) Bio-oil: Produced from a variety of biomass feedstocks, by fast pyrolysis (decomposing the feedstock at high temperature). The bio-oils that result are characterized by high acidity and oxygen content and are unsuitable as transport fuel without further processing, although they can be used for furnace fuel.
- (iv) Renewable diesel: Processing of vegetable oils, including waste products from the commercial food industry, to produce transport fuels.
- (v) Algae-based biofuels: A wide range of technologies is being examined that use microbes to convert carbon dioxide to liquid fuel products. The research is, however, only in the initial stages. Experiments have been carried out in small-scale processes, but the field is not yet commercially mature.

The Ministry of New and Renewable Energy in India, especially through the Department of Biotechnology and the Ministry of Science and Technology, have promoted R&D in second-generation biofuels. Cellulosic ethanol technology, for example, will be used to set up a 10 tons/day biomass-based pilot plant with Indian Glycol, which is expected to produce about 3,000 liters/day of bioethanol. The plant trials are expected to develop needed technology and determine the cost competitiveness of the process.

If the cellulose-to-ethanol technology progresses, it would be possible to use bagasse for the production of ethanol, which may nearly double the quantity of bioethanol available from sugarcane. India produces about 60 million tons of bagasse and other production trash, which could, in theory, be used to produce 18 million KL of cellulosic ethanol. If

even 30% of this can be made available, the ethanol production would be 5.4 million KL, close to the 20% blending requirement for 2017. In addition, large quantities of biomass are available as residue from the agriculture sector, including straw, stalk, and crop husks. The Ministry of New and Renewable Energy has estimated that of the total crop residue of 415.4 million tons, about one-quarter could be available for biofuel inputs (Ministry of New and Renewable Energy 2005). This surplus could produce more than 20 million KL of cellulosic ethanol.

The attraction of second-generation biofuels is clear: they promise to use waste to produce substitutes for fossil fuels. Currently, however, technical barriers mean that these are high-cost fuels that have yet to prove their commercial viability. Given the limited scope of first-generation biofuels, India's ambitions to reduce dependency on imported petroleum can be met mainly through second-generation biofuels. Therefore India's efforts on adaptive research on second-generation biofuels should continue.

VI. Concluding Remarks

The economic analysis in this paper was conducted from the perspective of the nation and focuses on the potential welfare increase or decrease due to interventions on bioethanol. The analysis was conducted separately for molasses and sugarcane juice-based bioethanol. Molasses ethanol does not compete for agricultural resources. Results show molasses-based bioethanol is economically feasible at the 2010 price of oil. However, if industrial and potable bioethanol are displaced, the costs exceed the benefits. Therefore the drive to blend bioethanol should not result in displacing the current use of alcohol for potable and industrial purposes. CDM benefits and oil price increases make molasses-based bioethanol economically more attractive.

In contrast, sugarcane juice-based bioethanol results clearly show that the cost of bioethanol exceeds the social benefits, even without considering the opportunity cost of sugar. Once the opportunity cost of displaced sugar is added, the already negative net returns becomes bigger, making sugarcane juice-based bioethanol economically even more unattractive. Higher oil prices (even up to up to 40% increase) cannot make sugarcane juice-based bioethanol economically attractive; hence, sugarcane-based bioethanol will not be beneficial to India even in the future. The use of sugarcane to produce bioethanol also compromises food production. Hence, the present study does not recommend sugarcane juice-based bioethanol production as a socially desirable or economically feasible venture in India.

As stated earlier, 20% blending of bioethanol cannot be achieved only from molasses. Given that molasses based bioethanol is economically feasible and that it does

not compromise food security, blending only from molasses-based bioethanol is recommended. From a technical perspective, bioethanol blending up to 10% can be achieved without any major change in vehicle fleet. The sugar industry is well established and a vibrant molasses-based bioethanol industry may also have a stabilizing effect on the cyclical sugar industry. However, if the use of bioethanol for transport displaces industrial and potable uses, the costs will exceed the benefits. Therefore excess bioethanol should only be used for transport. Given these findings, the national indicative target to 20% blending stated in the biofuel policy needs revisions. A more realistic target would be up to 5% blending using only excess molasses bioethanol.

Overall the bioethanol promotion in India needs to be treated with some caution because of its mixed economic feasibility and possible impact on the food sector and industrial and potable alcohol sectors. In particular, the use of sugarcane juice for bioethanol will not provide adequate benefits to justify the costs, and it will compromise food production in India. Alternative feedstocks such as SS and TSB are not economically feasible either. Therefore the future of the bioethanol industry in India relies on second-generation biofuel technologies, which require further research for cost reduction and commercialization.

Appendix

Appendix Table 1: Cost–Benefit Stream of Molasses-Based Bioethanol Base Case (millions)

Year	Quantity of Molasses (tons)	Quantity of Bioethanol (kiloliters)	Cost of Production (Rs)	Gross Benefits, (Rs)	Net Benefits (Rs)
1	8.40	1.85	32857.44	35235.56	2378.12
2	9.07	2.00	35483.80	38052.01	2568.21
3	9.74	2.14	38110.16	40868.46	2758.29
4	10.41	2.29	40736.53	43684.91	2948.38
5	11.09	2.44	43362.89	46501.35	3138.47
6	11.76	2.59	45989.25	49317.80	3328.56
7	12.43	2.73	48615.61	52134.25	3518.64
8	13.10	2.88	51241.96	54950.69	3708.73
9	13.10	2.88	51241.96	54950.69	3708.73
24	13.10	2.88	51241.96	54950.69	3708.73
25	13.10	2.88	51241.96	54950.69	3708.73

Rs = rupees.

Source: Authors' estimates.

Appendix Table 2: Cost–Benefit Streams of Without-Project Sugar cum Bioethanol Production (millions)

Year	Quantity of Sugar (tons)	Quantity of Bioethanol (kiloliters)	Cost of Sugar (Rs)	Benefits of Sugar (Rs)	Quantity of Bioethanol (kiloliters)	Cost of Molasses Ethanol (Rs)	Benefits of Molasses Ethanol (Rs)	NB ₁ (Rs)
4	3.27	2.29	68173.95	91318.42	0.46	8147.31	10653.82	25650.98
5	3.48	2.44	72569.25	97205.89	0.49	8672.58	11340.69	27304.75
6	3.70	2.59	76964.56	103093.37	0.52	9197.85	12027.56	28958.52
7	3.91	2.73	81359.86	108980.84	0.55	9723.12	12714.43	30612.29
8	4.12	2.88	85755.15	114868.29	0.58	10248.39	13401.30	32266.05
9	4.12	2.88	85755.15	114868.29	0.58	10248.39	13401.30	32266.05
24	4.12	2.88	85755.15	114868.29	0.58	10248.39	13401.30	32266.05
25	4.12	2.88	85755.15	114868.29	0.58	10248.39	13401.30	32266.05

NB₁ = (benefits of sugar + benefits of molasses ethanol) – (cost of sugar + cost of molasses ethanol); Rs = rupees.

Source: Authors' estimates.

Appendix Table 3: Benefit–Cost Stream for Bioethanol Production from Sugarcane Juice (millions)

Year	Quantity of Bioethanol (kiloliters)	Total Cost of Bioethanol Production (Rs)	Total Benefits of Bioethanol (Rs)	Net Benefits, NB ₂ (Rs)	Incremental Benefit (Rs)
4	2.29	54300.09	43684.91	-10615.19	-36266.17
5	2.44	57800.92	46501.35	-11299.57	-38604.32
6	2.59	61301.75	49317.80	-11983.95	-40942.47
7	2.73	64802.58	52134.25	-12668.33	-43280.62
8	2.88	68303.40	54950.69	-13352.71	-45618.76
9	2.88	68303.40	54950.69	-13352.71	-45618.76
24	2.88	68303.40	54950.69	-13352.71	-45618.76
25	2.88	68303.40	54950.69	-13352.71	-45618.76

NB₂ = total benefits of bioethanol – total cost of bioethanol production; Rs = rupees.

Source: Authors' estimates.

References

- ADB. 2011. Cross Sectoral Implications of Biofuel Production and use in India. Available: www.adb.org/documents/reports/consultant/IND/42545/42525-01-ind-tacr-01.pdf.
- British Petroleum. 2009. *Statistical Review of World Energy 2009*. London.
- Cabinet Committee on Economic Affairs. 2007. "Relief to Sugar Industry and Sugarcane Farmers." New Delhi.
- Department of Biotechnology, Ministry of Science and Technology, and Confederation of Indian Industry. 2010. Estimation of Energy and Carbon Balance of Biofuels in India. New Delhi.
- Gopinathan, M., and R. Sudhakaran. 2009. "Biofuels: Opportunities and Challenges in India." *In Vitro Cellular & Developmental Biology Plant* 45(3):350–71.
- Government of India. 2003. Report of the Committee on the Development of Biofuel. Planning Commission, New Delhi.
- . 2006. Integrated Energy Policy. Report of the Expert Committee. Planning Commission, New Delhi.
- . 2007. Relief to Sugar Industry and Sugar Farmers. Cabinet Committee of Economic Affairs, New Delhi.
- IEA. 2007. International Energy Authority. *World Energy Outlook 2007*. Paris.
- Indian Chemical Council. 2010. "Presentation to the Expert Committee on Ethanol Pricing for Fuel Blending." New Delhi.
- Ministry of New and Renewable Energy. 2005. *Biomass Resource Atlas of India*. Ministry of New and Renewable Energy, Government of India.
- MoPNG. 2007. "All India Launch of 5% Ethanol Blending Program." Hyderabad Press Information Bureau, New Delhi.
- . 2009. *Basic Statistics on Petroleum and Natural Gas 2008–2009*. Ministry of Petroleum and Natural Gas, New Delhi.

About the Paper

India's ambitions on enhancing energy security through bioethanol largely rely on second-generation technologies. Using a cost-benefit analysis, Herath Gunatilake and Piya Abeygunawardena show that sugarcane bioethanol is not economically viable and competes with agricultural resources. Molasses ethanol can support up to 5% blending while improving social welfare.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to two-thirds of the world's poor: 1.8 billion people who live on less than \$2 a day, with 903 million struggling on less than \$1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org/economics
ISSN: 1655-5252
Publication Stock No. WPS113615

