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Food Security, Energy Security, and Inclusive Growth in India

The Role of Biofuels

Asian Development Bank

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Herath Gunatilake

Asian Development Bank

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Abbreviations

ASEAN	–	Association of Southeast Asian Nations
CDM	–	Clean Development Mechanism
CER	–	certified emissions reduction
CGE	–	computable general equilibrium
DMC	–	developing member country
EIRR	–	economic internal rate of return
FIRR	–	financial internal rate of return
FY	–	fiscal year
GDP	–	gross domestic product
GHG	–	greenhouse gas
ha	–	hectare
IEA	–	Internatioal Energy Agency
kl	–	kiloliter
m^3	–	cubic meter
mm	–	millimeter
mt	–	million tons
OECD	–	Organisation for Economic Co-operation and Development
OMC	–	oil marketing company
PRC	–	People's Republic of China
R&D	–	research and development
Rs	–	Indian rupees
SVO	–	straight vegetable oil
TA	–	technical assistance
US	–	United States

Foreword

Promotion of renewable energy and energy efficiency is one of five pillars of the Asian Development Bank's (ADB's) energy policy. The South Asia Department of ADB has prioritized its support for renewable energy projects in its developing member countries. It has been actively seeking opportunities to broaden its assistance for renewable energy in many sectors to (i) ease growth in fossil fuel demand and upward pressure on energy prices, (ii) improve energy security, and (iii) reduce emissions of greenhouse gases. Biofuels are a renewable source of energy which could help achieve these objectives. The first-generation biofuels, however, compete for agricultural resources and therefore cautious approaches are needed in promoting biofuels.

This publication is an outcome of the ADB technical assistance (TA) project Cross-Sectoral Implications of Biofuel Production and Use in India*.* The objective of this TA project was to generate scientific information on biofuels to help implementation of the biofuel policy in India. This TA project included a series of studies using rigorous analytical tools, following a consultative and transparent process. The TA project report provides balanced and carefully drawn conclusions and a set of pragmatic recommendations to move the Indian biofuels sector forward. The Government of India has shown keen interest in this study and we hope that the government will consider the report's recommendations in formulating policies to achieve greater energy security, inclusive growth, and carbon emission reduction while taking necessary supplementary measures to avoid adverse impacts, if any, on the food sector.

This TA project was undertaken with limited resources, but produced a very valuable set of recommendations which will help India to develop a biodiesel industry to substitute diesel imports of about Rs650 billion per annum, while generating an estimated 18 million rural jobs. The TA project also generated a series of knowledge products on a new subject which has drawn serious attention from academics and policy makers.

I congratulate Herath Gunatilake, principal energy economist, Energy Division, South Asia Department, and his team for designing and carrying out these challenging studies on a new subject of major relevance to public policy.

Sultan Hafeez Rahman
Director General, South Asia Department

Acknowledgments

This ADB publication is a product of the ADB technical assistance (TA) project Cross Sectoral Implications of Biofuel Production and Use in India. The studies under the TA project were undertaken in consultation with a steering committee consisting of 10 line ministries. An oversight committee consisting of four eminent scientists and economists guided the study team to ensure rigorous analysis and high-quality outputs.

The study team was lead by Herath Gunatilake (principal energy economist, Energy Division, South Asia Department) and the study concept was initially developed by Priynantha Wijayathunga (senior energy specialist, Energy Division, South Asia Department). The computable general equilibrium modeling studies ware undertaken in collaboration with the Economics and Research Department of ADB. Guntur Sugiarto (senior economist, Economics and Research Department) collaborated from this side.

The studies were carried out by a team of consultants under the overall supervision of Gunatilake. The consultant team includes, David Rolan-Holst (University of California, Berkeley), Piya Abeygunawrdena (Texas A&M University), Sanjb Prohit (National Institute of Science, Technology and Development Studies), Jai Uppal, Ronnie Khanna, Thilottam Kolanu, and Jitendra Swami.

The Steering Committee includes H.L. Sharma (director, Ministry of New and Renewable Energy), Rajan Sehgal (senior assistant inspector general of forests, Ministry of Environment and Forests), Neetu Kejriwal (deputy secretary, Ministry of Rural Development), Rashmi Agarwal (director, Ministry of Petroleum and Natural Gas), S. Biswas (adviser, Ministry of Science and Technology), Alok Adholeya (director, Biotechnology and Bioresources Division, Energy and Resources Institute), Renu Swaroop (adviser, Ministry of Science and Technology, Department of Biotechnology), R.S. Kureel (director, Ministry of Agriculture), Ravinder Gaur (scientist, Ministry of Science and Technology), and Malay Srivastava (director, Ministry of Power). The study team appreciates the inputs from steering committee members at various stages of the study.

The Oversight Committee consists of David Zilberman (University of California, Berkeley), M.N. Mutry (Indira Ghandi Institute of Economic Growth, Delhi), Geetha Bali (vice chancellor, Karnataka State Women's University), and Vinay Shankar (former secretary, Ministry of Rural Development, India). The study team is thankful to the oversight committee members for their valuable inputs.

The Department of Economic Affairs in the Ministry of Finance served as the executing agency for the TA project. The study team is grateful to Anoop K. Pujari for his guidance at the conceptualization stage of the study. Anuradha Thakur, director of the Department of Economic Affairs, coordinated the study and her unending support and keen interest are highly appreciated.

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The study team acknowledges the guidance and support provided by Thevakumar Kandiah, former director of the Energy Division, South Asia Department. The study team is also grateful to Sultan Hafeez Rahman (director general) and Carmela Locsin (deputy director general) of the South Asia Department for their guidance.

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Executive Summary

The Asian Development Bank (ADB) granted the technical assistance (TA) project TA-7250 (IND): Cross-Sectoral Implications of Biofuel Production and Use with the objective of generating scientific information on biofuels to help the implementation of the biofuel policy in India. The broad objective of the TA project was to undertake a comprehensive analysis of the socioeconomic and environmental impacts of large-scale production and use of biofuels. The analyses include a review of (i) biofuel policy in India and an assessment of the adequacy of natural resources to support the national policy targets, (ii) supply chains and financial sustainability, (iii) economic viability, (iv) economy wide impacts, and (v) environmental and social impacts of large-scale biofuels production. The analyses were carried out using secondary data, and they mainly focused on first-generation biofuels and their use as transport fuels. This report provides a summary of the TA project findings.

Conclusions

India's biofuel policy is comprehensive. Given the differences between bioethanol and biodiesel, future policy should deal with these two sectors separately.

Economic Viability

Molasses-based bioethanol is economically viable if molasses is not diverted from other uses. If oil prices increase, molasses-based bioethanol becomes economically more attractive. In contrast, the costs of sugarcane juice based bioethanol exceed the benefits. Higher oil prices do not change this. Alternative feedstocks, such as sweet sorghum or sugar beet, are not economically feasible at March 2010 oil prices.

The use of either jatropha or pongamia for producing biodiesel can provide acceptable economic returns, and an increase in the price of diesel makes biodiesel more attractive. Employment generation and avoided greenhouse gas emissions are also significant. Biodiesel production is economically justifiable, and this report recommends a support program for biodiesel (Box 1).

Box 1 **20% Blending of Biodiesel**

- Can generate about 18 million rural jobs
- Can avoid diesel imports worth of Rs656 billion per annum, at 2010 prices
- Can generate 1% incremental growth in the economy
- Will result in insignificant fiscal deficit
- Can significantly offset negative economic impacts of moderate oil price hikes
- Biodiesel plantations and blending can generate about 244 million certified carbon emission reductions and about Rs55 billion carbon revenue per annum
- Does not cause any major adverse effects on other sectors of the economy
- Does not compromise food production

Economy-Wide Impacts

The use of general equilibrium models shows that biodiesel could allow India to enhance economic growth and the wellbeing of rural populations through employment creation. Policies that encourage better efficiency in energy use and productivity in the agricultural sector would enhance these results. In contrast, 20% bioethanol blending does not add much value to the economy.

Financial Viability

Until July 2010, bioethanol producers faced an administratively determined price of Rs21.5 per liter. This price did not provide for sustainable financial operations. The August 2010 price revision to Rs27.0 per liter may provide adequate profits to the producers. Biodiesel production is not financially feasible under 2010 prices.

The Impact on Land

Simple natural resource accounting shows that 20% blending of bioethanol with petrol can be achieved by 2017, but only if arable land is diverted from food production to produce bioethanol. To meet a 20% blending target for biodiesel, about 32 million hectares of wasteland would be required for new crop cultivation, together with yield improvements. Bringing this much wasteland into cultivation together with the technological improvements and subsidiary industries are serious challenges.

The Impact on Water Resources

Sugarcane is a water-intensive crop, but if confined to existing lands or with molasses as an input, bioethanol production will not add to irrigation water demand. Biodiesel crops would not significantly increase the country's water demand.

Food Security

At current levels of productivity, 20% blending of bioethanol cannot be achieved without affecting the food sector. Sugarcane, sweet sorghum, and sugar beet all compete with food crops for land and water. Molasses-based bioethanol would not permit a 20% blending, but lower levels (up to 5%) might be accomplished without impacting food security. If confined to wastelands, and with limited irrigation during the beginning phase of the crops, biodiesel production would not have major adverse impacts on the food sector. However, there is a possibility of biodiesel cultivations expanding into arable lands under high profitability scenarios, and additional policy measures may be required for preventing such adverse impacts.

Environmental Impacts

Available data suggest that biodiesel crops would have positive environmental impacts—especially in the provision of tree cover for wastelands. Possible negative impacts of both bioethanol and biodiesel can be mitigated using available technology and regulatory measures.

Recommendations

Based on the findings of the TA project, the report identifies the following recommendations:

(i) **Separate policies for bioethanol and biodiesel.** Separate policies for bioethanol and biodiesel would serve the two sectors better given the difference in performance and issues.

(ii) **Focus on molasses-based ethanol.** Ethanol blending should be limited to molasses-based ethanol.

(iii) **Research on second-generation biofuel.** There is limited scope for first-generation bioethanol in India. However, there seems to be a large potential for second-generation bioethanol. Therefore, research efforts on second-generation bioethanol should continue.

(iv) **Public sector support for biodiesel.** The main focus of public support, at this point in time, should be for biodiesel. The following are the specific areas that require immediate attention:

  (a) land use mapping and land allocation study and initiating the necessary legal, institutional, and other provisions to make wasteland available for biodiesel production;

  (b) revision of biodiesel and oil seed prices and provision of a stable policy environment for the biodiesel sector to develop;

  (c) an accelerated research program on agronomy, selection and breeding, pest and diseases control, other management practices, and the propagation of high-yielding planting materials for plantation development;

  (d) incentive packages for the private sector to mobilize private investment resources for the development of the biodiesel sector;

  (e) further studies to examine the potential synergy between India's rural development programs and biodiesel sector development, particularly focusing on the long gestation period of biodiesel crops; and

  (f) establishment of a national agency with branches in relevant states to design and implement the above-stated public support program, oversee and monitor the biodiesel industry, periodically review the cost of production and prices, and design and recommend subsidies and taxes based on changes in oil prices.

(v) **Further studies on the incentive packages for biodiesel.** It is necessary to design a combination of tax, subsidy, and regulatory measures to ensure that the incentives given to the biodiesel sector do not lead to expansion of biodiesel cultivation into arable lands.

Introduction

A nation's energy policy often involves choices between complex tradeoffs amid uncertainty concerning future developments. For rapidly growing India, the growing energy demand can be partly met by biofuels such as bioethanol and biodiesel. Energy and food policies, however, must balance different and conflicting uses of resources such as land and water.[1]

In India, like many other developing countries, food security is a prime concern. Meeting the increasing food demand has been a challenge with a growing population and a fixed amount of arable lands. Growing rural incomes and frequent weather fluctuations experienced in recent times will make this an even bigger challenge. The Green Revolution, with its tremendous impact on increasing yields and production, has cushioned India against food shortages. However, policies related to food production and distribution continue to be vital. The need for concerted efforts to maintain access to food for all will remain.

Energy policy, while needing to underpin sustained economic growth through increasing supply, has also come to focus on ways to reduce reliance upon fossil fuels, particularly imported petroleum products. Global energy supplies are likely to tighten over the next few decades and this could lead to debilitating price shocks. Petroleum fuels also contribute to global warming through emissions of greenhouse gases (GHGs).

Biofuels lie at a nexus of food and energy policies. Biofuels can be produced from domestic agricultural sources and represent alternatives to the use of petroleum-based fuels (Box 2). Bioethanol can substitute or be blended with petrol, as can biodiesel with conventional diesel. These fuels can lower fossil fuel imports and reduce GHG emissions. However, biofuel feedstocks require resources such as land and water, and care must be taken to ensure that policies to enhance energy security do not worsen food security.

Box 2 **Biofuels**

Biofuels are liquid energy substitutes for traditional petroleum-based products such as diesel or petrol (gasoline).

In theory, or in laboratory procedures, a large number of biofuels can be produced from a variety of different organic sources, including waste products. However in practice, in the immediate future, there are only a limited number of processes and feedstocks that can be brought onstream to reduce the current reliance upon petroleum-based fuels. In India, there is the potential to produce bioethanol and biodiesel.

- Bioethanol is ethanol or ethyl alcohol produced from plant sources, especially from sugar or starch-laden feedstocks. Bioethanol has many uses, including as a base for alcoholic beverages, but also in industrial processes. It can be blended with petrol.
- Biodiesel is a substitute for petroleum-based diesel fuel that can be produced from plant oils or animal fats. It can be blended with petroleum-based fuel and can be used in most conventional diesel engines.

[1] Unless otherwise noted, all information is from the Asian Development Bank funded study TA-7250 (IND): Cross-Sectoral Implications of Biofuel Production and Use (Box 2).

This report focuses on transport biofuels that can be produced with existing technology (Box 3). Sugarcane is the main bioethanol feedstock (either through the use of molasses or from sugarcane juice), but the tropical sugar beet and sweet sorghum were also examined as alternatives. Jatropha and pongamia were the biodiesel crops considered.

Box 3 **The Asian Development Bank Grant TA-7250**

This report is the result of work done under an Asian Development Bank (ADB) grant, TA-7250 (IND): Cross-Sectoral Implications of Biofuel Production and Use. The grant provided the Government of India resources for a comprehensive analysis of the impacts of large-scale production of biofuels. A team of consultants, under the direction of ADB staff, undertook the studies beginning in December 2009. This team worked with a steering committee to ensure a transparent and consultative process. An oversight committee, consisting of eminent economists and scientists, endorsed the findings on 26 September 2010. The detailed final report of the technical assistance project is available on the ADB website at: www.adb.org/Documents/Reports/Consultant/IND/42545/42525-01-ind-tacr-01.pdf

Biofuels: The Nexus of Energy and Food Policies

Global Energy Issues

Energy security has been an important policy issue for more than 4 decades, especially since the global energy shocks of the 1970s. World energy markets continue to rely heavily on fossil fuels like coal, natural gas, and oil. These products provide almost 80% of the world's primary energy supply.[2] However, they have brought problems, including price shocks that have destabilized economies across the globe. The extensive use of fossil fuels has not only threatened energy security but has resulted in serious environmental concerns, particularly a build-up of GHGs, contributing to global warming.

Global primary energy demand could increase by as much as 40% by 2030 with coal, gas, and oil continuing to dominate the energy mix for the next quarter of a century.[3] The demand for energy will be driven by non-Organisation for Economic Co-operation and Development (OECD) countries, which are likely to account for over 90% of this increase. The People's Republic of China (PRC) and India are expected to be responsible for roughly 53% of this incremental demand. Both countries will increasingly compete for a larger share of the world's energy supplies (Figure 1).

This competition is likely to exacerbate tight energy markets, particularly for oil. Global oil supplies may peak in 2020–2040 and oil prices could rise dramatically. Significantly higher energy prices would adversely affect economic growth and complicate poverty reduction efforts in developing countries like India.

A challenge facing the world is how to meet increasing energy needs and sustain economic growth without continuing to rely upon fossil fuels. Cleaner, renewable energy, including biofuels, is one of the main solutions to the global energy crisis.

India's Energy Outlook

India relies upon imported energy to fuel its rapidly growing economy. The country's reserves of fossil fuels are limited. Petroleum imports in the last few years ran to nearly four times domestic production.[4] This dependence is likely to increase (Figure 2). India's per capita energy consumption was roughly one-quarter of the global average, a figure that will only increase as living standards rise.[5] Transport fuels have seen very rapid growth in usage; diesel fuel consumption grew at an average annual rate of 7.2% between fiscal year (FY) 2004 and FY2009, while the smaller petrol consumption grew 9.2% over the same time period. If current trends are unchanged, the remarkable economic growth the country is enjoying will further increase dependence on outside energy sources. This leaves the country vulnerable to price shocks if oil prices rise on global markets.

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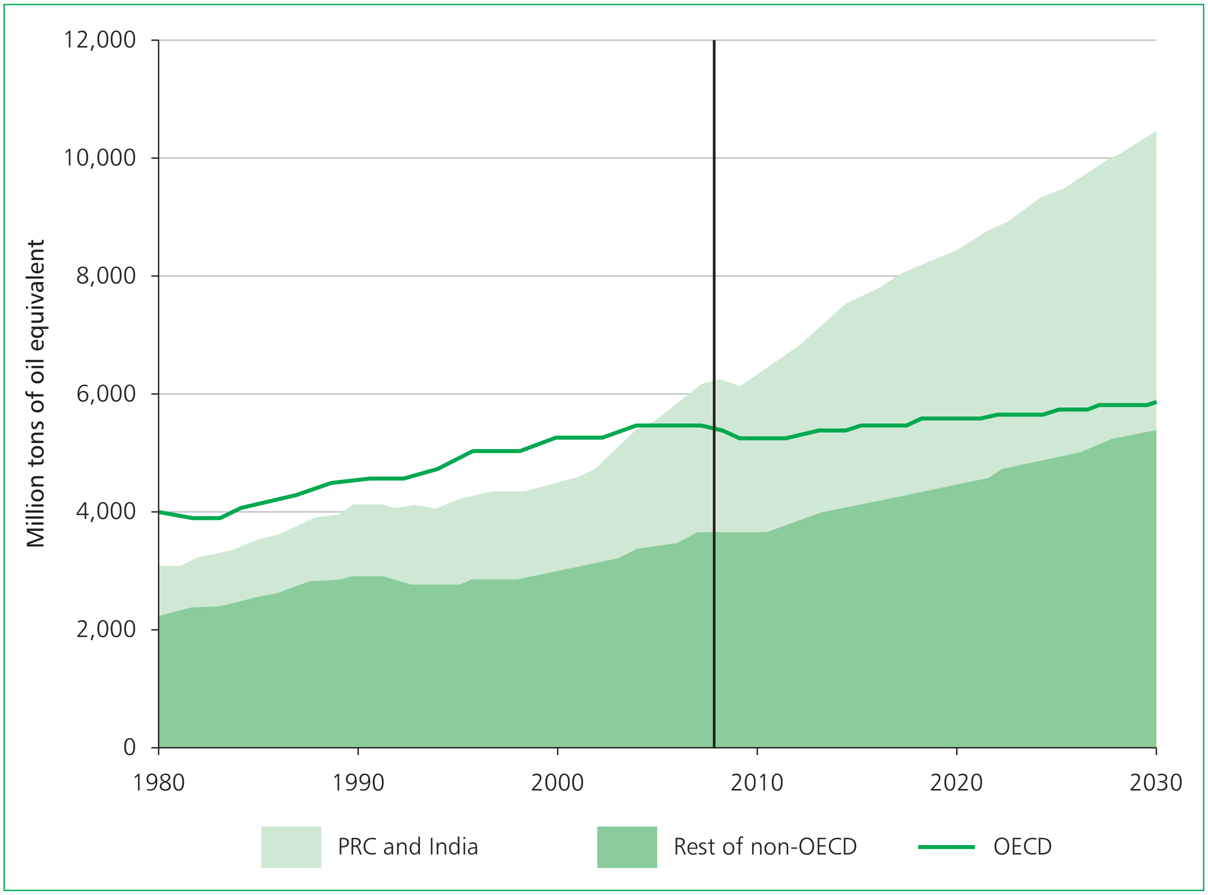
[2] International Energy Agency (IEA), *World Energy Outlook 2007*. Paris.

[3] IEA. 2009. *World Energy Outlook.* Figures for 2030 are from the reference scenario.

[4] Domestic production in FY2008 ran at 33.5 million tons against imports of 128.2 million tons. Statistics in this section come from: Government of India, Ministry of Petroleum and Natural Gas. 2009. *Basic Statistics on Petroleum and Natural Gas, 2008–2009.*

[5] Government of India, Planning Commission. 2006. *Integrated Energy Policy.*

Figure 1 **World Primary Energy Demand**



OECD = Organisation for Economic Co-operation and Development, PRC = People's Republic of China.

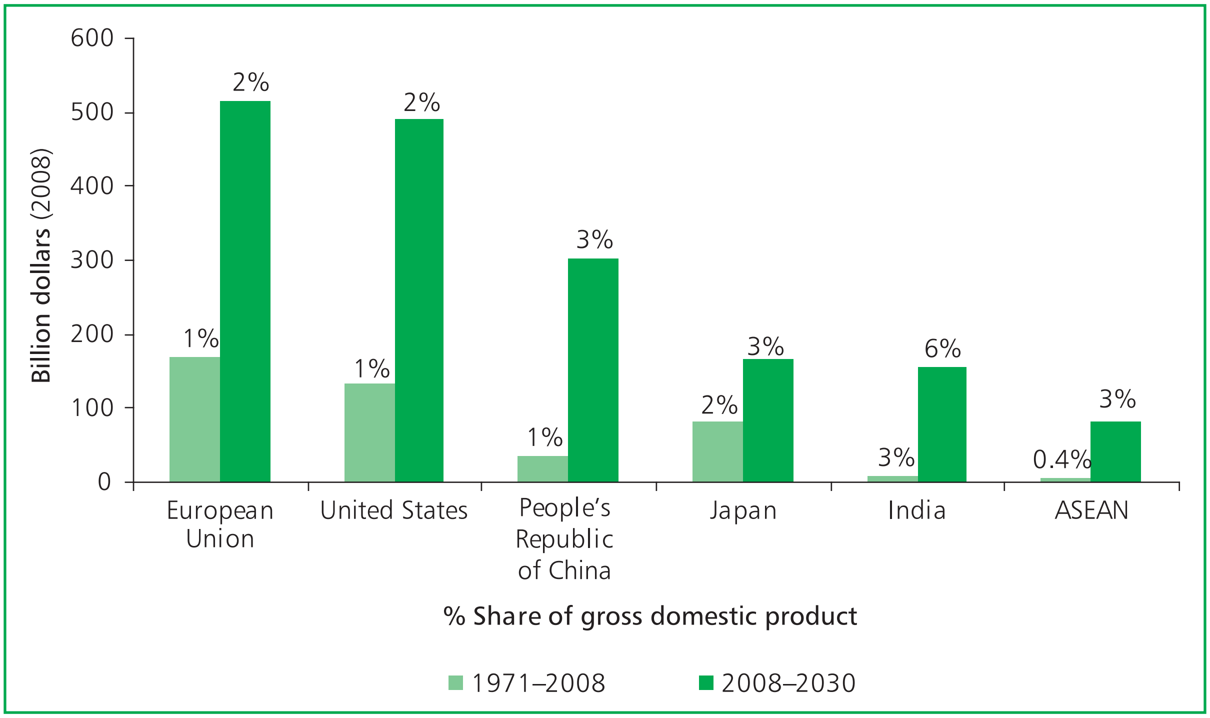
Source: International Energy Agency.

Biofuels may offer an attractive option for meeting part of India's energy needs. In theory, biofuels can be produced using a wide variety of domestic feedstocks. Like solar or wind power, biofuels are considered renewable energy sources as they rely upon plant or waste products. The experience in some other countries is encouraging.

Global bioethanol production in 2008 increased by 34% over the 2007 level, reaching 67 billion liters, and has more than doubled during 2004–2008. Major biofuel programs are found in many countries, but especially in Brazil and the United States (US). Brazil's National Alcohol Program (ProAlcool) is particularly successful. Initiated during the global oil price shocks of the 1970s, the country dramatically increased sugarcane-based bioethanol production, progressing from a 5% blending to a 20%–25% mix for transport fuels. This success in Brazil was a result of incentive measures, such as a guaranteed procurement price, lower taxes for flex fuel vehicles, subsidies for sugar production and processing, compulsory sale of ethanol at all fuel pumps, and government control over ethanol stocks to guarantee uninterrupted supply. The US is the world's largest bioethanol producer—leveraging its productive agricultural sector and utilizing corn as a feedstock. The incentives provided in the US include a federal blending subsidy, volumetric ethanol excise tax credits, ethanol small producer credits, and penalties for violating blending requirements.

Biodiesel saw an even more dramatic rise, increasing sixfold during 2004–2008, from 2 billion liters to

Figure 2 **Average Annual Net Imports of Oil and Gas**



ASEAN = Association of Southeast Asian Nations.

Source: Ministry of Petroleum and Natural Gas.

more than 12 billion liters.[6] The European Union (EU) accounted for more than two-thirds of this production. The main drivers of biofuel adoption in the EU have been the targets set by European Commission Directives: 2% blends of biofuels in petrol and diesel by 2005 and and 5.75% by 2010.

The success of these programs should encourage the development of biofuel sectors in other countries such as India. Biofuel feedstock cultivation has the potential to act as a development agent by enhancing livelihood opportunities for rural communities, while at the same time reducing the fuel import bill of the country. However, large-scale programs require careful planning and implementation. Improper planning and biofuel policies can have negative consequences for food security, the environment, and rural populations. Good planning and proper policies can avoid these problems.

Food Policy: Ensuring Security amid Limited Resources

Successive governments have always focussed on improving food supply and security in India, one of the largest and most populous developing countries. The country was one of the world's most successful examples of the positive impact of the Green Revolution in the 1960s and 1970s.[7] The Green Revolution achieved striking results in certain areas (northwest and south) and in particular crops (rice and wheat). The lesser known White Revolution showed that similar results could be achieved in milk production. By FY2008 India was a net agricultural

[6] Tyner, 2007.

[7] Information in this section is largely drawn from T. Nandakumar, et al. (2010). The discussion on the Green and White Revolutions are found on page 5.

exporter, earning in the order of $10.7 billion from foreign sales. Production and inventories are volatile, reflecting weather as well as changing market conditions. However, at the national level, evidence of food commodity shortages is not obvious in most periods for most crops.

A paramount issue of food security is that of access, especially for the poor. Large numbers of people still need improvements in nutrition. This heightens the importance of public policy decisions related to food security. Moreover, increasing population and increasing incomes as a result of robust economic growth mean rising demand for food commodities in the future. A recent study concluded that for a wide range of food crops, demand will grow faster than supply over 2010–2030.[8] For instance, the study projects a shift for India from a surplus production of cereal grains in 2011 of 21.2 million tons, to a shortage of supply relative to expected demand of 17.0 million tons in 2026. The overall picture of food demand and supply will become more complicated as the consumption mix for food products changes—higher incomes for many provide for reduced per capita demand for staples such as grains and increased consumption of higher-valued goods.

Spikes in food prices in 2010, both nationally and internationally, have highlighted the importance of policies to enhance food security. In 2010, after trending downward from an annual rate of over 20%, food price inflation rose at the end of the year above 18%.[9] The broader index reflected movements in a wide range of agricultural products, including onions and other vegetables, fruits, meats, fish, and eggs. This reversal mirrored international conditions as the Food Price Index of the Food and Agriculture Organisation of the United Nations hit a record high in December 2010.

This need to spotlight food security is particularly important given concerns about the sustainability of the productivity gains seen in earlier decades. Trends in yields are notoriously sensitive to short-term weather conditions, but across a number of important crops in India there appears to be a falloff in productivity improvements. Figure 3 shows the impact of actions taken in earlier decades that boosted productivity through the 1980s. However, since then, productivity appears to have stagnated. Kumar and Mittal (2006, 82), summarizing the very complex nature of the agricultural sector across a country as large and varied as India, conclude that concerns about maintaining productivity increases are real and that the "sharp fall in the total investment," especially from the public sector, is a key problem.

Policies to enhance food security need to address the underlying resource envelope and the productivity of resource use. The uneven availability of water for irrigation poses a particular challenge. India is a water-stressed country, not as a result of limited water resources nationally, but due to their uneven distribution. India overall is not water constrained; some observers suggest it is one of the ten most water rich countries in the world.[10] The per capita fresh water availability in 1997 was 1,957 cubic meters (m^3), but this average masks a tremendous range of availability of water resources. In the Sabarmati Basin there is an estimated 360 m^3 available for each person, while people in the Brahmaputra and Barak basins enjoy 16,589 m^3 per person. Vast regions across the country experience localized water shortages.

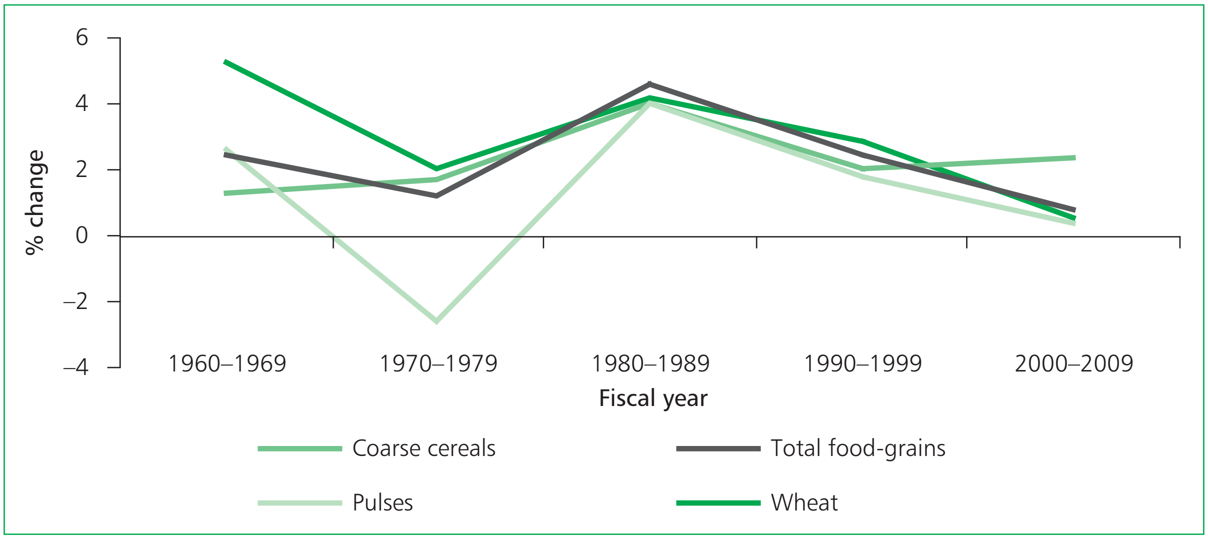
Water availability is important to the issue of land as a productive resource. India's agricultural production faces severe limits on the availability of irrigable land. The discussion elsewhere in this report is based on the premise that the present stock of arable or irrigable land, 102.8 million hectares (ha), is likely the limit for the country in the foreseeable future. Thus discussions of increasing agricultural production must be framed in "doing more with the same" (i.e., increasing productivity). Increasing

[8] Mittal (2008).

[9] Mehra (2011).

[10] Development Alternatives (2001).

Figure 3 **Yields for Major Food Crops in India**



Data are average annual productivity changes for the given time period.

Source: Reserve Bank of India, Web Access 2011.

the output of particular crops must come either from increasing crop productivity or from impinging upon land resources available for other crops.

Foreshadowing the discussion developed elsewhere in this report, food security rests on increasing production against growing demand; energy security likewise will call for increased agricultural production—for biofuels production. Careful consideration of how to broker limited land and water resources will be the challenge of balancing food and energy security.

Biofuel Initiatives in India

The Bioethanol Program: 2001–2008

In response to rising oil prices and increased dependence on imported oil, India established a bioethanol pilot program in 2001. A highlight of the program was 5% (E5) blending pilots in Maharashtra and Uttar Pradesh.[11] 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.[12] The program relied upon the use of molasses, a by-product of the production of sugar from sugarcane, to produce bioethanol.

At the time the initial policy was established, India enjoyed plentiful sugar production. However, severe droughts in 2003 and 2004 reduced supplies by more than half. As a result India had to import 447 million liters of ethanol from Brazil in 2004 to meet the blending target. Further, ethanol is subject to central and state alcohol regulatory measures, which hindered transport of imported ethanol between different states.[13] In October 2004, the program was relaxed, requiring E5 blends only when adequate bioethanol supplies were available and when the domestic price of bioethanol was comparable to the import price of petrol.[14] India continued importing bioethanol to meet its blending targets as well as for the chemical industry. The country became the largest buyer of Brazilian bioethanol in 2005, accounting for approximately 9% of the global bioethanol trade.[15] Despite the higher indicative blending targets, over the period 2007–2009 only about 2% bioethanol blending was achieved.

The Biodiesel Program: 2003–2008

India introduced its biodiesel program in 2003 with the formulation of the National Mission on Biodiesel.[16] The program focused on producing biodiesel from *jatropha curcas*, a small shrub that grows on degraded land or wasteland producing non-edible oilseeds. The ability of this crop to be grown where food crops cannot be cultivated explains some of the appeal of biodiesel—cultivation does not reduce food supplies. Although 400 non-edible oilseeds can be found in India, jatropha was selected for the program because of its high oil content and relatively low gestation period.

The mission recommended a 20% biodiesel blending target (B20) by FY2011, to be met by cultivating jatropha on 11.2 million ha of underutilized and degraded land. To illustrate the scale of this project, the total irrigable farmland available to the country is just under 103 million ha.

To support the program, the Ministry of Petroleum and Natural Gas enacted the National Biodiesel Purchase Policy, setting a price of Rs25 per liter, effective 1 November 2006.[17] The buyback program remains in effect, but the price was raised to

[11] Gopinathan and Sudhakaran (2009).

[12] Ministry of Petroleum and Natural Gas. 2002. Resolution No. P 45018/28/2000-CC.

[13] Gopinathan and Sudhakaran (2009).

[14] Gopinathan and Sudhakaran (2009) citing Ministry of Petroleum and Natural Gas. 2004. *Basic Statistics*.

[15] Planning Commission. 2006. *Integrated Energy Policy.*

[16] However, the National Mission on Biodiesel was not implemented.

[17] Ministry of Petroleum and Natural Gas. 2005. *Bio-Diesel Purchase Policy.*

Rs26.50 per liter in October 2008.[18] Because of difficulties across the industry the blending targets could not be met, but India became the world's leading jatropha producer in 2009, cultivating approximately 900,000 ha.[19]

The program was clearly ambitious, both due to the scale of the endeavor and the limited experience with commercial cultivation of jatropha. Being a wild tree crop, there is great uncertainty surrounding jatropha seed yields and input and cultivation requirements, and this uncertainty has inhibited market development.[20] Problems surrounding land tenure and rural livelihood benefits have further stymied the industry.[21] Reflecting this, the government broadened the biodiesel program to examine other non-edible oilseeds, such as pongamia, that could be grown on wasteland.

The National Policy on Biofuels

The December 2009 National Policy on Biofuels called for an indicative blending target of 20% by 2017 for both bioethanol and biodiesel.[22] Both targets are to be phased in over time and, until a plan is finalized, the current 10% (E10) bioethanol blending target will remain in effect. The Ministry of New and Renewable Resources is tasked with overseeing the program.

The blendiwng targets are the visible, salient features of the biofuel program. To understand what these programs mean in practice, we start by estimating the fuel requirements to meet 20% blending in 2017.For biodiesel, at an average annual rate of growth of 6%—the trend of 1999–2008—petroleum diesel consumption would be around 87.3 million tons by 2017.[23] To achieve the target of a 20% blend, the biodiesel requirement will be 20.54 million kiloliters (kl) per year. Petrol consumption has been growing even more rapidly, with an average annual rate of increase of 7.5% in1999–2008. Based on this, annual petrol consumption would be approximately 21.6 million tons by 2017. The bioethanol required to achieve the target of a 20% petrol blend would then be 5.76 million kl per year. These figures will be used below to define the scale of the projects for cost–benefit analysis.

[18] Cabinet Committee on Economic Affairs. 2007. *Relief to Sugar Industry and Sugarcane Farmers.*

[19] Global Exchange for Social Investment (GEXSI) (2008, 123).

[20] Achten, et al. (2008).

[21] Friends of the Earth Europe (2009).

[22] Ministry of New and Renewable Energy (2009).

[23] The cumulative average annual rate of growth in diesel and petrol consumption is from the website of the Ministry of Petroleum and Natural Gas, *Basic Statistics on Indian Petroleum & Natural Gas 2008–2009*.

Economic Viability of Biofuel Production

Public policy on biofuels, like any other economic venture, should be guided by the net gains to the society: the benefits of biofuels should exceed their costs. This section seeks to answer the question, "Is it economically desirable to encourage these industries?" To answer this, we undertake an economic analysis comparing costs and benefits to the economy as a whole, not just to the private sector operatives.

Economic Viability of Bioethanol

The bioethanol analysis focuses on three feedstocks: sugarcane, sweet sorghum, and sugar beet. Given that all of India's arable land is already under cultivation, bioethanol production cannot be undertaken without displacing other crops. For instance, when sugarcane used to produce sugar is diverted to produce bioethanol, there is an opportunity cost of the lost sugar production. Net social benefits are estimated as the economic value of bioethanol (resource cost savings due to substitution of bioethanol for petrol) minus the economic value of sugar. The other feedstocks are treated similarly.

Molasses-Based Bioethanol

As stated earlier, around 21.6 million tons of petrol will be consumed annually by 2017 and a 20% blending target would require 5.76 million kl of bioethanol per year. For the sake of analysis, we assume that half of this—2.88 million kl—is produced from molasses.[24] The total quantity of molasses currently produced in India is about 8.4 million tons per year, sufficient to produce 1.85 million kl. Molasses ethanol has alternative uses; it can be used in various industrial processes or as potable alcohol. If we use more bioethanol for transport, there is less available for these other uses. In 2010, the Indian Chemical Council estimated total ethanol usage in India to be 3.4 million kl, of which 41% is for potable alcohol and 29% is for the industrial sector. The remaining 30% is available for blending with petrol.

Every liter of bioethanol displaces 0.67 liters of petrol on energy parity basis. The market price of petrol as of March 2010 was Rs47.43 per liter. When we deduct net taxes and subsidies, and factor in the different energy contents in bioethanol and petrol, the shadow price, or economic value of bioethanol was estimated to be Rs19.07 per liter.

Table 1 provides a summary, comparing the benefits of using molasses to produce bioethanol against its economic costs. The results show that the net present value at March 2010 prices for molasses-based bioethanol is positive, as long as the molasses is not taken from industrial and potable alcohol uses. Adding in the opportunity value of diverted molasses results in negative net present values.

The clear message is that, at current prices, India should try to use only molasses bioethanol in excess of demand in other sectors for blending. How much will be available is uncertain, but if markets are allowed to clear properly, there will be some. This would have clear economic benefits. Interventions

[24] This assumption defines the scale of the analysis. The scale, however, does not affect the decision as to whether to accept or reject a particular biofuel based on economic efficiency.

Table 1 **Economic Analysis of Molasses-Based Bioethanol**

Scenario	Net Present Value (Rs million) 10% Discount Rate	12% Discount Rate	15% Discount Rate
Base Case	29,612	25,229	20,375
Base Case + Opportunity Cost*	(77,390)	(65,934)	(53,250)
Petrol price increase by 15%	95,426	81,300	65,659
Base Case + CDM benefits	32,348	27,361	21,873

( ) = negative, CDM = Clean Development Mechanism, Rs = Indian rupees.

* Opportunity cost factor in value of ethanol displaced from industry or potable uses.

Source: Estimates by the Author.

Table 2 **Economic Analysis of Different Feedstocks for Bioethanol**

Scenario: Net Present Value (12% Discount Rate)	Net Present Value (Rs million) Sugarcane Juice	Sweet Sorghum	Sugar Beets
Base Case	(234,875)	(40,028)	(24,402)
Petrol price increase by 40%	(121,706)	193,139	131,042
Base Case + CDM Benefits	(231,338)	(37,896)	(22,271)

( ) = negative, CDM = Clean Development Mechanism, Rs = Indian rupees.

Source: Estimates by the Author.

to blend bioethanol, such as mandatory blending requirements and guaranteed prices, however, should be applied with care to make sure only excess ethanol is used for transport.

This conclusion is, moreover, sensitive to the price of petrol. As shown in Table 1, petrol price increases of just 15% would render the use of molasses very desirable. Table 1 also shows the potential importance of carbon financing mechanisms. Even at current prices, if carbon credits (United Nations Clean Development Mechanism [CDM] payments) could be found to finance bioethanol, it would be economically reasonable. However under current rules, India's program for bioethanol production may not be eligible for this benefit. If the blending, operates under a mandatory blending requirement CDM benefits may not be realized; only the carbon reduction over and above a mandatory requirement will be eligible for CDM benefits.

Sugarcane Juice Bioethanol

As molasses would be insufficient to meet the full blending needs at the 20% level, we look at other feedstocks. This section undertakes an economic analysis of providing ethanol from sugarcane juice, without going through the sugar production process. One kilogram (kg) of fermentable sugar produces about 0.56 liters of bioethanol. The cost of producing sugar was estimated to be Rs23,723 per ton and the market value was taken as Rs30,000 per ton.

Table 2 shows the results of cost–benefit analysis of using sugarcane juice to make bioethanol. The results are clear: converting sugarcane juice to bioethanol is not economically desirable. Sugar is simply too valuable as a food product to use as a fuel. Adding CDM benefits does not change this basic conclusion. This situation does not change even if petrol prices rise by 40%. Thus, sugarcane juice bioethanol cannot be justified on economic grounds.

Sweet sorghum can be cultivated under harsh conditions, but it still has to compete for land and other resources with food or feed crops such as corn or millet. Sugar beet can require considerable water and soil nutrients to produce an economically attractive yield and it competes with crops like legumes or onions. The opportunity cost for sugar beet is higher than for sweet sorghum. For the sake of analysis, it is assumed that molasses-based bioethanol production meets 50% of the bioethanol requirements while the two other crops jointly produce the rest, with sweet sorghum contributing 30% and sugar beet 20% of the overall requirements. Table 2 provides a summary results of this joint cost–benefit analysis.

Similar to the results with sugarcane juice bioethanol, in both cases the costs of these alternative crops outweigh their benefits at March 2010 prices. Carbon financing, if available, would not make a credible difference. When petrol prices increase, however, these crops show some promise. It needs to be kept in mind that regardless of oil prices, these crops compete with food crops for land and other resources. Even if sweet sorghum or sugar beet pass economic and financial tests, they still conflict with the government policy of not compromising food crops security in order to promote energy crops.

Second Generation Biofuels

Biofuels can be classified as first generation or 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 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. In India, as discussed above, first-generation bioethanol fuels have limited scope as their economic feasibility is not promising, except for molasses-based bioethanol.

The impact of first-generation biofuels on food security has encouraged the development of second-generation biofuels, often produced from non-edible 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 commercial basis. Some examples include:

- **Cellulosic ethanol.** The feedstock is non-food 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.
- **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.
- **Bio-oil.** This is 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 as furnace fuel.
- **Renewable diesel.** Vegetable oils, including waste products from the commercial food industry, are processed to produce transport fuels.
- **Algae-based biofuels.** A wide range of technologies are being examined that use microbes to convert carbon dioxide into liquid fuel products. However, the research is 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, especially through the Department of Biotechnology, and the Ministry of Science and Technology have promoted research and development (R&D) in second-generation biofuels. Cellulosic ethanol technology, for example, will be used to set up a 10 ton per day biomass-based pilot plant with Indian Glycol, which is expected to produce about 3,000 liters per day of bioethanol. The plant trials are expected to develop necessary 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 crop residues from sugarcane, 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, stalks, 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.[25] 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 and do not compromise food security. Currently, however, technical barriers mean that these are high-cost fuels which have yet to prove their commercial viability.

Economic Viability of Biodiesel

For biodiesel it was assumed that all crops were cultivated using wasteland or fallow land without any productive present use. Therefore, there is no opportunity cost for the land—biodiesel crops do not compete with other crops for this resource. As in the case of bioethanol, financial costs along the supply chain were aggregated and converted to economic costs. Resource cost savings were estimated based on the quantity of displaced diesel. If the targeted 20% blending of biodiesel is achieved by 2017, about 20.54 million kl of biodiesel should be produced annually with production gradually increasing from the current period.

It was assumed that 60% of the biodiesel would be produced from jatropha while the rest would come from pongamia, simply because there is a better information base in the case of jatropha. The shadow price of diesel was estimated by starting with the March 2010 market price (Rs38), deducting the excise tax and educational levy (Rs4.47 per liter) and the value added tax (Rs4.20), and adding the "under recovery" subsidy payment (Rs2.89) to oil marketing companies (OMCs).

Table 3 presents the results of the joint economic analysis of producing biodiesel to meet a 20% blending mandate. The base case provides a 14.9% economic internal rate of return (EIRR) which is higher than the government's cut-off rate of 12%. The inclusion of some carbon benefits increases the economic attractiveness and the net present value becomes positive even at a 15% discount rate. Overall, the results show that biodiesel is economically feasible but the benefits are sensitive to social discount rates and cost increases. As diesel prices increase, the economic benefits become larger. Given the likelihood of oil prices rising, the results warrant promoting biodiesel in India.

The economics of biodiesel are very different from those of bioethanol because both jatropha and pongamia provide acceptable returns and increases

Table 3 **Biodiesel Economic Analysis**

		NPV at Varying Discount Rates (Rs million)		
Scenario	EIRR (%)	10%	12%	15%
Base case	14.85	398,364	151,297	(6,177)
Petrol price increase by 40%	26.48	855,441	550,279	322,670
Base case + CDM benefits	20.10	841,567	468,302	220,247

( ) = negative, CDM = Clean Development Mechanism, EIRR = economic internal rate of return, NPV = net present value, Rs = Indian rupees.

Source: Estimates by the Author.

[25] Government of India, Ministry of New and Renewable Energy. *Biomass Resource Atlas of India 2004–2005*. Delhi.

in the diesel price make them economically more attractive. If confined to wasteland with irrigation only at planting, biodiesel will not compete with food crops for land or water in any significant manner. Therefore, the results support an aggressive program for biodiesel production in India. While the economics of biodiesel are promising, they are based on a major assumption that about 32 million ha of wasteland can be put under oilseed plantation. The biodiesel industry in India is at an early stage of development and an enormous amount of work needs to be done to create an enabling business environment for India to meet its biodiesel production target.

Economy-Wide Impacts of Biofuels

Much of the earlier discussion has focused on the economic viability of biofuels. This analysis was undertaken in a partial equilibrium setting.[26] In this section we take a broader view. Biofuels can have a huge impact on national development, especially through poverty reduction and employment generation. This is especially true for biodiesel crop cultivation and processing involving small farmers. We sketch out the possible increase in employment due to biofuel development. It gives a useful first look at the implications of encouraging biofuels.

To give a more complete picture, the economy-wide impact of biofuel production and use is examined using computable general equilibrium (CGE) models that calculate market-clearing levels of supply and demand across the economy as policy actions are taken, while accounting for the interactive affects amongst different sectors.

Employment—First Estimates

From a social perspective, the major impact of biofuel production could be job generation in poorer regions. Starting with bioethanol, sugarcane is a labor-intensive crop, but unless sugar cultivation is increased, only a small number of new jobs would be created in molasses processing for bioethanol manufacture. Interviews have shown that about 80 to 100 workers are employed by a typical bioethanol plant producing 30,000 liters per day. For sweet sorghum and sugar beet, in a typical facility of similar capacity, the employment figures might be 10% greater. Based on these rough figures, about 120,000 jobs will be created by the bioethanol industry if output expands to support blending at 20%.

For biodiesel, assuming that an established 1 ha oil seed crop requires about 140 person-days per annum for maintenance and seed harvesting, the employment generated was estimated to be 16 million jobs. The estimated national goal of 20% diesel blend by 2017 could generate about 2.3 million jobs each year in the rest of the biodiesel supply chain. Altogether 20% blending of biodiesel will create about 18.3 million jobs, many of them in rural areas.

Also important is the type of employment which might be generated, and whether there will be differences in the opportunities for women and men. For biodiesel, field observations in several states revealed that women were employed in large numbers during the nursery development stage, planting, adding fertilizer, pruning, and collecting seeds; whereas men were employed largely to work the land and in watering. In transport, seed processing, and biodiesel manufacturing, men are employed in larger numbers than women. Overall there would seem to be rough gender parity in biodiesel manufacturing across the value chain in terms of the numbers of people employed. The same cannot be said about wage parity as women are paid less than men. In the manufacturing of bioethanol, as the majority of employment is created at the distillery stage, men tend to be employed in larger numbers than women.

[26] Partial equilibrium analysis considers only the sector of the economy under consideration and ignores the interactive effects with other sectors of the economy.

Computable General Equilibrium Modeling of the Impact of Biodiesel

Introduction to Computable General Equilibrium Modeling

In a CGE model, economic decision making is pictured as the outcome of decentralized optimizing by producers and consumers within an economy-wide framework. A variety of substitution mechanisms are specified, including among labor types, between capital and labor, between imports and domestic goods, and between exports and domestic sales, all occurring in response to variations in relative prices. These models

- allow simulation of the functioning of different markets in the economy, including for labor and capital as well as for a variety of commodities;
- permit consideration of new markets or products such as biodiesel;
- ensure that all economy-wide constraints are respected, for instance ensuring that only a given amount of jatropha planting can be undertaken, respecting limitations on the use of land; and
- are able to show how different policies and actions will interact, and welfare indicators such as gross domestic product (GDP) growth and income can be quantified.

Two CGE models were developed for this work, the first covering the Indian economy, and the second a global model. The first model examines the one-time impact of increasing biodiesel production to the level of 20% blending. At this level of analysis, the two biodiesel feedstocks—jatropha and pongamia—are very similar and hence the analysis here considers only jatropha. The second model uses a dynamic approach and, incorporating international trade, examines the impact of blending at the 20% level of both bioethanol and biodiesel. The second model also examines other policies available to the Government of India for counteracting energy price hikes.

A Computable General Equilibrium Model of the Indian Economy

The model of the Indian economy consists of 30 sectors or commodities, consisting of 9 agriculture-related sectors, 7 service sectors, and 14 manufacturing sectors. Four factors of production are identified: 2 types of labor (unskilled and skilled), land, and capital. Within the CGE model, feedstock cultivation and the processing sectors of biodiesel are modeled as separate entities. Although processing consists of two stages—extraction and transesterification (chemical oil processing)—in the model both are included in one biodiesel sector.

The analysis is based on a static CGE model with FY2006 chosen as the base year. Since India is a small player in the global energy market, it is assumed that the country is a price taker, with changes in its supply and demand having little impact on world markets and prices. Most resource endowments (land, capital, and skilled labor) are fixed and there is full employment of these factors—at equilibrium the supply of factors or commodities must be equal to their demand. Barring land, we have assumed that there is full mobility of factors between sectors, so the returns are the same across sectors. However, land is assumed to be a sluggish factor, which is immobile across sectors. This is a realistic assumption since it takes a long time to change land use from one crop to another.

Contrary to other resources, in some scenarios we have assumed that the supply of unskilled labor is not fixed. India is a labor surplus economy. So, we have looked at how the economy would behave if there were an infinitely elastic supply of unskilled labor at any given real wage. This "infinite supply" of unskilled labor in rural India is changing as a result of the country's recent rapid economic growth. Agricultural operations have already been affected due to seasonal shortages of unskilled labor in many parts of India, and there is seasonal variation in agricultural wages. In these areas, biofuel plantations would increase the demand for unskilled labor and stimulate a further rise in their wages. To reflect this, in some scenarios we have assumed a fixed number of unskilled workers.

We consider three policy scenarios for our modeling:

- **Scenario 1: Base case.** The area under jatropha cultivation increases from the initial year's value to the final target amount of 32 million ha. It is assumed that the increased land comes from the pool of fallow land, wasteland, or degraded forest with no alternative use.
- **Scenario 2: Base case plus productivity increases.** Productivity rises 20% due to improved tree varieties, better access to fertilizer, and better agricultural practices.
- **Scenario 3.** Scenario 2, but with the added assumption that the supply of unskilled labor in the economy is fixed. In this case, it is the real wage of unskilled workers that changes.

The results show clear benefits for the economy of encouraging biodiesel. Underlying this is the assumption that there is an increase in the endowment of land, i.e., jatropha uses wasteland that otherwise is unused. Apart from land, the principal input required for jatropha is unskilled labor, which in some scenarios is assumed to be infinitely elastic. Thus, economic intuition indicates that the increased cultivation of biodiesel crops would not compete with other agricultural products for resources.[27]

Table 4 summarizes the results for the three different scenarios, showing that in each, GDP increases by 0.74%–1.00%. The smaller result for Scenario 3 reflects the competition that results for the services of unskilled labor, which must now be allocated to biodiesel at a cost to the other sectors. There is a small increase noted in the federal deficit of 0.26%–0.28%, flowing from increased subsidy payments for fertilizers as agricultural production grows, but also as some payments need to be made in the biodiesel sector to keep prices aligned with lower petroleum diesel prices. This increase is from the original deficit, not a percentage of GDP, and is therefore not significant. In the scenarios in which we assume that unskilled labor expands to meet rising job opportunities, employment increases by 30 million to 33 million, somewhat larger than the first estimate reported above. As most of these jobs will be in the rural sector, biodiesel could be a

Table 4 **Impact of Jatropha Cultivation on the Indian Economy**
(Computable General Equilibrium Model)

Change in Variable from Base Case	Scenario 1 (%)	Scenario 2 (%)	Scenario 3 (%)
National Income (Rs million)	360,878	374,845	278,095
GDP (%)	0.95	1.00	0.74
GDP (Rs million)	376,842	393,004	290,397
Real Returns to Land (%)	1.72	1.74	1.41
Real Returns to Unskilled Labor (%)	…[a]	…[a]	0.48
Real Returns to Skilled Labor (%)	0.81	0.84	0.44
Real Returns to Capital (%)	0.64	0.71	0.48
Fiscal Deficit (%)	0.27	0.28	0.26
Reduction in GHG Emissions (million tons)	12.12	13.21	11.11
Employment (million)	30.11	33.21	…[a]

… = not applicable, GDP = gross domestic product, GHG = greenhouse gas, Rs = Indian rupees.

[a] Not applicable as the quantity or income is fixed.

Source: Estimates by the Author.

[27] This is also why bioethanol is less advantageous; increases of bioethanol feedstocks compete with food crops. For this reason, bioethanol production has not been explicitly modeled in this section. On balance it is not attractive for the Indian economy.

Table 5 **Cross-Sectoral Impacts of Biodiesel Intervention** (% change)

	Scenario 1		Scenario 2		Scenario 3	
Sector	Output	Price	Output	Price	Output	Price
Paddy	0.29	1.29	0.31	1.30	0.18	0.88
Wheat	0.33	0.87	0.35	0.91	0.22	0.59
Cereals	0.30	1.17	0.31	1.18	0.21	0.82
Cash crops	0.09	1.10	0.11	1.14	0.05	0.77
Petroleum Products	0.84	(0.08)	0.87	(0.10)	0.62	(0.03)

( ) = negative.

Source: Estimates by the Author.

powerful instrument to meet the government's goals for enhancing development in rural areas of the country. Finally, there is a clear environmental benefit as GHG emissions drop by 11 million to 13 million tons as a result of encouraging production and use of biodiesel.

Table 5 shows price and output effects of the biodiesel expansion on other sectors of the economy. Results show that there is no significant food price inflation due to biodiesel intervention. The negative price impact of the petroleum products shows that for the overall energy economy 20% blending of biodiesel is not large enough to reduce prices significantly.

An International Computable General Equilibrium Model

One of the major reasons for interest in biofuels comes from the hope that India can lessen its vulnerability to international energy price shocks. To assess this, we use a global forecasting model: a multiregion, multisector, dynamic, applied general equilibrium model—a version of the World Bank's LINKAGE model. The model assesses the complex domestic and international effects of a modern economy. In particular, the analyses examine how international food and fuel trends interact with domestic policy options open to India. For this report, the model has been defined for an aggregation of 13 countries or regions and 10 sectors, including sectors of importance to India—grains, textiles, and apparel.

To better understand the influence of global energy price uncertainty on the Indian economy and options available to policy makers, we consider a range of scenarios. The first of these is a business-as-usual reference case assuming a 50% increase in the price of oil and natural gas by 2030.[28] We then look at four alternative policy scenarios. Scenario 2 assumes a scaling up of biodiesel production to meet 20% blending. Scenario 3 adds a similar development of the bioethanol industry. Scenario 4 adds improvements in energy efficiency by 1%, and scenario 5 adds food sector productivity of 1% annually to Scenario 3, full biofuel development.

A modest increase in oil price will have a significant negative impact on the Indian economy. As shown in Table 6, biodiesel intervention has the ability to offset these negative impacts significantly, though not completely.

In conformity to the cost–benefit analysis results, bioethanol has minimal or no offsetting impacts on the adverse effects of oil price hikes. A comparison of the results in scenario 3 with those in scenario 2 clearly demonstrates this. This is because, in India, increased bioethanol production requires agricultural resources that would have been used in other sectors. While bioethanol production has some specific positive impacts—such as less GHG

[28] We used a modest oil price increase in this analysis. Most of the predictions show oil price increasing by 50%–100% during the next 2 decades. Biodiesel intervention in India will not be sufficient to offset the impacts of oil price increase by 100%.

Table 6 **International Computable General Equilibrium Modeling Results** (% change)

Item	S1: Base Case of 50% Energy Price Shock	S2: S1 + Biodiesel	S3: S2 + Bioethanol	S4: S3 + Energy Efficiency	S5: S4 + Food Sector Productivity
Real GDP	(4.8)	(0.5)	(0.5)	(0.4)	2.9
Exports	(4.1)	(0.9)	(1.0)	2.4	1.3
Imports	(9.3)	0.0	(0.1)	2.7	3.2
Consumer Price Index	3.0	0.7	0.8	4.6	1.7
Food CPI	(2.6)	0.4	0.6	1.9	(11.9)
Energy CPI	48.6	5.4	5.8	(9.0)	0.4
Real Household Income	(4.7)	(0.4)	(0.4)	2.3	4.2
Real Wages	(5.9)	(0.2)	(0.3)	3.7	7.9
GHG Emissions	(26.2)	(6.7)	(7.5)	(18.1)	(15.6)
Food Imports	(8.3)	2.3	3.0	9.5	(29.5)

( ) = negative, CP1 = consumer price index, GDP = gross domestic product, GHG = greenhouse gas, S1 = scenario 1, S2 = scenario 2, S3 = scenario 3, S4 = scenario 4, S5 = scenario 5.

Source: Estimates by the Author.

emissions—it reduces resources available for other sectors, including food.

Overall, the development of biodiesel, especially the use of wasteland to produce biodiesel, can have a significant impact on energy security through the increase in domestic energy supplies. However, much more can be accomplished if other policies are combined with this supply-side approach. The development and diffusion of more efficient technologies (scenario 4) for energy use could multiply this impact. Even with only modest improvements of 1% annually, energy efficiency can be a potent catalyst for employment creation and growth.

The introduction of more efficient technologies entails costs—R&D and the capital investments of diffusing energy-efficient techniques through the economy to households, farms, and firms—but the benefits are far-reaching and lasting. Energy efficiency moderates energy price inflation and adverse real income effects while creating jobs elsewhere in the economy. Moreover, energy efficiency improvements can more than double the reduction in GHG emissions generated by developing the biofuel sector. Scenario 4 (adding energy efficiency to biofuels development) results in an 18.1% decline in GHG emissions. This is a very significant impact, and shows that slowing the rise in GHG concentrations in the atmosphere can be compatible with robust growth and development, given the right mix of policies.

One interesting result of the modeling exercise is the projected impact on food security, as measured by food imports. In the base case (scenario 1), the loss of income and growth due to higher international oil prices reduces food imports, but this is a poverty-induced fall in dependence on foreign food sources. Biofuels and energy efficiency reverse the falloff in income, leading to higher food imports. Food imports increase by 9.5% in scenario 4.

A third line of attack, addressing both energy and food security, is captured in scenario 5, where public resources are targeted at both energy efficiency and food sector productivity. The scenario 5 simulation results show that most macroeconomic indicators have improved: real GDP, consumption, employment, and other variables related to living standards rise substantially. At the same time, imported food dependence falls by nearly 30%, food prices are substantially lower, and we can expect that national health indicators would improve accordingly. Energy imports still fall relative to the baseline, but somewhat less because of economic expansion. Overall, combining the development of biofuels—especially biodiesel—with energy efficiency and food sector productivity we have a virtuous cycle of greater national self-sufficiency in food and energy, higher incomes and employment, and lower GHG emissions.

How feasible is the last scenario? Data on other countries (Table 7) suggest that the right policy initiatives can do as well or better than we have assumed. The economy of the People's Republic of China (PRC), for example, has experienced annual increases in agricultural output to the order of 4% during 1970–2006. In previous decades the Indian economy has shown that agricultural productivity can be substantially increased through public sector interventions.

More importantly, addressing agricultural productivity means we can reduce the essential tension between developing biofuels and food security. As discussed at the beginning of this report, the Government of India is very sensitive to the availability and cost of food, especially for the poor. An aggressive program to increase food productivity—repeating in some sense the successes of the Green Revolution—will not only advance food security, but can ease the impact of biofuel development on the economy, while also advancing energy security.

Table 7 **Increases in Agricultural Output in Selected Regions** (%)

	1970–1979	1980–1989	1990–1999	2000–2006
Developing countries	2.82	3.46	3.64	3.09
Latin America and the Caribbean	3.07	2.37	2.87	3.13
South Asia	2.56	3.39	3.00	2.19
Southeast Asia	3.68	3.59	3.13	3.54
Brazil	3.83	3.73	3.29	4.41
People's Republic of China	3.09	4.60	5.17	3.87
India	2.69	3.52	2.94	2.00

Source: Jha et. al 2010.

The Potential for Biofuel Production in India

This section provides a sense of the potential for biofuel production in India by looking at the natural resource needs—both land and water—and also at issues of technology, pointing out where research and development efforts are particularly needed. The previous discussion described the potential social welfare improvement with biodiesel development and lack of such improvements with bioethanol, except for molasses-based ethanol. Therefore the following discussion mainly focuses on biodiesel while also briefly addressing bioethanol issues.

Natural Resources Availability Assessment

Land Requirements for Biodiesel

The primary crops for producing biodiesel are the jatropha curcas and pongamia pinnata, oilseed-bearing trees that can be grown on wastelands and require little water, reducing any conflict with food security. Of the total land area of India (328.7 million ha), about 16.8% is wasteland.[29] Of this total, approximately 32.3 million ha would be suitable for growing these oilseeds. In addition to wastelands, other unused lands, including agricultural border fences, hedgerows, and land along roads, railways, and canals, might total a further 8 million ha.[30]

These estimates of the availability of wasteland for biofuel production are only theoretical. The practical availability of any particular piece of land for biofuel plantations depends on a number of factors including its slope and soil quality, ownership, and access to infrastructure such as roads and electricity. A full land-mapping exercise is needed to assess actual land availability for biodiesel production in India.

These estimates of land available for biodiesel crops provide an upper bound to the supply of land. Total land demand would depend on the productivity of the plantation, which varies depending on the climate, the quality of the planting material, and plantation management practices such as the use of irrigation water and fertilizer. Under a relatively pessimistic scenario (yield of 1 ton per ha and 30% oil content), 63.8 million ha of land are required to meet the 20% blending goal. Under a more optimistic scenario (yield of 3 tons per ha and 30% oil content), the land requirement by 2017 will be about 21.3 million ha. This huge variation indicates the importance of finding high-yielding varieties and developing better agronomic practices.

Land Requirements for Bioethanol

By far the dominant feedstock for the production of bioethanol has been molasses, which is a by-product of producing sugar from sugarcane. In the past decade, India produced about 8.4 million tons of molasses per year. On average, looking across the sharp fluctuations that occur in the sector, sugar production has been growing at about 4.5% over 1999–2008. This growth rate would allow molasses production to increase to 17.6 million tons by 2017.

[29] Government of India, Ministry of Rural Development. 2005. *Wasteland Atlas of India.* Delhi.

[30] Estimates come from Planning Commission (2003) and Central Intelligence Agency, United States Government (2009).

This could support a 11.6% blending with petrol, if fully used as transport fuel. However, the use of the total national production of bioethanol for transport is neither likely nor recommended because the chemical has other high-value uses in industrial processes and in potable alcohol. For the purposes of analysis in this section, we assume that molasses will be used to meet a 5% blending ratio.

The use of sugarcane juice is an obvious choice as an alternative feedstock. For the purpose of assessing land resource requirements, we use the average Indian yield of sugarcane at about 70 tons per ha, producing about 4.9 kl per ha of bioethanol. In this case, if molasses is used for 5% blending, we would need to use sugarcane juice from about 0.9 million ha of sugarcane land to meet the 20% blending target. This is a substantial fraction of the total land being devoted to sugarcane cultivation, which fluctuated between 4.2 million ha in FY1999 and 5.2 million ha in FY2006. If 0.9 million ha of sugar lands are diverted to bioethanol production, sugar production will be reduced by about 6.3 million tons per year. Importing of this amount of sugar will cost about Rs99 billion per year.

One key assumption used in the economic and natural resource availability analyses is that biodiesel crops will be grown in waste or fallow lands and there is no displacement of food crops. This approach has merit in a stable market environment, but if the prices of food, land, or both were to escalate significantly, marginal or waste lands might be reclaimed to produce food. In such situations, biodiesel crops would compete with food crops. Incentives and a stable, conducive business environment for biodiesel also might induce conversion of food lands for biodiesel crops, undermining food security. Likewise, today's food cropland could be expanded if the relative price of food is high enough to justify investments in land reclamation, forest conversion, or other expansions of farming. To a growing extent, these dynamics may be driven by forces external to India as an emerging middle class triggers greater food import dependence. Therefore, any program to support biodiesel should factor this in and incorporate additional policy measures to ensure that food security is not jeopardized by biodiesel expansion.

On one hand, there are suitable policy measures, such as land certification for biodiesel incentives, taxes on biodiesel (under high oil price scenarios), and additional incentives to agriculture sector, to prevent adverse impacts of biodiesel expansion on the food sector. On the other hand, biodiesel expansion, in the very long run, can benefit the agriculture sector. Converting wastelands into oil seed croplands is similar to a land reclamation program that prevents natural decay of lands. Limited irrigation and incorporation of organic wastes of oil seed crops into soils will improve soil fertility over time. After one cycle of biodiesel crops, these lands can be used for horticultural crops if prevailing economic conditions permit such a change. In that sense, adding about 32 million ha to agricultural lands in India would enhance the agricultural resource base significantly.

Assessment of Water Requirements for Biofuels

The introductory discussion noted the limitations of the country's water resources. In particular the uneven distribution of water poses serious challenges to increasing agricultural production in areas where water availability is already limited. Moreover, there is some evidence that areas that have experienced successful programs for increasing agricultural productivity may be tapping water resources in an unsustainable fashion. For example, some observers note that the states of Haryana and Punjab may be depleting their groundwater.[31]

In terms of water consumption, 83% of India's available water is devoted to agriculture, mostly in the form of irrigation. With the demand from other sectors rising at a fast pace, the competition for

[31] Nandakumar, et al. (2010).

available water sources will increase. World Bank projections[32] suggest that the demand for water for industrial, energy production, and related uses will rise from 1999 levels of 67 billion m^3 to 228 billion m^3 by 2025. Demand from the domestic sector will likewise increase strongly, from 25 billion m^3 to 52 billion m^3. It is against this likely increasing competition for water resources that the needs of the biofuels sectors must be analyzed.

Water Requirements for Bioethanol

The major need for water for bioethanol is in crop production—processing requires comparatively little water. Sugarcane in particular requires considerable water to grow, 200–300 m^3 per ton. The water required for sugarcane varies from 1,400–1,600 millimeters (mm) per ha per year for subtropical regions, to 1,700–3,000 mm per ha per year in tropical areas. Generally, sugarcane is cultivated in states such as Andhra Pradesh, Bihar, Karnataka, Maharashtra, Tamil Nadu, and Uttar Pradesh, where rainfall is around 550–700 mm per year and therefore, irrigation has to be provided.

From the standpoint of final fuel production, the water requirements per liter of bioethanol for sugarcane are 4.1 m^3 against 1.8 m^3 for sweet sorghum and 2.1 m^3 for sugar beet. The water requirements for sugarcane are 50% higher than for either of the other feedstock crops. However, as noted above, sweet sorghum and sugar beet are not credible candidates for large-scale cultivation in the near term.

The overall impact of sugarcane-based bioethanol production on water resources depends on how the bioethanol target is achieved. If the additional bioethanol comes from utilizing sugarcane that would otherwise be used for sugar, then there is no net impact on water (or land) resources—there is an impact on food supply through diminished sugar supplies. If new land is brought under sugarcane cultivation the impact will depend on what type of land is being diverted. If land used for water-intensive crops such as rice is converted to sugar for the production of bioethanol, the incremental increase may be relatively little. If the displaced crop is less water intensive than rice or sugarcane, the shift may require a considerable increase in water inputs.

Opportunities exist for productivity improvements. The common practice of flood irrigation utilizes only about 35%–40% of the water provided, with the rest wasted. Here, as in many other areas, productivity improvements could reduce the competition for resources from biofuel production.

Water Requirements for Biodiesel

Relative to the crops discussed above, oilseed trees (jatropha and pongamia) do not generally require significant irrigation. Water is required at the nursery for growing seedlings and saplings. Certain studies suggest that on average one jatropha plant requires 2 liters of water per round of watering for perhaps 10 rounds, which means that 1 ha of jatropha would require as little as 50 m^3 of water per year. If the saplings are grown for 4 to 6 months they will not require additional irrigation if they are planted in the monsoon season in areas with reasonable rainfall (600 mm and above). In case there is a drought or the area is deficient in rainfall, some irrigation may be required in the first 2 years. Pongamia has the advantage that, since the roots go deep into the ground, it can survive with lower rainfall once established.

Given the variability of climate and soil conditions and lack of field research findings, it is hard to estimate what the additional water requirements would be at a national level for any given level of biodiesel production. The general characterization is that, based on the nature of the trees and the environment in which they grow, biodiesel crops would probably not exert significant pressure on water consumption in India.

[32] These World Bank figures are quoted from Center for Science and Environment. 2004. It Isn't Agriculture: Water Use is Increasing and it is Industry that is Taking it Up. *Earth Magazine*. 15 February. www.cseindia.org/dte-supplement/industry20040215/agriculture.htm

Technological Challenges

Almost all of the country's feedstock for bioethanol has been from molasses, although a few companies have taken the first steps toward using alternatives. All feedstocks face technological challenges:

(i) **Molasses.** A key technological constraint in the use of molasses is the effluent, or liquid waste, which has a high organic content. It can be used as a fertilizer during irrigation but not throughout the rest of the year, and it requires a large amount of irrigated land to take the output of a typical plant. It is possible to compost this waste but this cannot be done in the monsoon season. The related use of sugarcane juice faces the issue that it cannot be stored, but must be processed soon after harvest. This necessitates investments in processing capacity that can be used only for a short period of time.

(ii) **Tropical sugar beet.** This crop has been introduced only recently in India and the technology for processing it is still maturing. Constraints to widespread use include poor sugar extraction, perishability of the crop, and the need to extract sugar quickly after harvest. As a result, mills can only be operated for a few months of the year. Without other feedstocks, this may make processing units financially unattractive.

(iii) **Sweet sorghum.** This is a crop with a sugar-rich stalk similar to sugarcane. It has a short crop cycle of 4 months and provides grain as well as sugar. Sweet sorghum is reputed to have wide adaptability, rapid growth, and high sugar content, as well as being water and fertilizer efficient. However, there has been little field experience in India. The main constraints are the low sorghum yield, and the requirement to extract juice and ferment it within a short period of time.

Feedstock development for biodiesel in India is at an early stage, and aggressive R&D is needed if the sector is to meet the targets set out in the biofuel policy. Jatropha and pongamia have been domesticated recently and high-yielding varieties have not been identified. Being a wild plant, there is great variability of yield and oil content and reliable information on yields is lacking. Current jatropha plantations comprise, at best, marginally improved wild plants.[33] Although current yields are low, there is ample opportunity to apply available Green Revolution technologies to realize the untapped potential. Better-yielding trees can be selected and vegetative propagation or tissue culture can be used to multiply them to obtain a significant increase in yields.

One of the biggest problems is that many such activities will not be undertaken by the private sector, especially at the initial stages of the biodiesel industry. The public sector has to undertake most of the R&D activities to ensure that the industry can take off.

In spite of inadequate progress in oil seed crop variety development, processing plants have been established that are designed to use a variety of inputs. This relatively new industry is estimated to have a total capacity of about 1 million tons per year. Many of these plants are based on imported crude palm oil and related products. Some plants also use fish oil and recycled commercial oil. Most of the plants are either set up in special economic zones or as 100% export-oriented units, located in Andhra Pradesh or West Bengal. Although there are technological constraints, the main issue in the commercial development of biodiesel in India is the availability and yield of the feedstock.

[33] Brittaine and Lutaladio (2010).

Biofuel Supply Chains and Financial Viability

For biofuels to play a major role in the Indian economy, a vibrant private sector will need to be present that can produce and distribute the fuels. This section describes the supply chains for biodiesel and bioethanol in India and identifies the major bottlenecks that must be removed for the sectors to perform. The discussion also examines whether adequate financial incentives are available for the private sector to profitably operate in all segments of the supply chain.

Biodiesel Supply Chain and Profitability

The key elements of the biodiesel supply chain are given in Table 8, together with the critical bottlenecks at each segment. The biodiesel supply chain shares a number of formal similarities with the bioethanol supply chain, however, processing biodiesel includes the need to chemically transform the oils transesterification.

Table 8 **Supply Chain Bottlenecks for Biodiesel from Jatropha and Pongamia**

Supply Chain	Stakeholders	Major Critical Bottlenecks
Nursery	R&D institutions, seed development companies, agricultural universities	• Lack of high-yielding varieties and quality planting material, and high variation in yields
Plantation	R&D institutions, agricultural universities, fertilizer and pesticide companies, farmers, farm workers, agriculture extension workers, governments	• Land availability and allocation • Agronomic (plant and soil management) practices not fully developed • Absence of adequate prices for seed • Long gestation period, lack of revenue in first years • High harvesting costs
Transport	Farm owners and workers, cooperatives, state forest departments	• High transport costs
Oil Extraction	Industry enterprises, state nodal agencies, traders	• Lack of adequate supply of seeds • Dispersed production limits scale economies
Transesterification	Industry enterprises, state nodal agencies, OMCs, oil technology companies	• High cost of transesterification due to low capacity utilization • Shortage of feedstocks • Dispersed feedstock production limits scale economies
Blending or Retailing	OMCs, governments, automobile companies, consumers	• Unremunerative prices set by OMCs • Lack of timely revision of prices • Opposition of OMCs to direct retailing of biodiesel by others

OMC = Oil marketing companies, R&D = research and development.

Source: Compiled by the author.

Plantation Stage

Supply Chain Constraints.

Lack of high-yielding varieties. This is one of the biggest constraints for the sector. Although both trees have long been present in the wild, systematic analysis of them has begun only recently. Present strains are generally low yielding and there is high variability among the plants. A study by the Food and Agricultural Organization of the United Nations suggests that the potential yield for jatropha in a typical Indian setting (the semi-arid conditions in Andhra Pradesh) is 1.0 tons per ha.[34] At this level, large-scale commercial cultivation of biodiesel crops may not be viable. However, field observations reveal that some plants give much higher yields. Selection alone can provide significant yield improvements given that the yield potentials are untapped.

Lack of quality planting material. Nurseries have yet to be established to make seedlings and saplings available to farmers, although some state governments, such as those of Andhra Pradesh, Chhattisgarh, and Uttarakhand, are providing seedlings free or at nominal cost. This lack of access is a key impediment to biodiesel feedstock cultivation.

Availability of land. In India, cultivation of biofuel crops is to be taken up on fallow or wasteland. The public sector needs to play a role in identifying and allocating this land. However this may be challenging as land in India is often disputed and litigation is common and time-consuming. Privately owned wastelands can be allocated for biodiesel production only if adequate profitability is assured.

Lack of commercial experience. Jatropha and pongamia lack records of mature plantations. There is considerable uncertainty concerning the agronomy, pest and diseases, fertilizer responsiveness, and irrigation water requirements at the field level.

Low minimum support price for jatropha seed. The price of seeds offered in most states is not high enough for seed collectors to earn even minimum wage. Growers also find that the administratively set price is not adequate to make a profit. Because of this, seeds are not being gathered, for example, in plantations across Chhattisgarh. The network for seed procurement also needs to be organized. The financial analysis further demonstrates this.

Financing. Jatropha and pongamia have long gestation periods with limited or no returns in the early years. Without financial support, it is almost impossible for poor farmers to take up the planting of these tree crops. In addition, the lack of commercial experience means there is tremendous risk for farmers. The problem of risk mitigation and financing will need to be faced at the industry level, likely with state support.

Financial Viability of Biodiesel Plantations

The financial viability of biodiesel is based on its input costs against income from the sale of products. Most importantly, the prevailing minimum support price is inadequate to earn a reasonable income for growers. For instance, the Rs6 per kilogram price for oil seeds in Chhattisgarh yields an financial internal rate of return (FIRR) in the range of 13%–15%, which is lower than the expected rate of return of 16%–18%. The financial analysis suggests the sales price of jatropha oil seeds should be set at a minimum of Rs7.5 per kilogram and of pongamia oil seed at Rs8.5 per kilogram to yield an acceptable financial rate of return for producers.

Processing and Blending

Bottlenecks in the Production of Biodiesel

Dispersed feedstock production. Widely scattered oil seed production creates challenges for firms to achieve reasonable economies of scale for extraction and transesterification facilities.

Technology selection. Different technologies, such as solvent or mechanical extraction, have a direct bearing on the cost of production. The uncertainty of information on the properties of future feedstock makes reliable decisions very difficult to make.

[34] Brittaine and Lutaladio (2010).

Low prices for biodiesel. OMCs initially offered a procurement price of Rs25.00 per liter for biodiesel. When no supplier was forthcoming, this price was increased to Rs26.50 per liter. However, even this price appears too low in relation to the costs of producing seeds and processing, as up to the time this report was drafted (December 2010) no biodiesel had been supplied to OMCs.

Controlled markets. OMCs are reluctant to allow biodiesel producers the freedom to directly retail biodiesel to consumers. This limits the ability of producers to develop markets and maintains the inflexible pricing structure. This situation requires further analysis.

The biodiesel supply chain is complex as it depends on a wide variety of inputs from multiple stakeholders. It is in an early stage of development. Nurseries and plantations need immediate attention. Without high-yielding varieties and a proper understanding of suitable agronomic practices, the industry cannot take off. Processing and other downstream segments could develop if upstream technical and pricing issues are resolved.

Financial Viability of Biodiesel Processing

An analysis of the financial viability of biodiesel production needs to focus on (i) oil extraction or the production of straight vegetable oil (SVO), and (ii) the conversion or *transesterfication* of SVO to biodiesel.

Production of straight vegetable oils. Processing the seed and extracting the oil produces SVO and oil cake. Oil cake is used as an organic fertilizer or as fuel for power generation. As a common practice, the oil extraction units are set up close to farms to minimize the transport cost of bringing oil cakes to the growing areas. The feedstock is the largest contributor to the overall cost; therefore, any small change in the market price of feedstock will drastically change project viability. Moreover, the market price of SVO is linked to the market price of oil cake. At likely prices for seed cake (Rs2–Rs3 per kilogram) and seed (Rs7.5–Rs8.5 per kilogram, including Rs1 per kilogram transport charge), achieving an FIRR of 18% would require a price for SVO of Rs27–Rs28 per liter. A few states have announced a support price of SVO at Rs16 per liter, which is too low for financial viability. Currently, oil extraction is not a viable investment in these areas.

Production of biodiesel. The next stage in biodiesel production is transesterfication—processing of the vegetable oil to produce a fuel that can be blended with diesel. This stage produces glycerol as a by-product. The transesterfication technology for processing SVO is commercially proven and well established, so the current technical parameters can be assumed as standards for all types of plant.

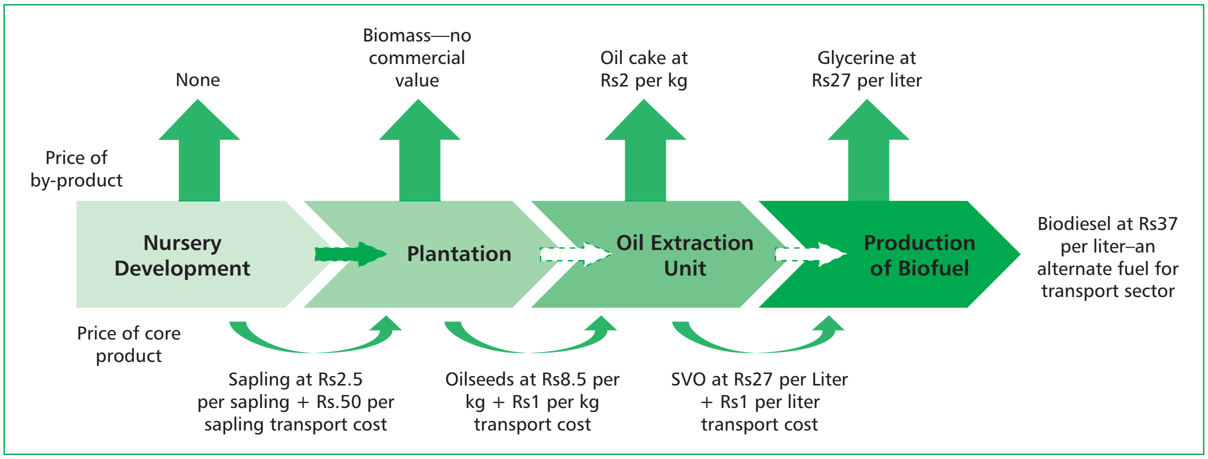
The financial analysis shows that, taking all cost and revenue components into consideration, the price of biodiesel received by the producer needs to be at least Rs37 per liter (excluding taxes and duties).[35] The central government and some state governments have set an administered price at Rs26.5 per liter, which is below this minimum required price. At prevailing prices and productivity, the financial return for producing biodiesel is negative. This is one of the key hindrances to the development of the biodiesel market in India. There is a critical need to revise current biodiesel prices. Figure 4 presents a summary of the price formation resulting from the financial analysis in this section along the value chain.

Oil Prices and Profitability of Biodiesel

As biodiesel is a substitute for diesel, its price should be closely linked to the diesel price. The energy content of biofuels is lower than that of petroleum fuel: each unit of biodiesel has about 90% of the energy of an equivalent volume of petroleum diesel. Thus the price per liter of biodiesel will be some fraction of the price of an equivalent volume of the petroleum-based fuel.

[35] The production of biodiesel yields glycerin, a by-product with many industrial uses. The analysis assumed a constant Rs27 per liter price for glycerin. But there is considerable uncertainty as to how the market could develop if biofuel production increases.

Figure 4 **Price Structure of the Biodiesel Supply Chain**



kg = kilogram, Rs = Indian rupees, SVO = straight vegetable oil.

Source: Compiled by the author.

Table 9 **Diesel Price and Financial Returns for the Biodiesel Supply Chain**

Diesel Price (Rs/liter)	Average FIRR from Jatropha Feedstock (%) Oil Seed	SVO Production	Biodiesel Production
38	14.6	13.2	16.0
42	20.5	19.9	21.9
48	29.4	27.8	31.6

FIRR = Financial internal rate of return, Rs = Indian rupees, SVO = straight vegetable oil.

The relationships depicted in Figure 4 can be used to examine the implications of changes in market prices of retail petroleum products on the profitability of biofuels. Here, we employ a top-down analysis, allocating the revenue from the final sale of biofuels, at a level equivalent to petroleum prices, to the intermediary products at fixed ratios—the ratios illustrated in Figure 4. For instance, we can derive the price of SVO and oil seeds starting from a biodiesel price that is based on a given price of conventional diesel. These prices can be used to estimate an FIRR for the different segments of the supply chain.

Table 9 shows, for instance, that at the current diesel price of Rs38 per liter, the different sectors of the supply chain do not show reasonable rates of return. Even biodiesel production—generally the most profitable sector—generates only the lower bound of required FIRR. As diesel prices increase, the FIRR also increases, and at a diesel price of Rs40.3 per liter all the segments of the biodiesel supply chain provide acceptable returns of 18%. Below this break-even price, the biodiesel industry will not take off without government interventions, such as producer subsidies.

Bioethanol Supply Chain and Profitability

Table 10 provides a sketch of the bioethanol supply chain—the different parts of the industry involved from feedstock cultivation to retailing of the finished fuel. The listing of the key stakeholders reminds us that this industry requires support from groups of people across the country from the agriculture, government, industry, logistics, and trade sectors.

Table 10 **Bioethanol Supply Chain**

Supply Chain	Major Stakeholders	Major Bottlenecks	
		Sugarcane	Tropical sugar beet or sweet sorghum
Nursery	R&D institutions, agricultural universities, seed companies	• Lack of appropriate high-yielding varieties suitable for different regions	
Plantation or crops	R&D institutions, agricultural universities, fertilizer and agricultural chemical companies, farm workers, farm owners, agriculture extension workers	• Cyclical production due to variation in yields, and area under cultivation • Low prices • Lack of support from sugar mills • Lack of investment and mechanization	• Lack of commercialization
Transport	Farm owners, sugar factories, logistics firms	• High cost of transport from producer to markets	
Milling/Juice Extraction	Sugar factories	• No significant issues	• Commercialization yet to be achieved • Milling units not financially sustainable
Processing or distilling	Distilleries	• No significant issues	
Blending or retailing	OMCs, automobile companies, consumers	• Long-term, inflexible price contracts by OMCs • Non-remunerative prices for ethanol • Resistance to direct retailing by OMCs • Inappropriate regulations • Lack of support by automobile companies for ethanol blending	

OMC = oil marketing company, R&D = research and development.

The major differences between bioethanol crops reflect the history of their commercialization. Sugarcane is a well-developed crop and the problems facing the sector can be identified. For sweet sorghum and sugar beet, the opposite is true.

Across the country, the economics of producing sugarcane differ in terms of costs and financial viability, especially due to the varied growing climate.

(i) Across India sugarcane yields average about 70 tons per ha. As a result of higher yields and prices in the western states, especially southern Maharashtra and northern Karnataka, returns are very attractive in comparison to north and south India.

(ii) At the prevailing average market price of Rs2,250 per ton, sugarcane gives a relatively high FIRR to farmers, ranging between 20% and 31%.

(iii) The price of sugarcane across the country is highly volatile and varies from year to year, especially reflecting weather conditions and supply cycles.

(iv) The financial returns for small growers (1–5 ha) are lower than for large growing units (10 ha or above) due to economies of scale.

Sweet sorghum and sugar beet are alternatives to sugarcane as sources of bioethanol, but neither crop has a history of commercial cultivation. Research trials have been undertaken by agencies including the International Crops Research Institute for the Semi-Arid Tropics, which provided the information for analyzing these crops. Sweet sorghum produces grain as well as cane twice a year. The financial analysis assumes grain yields of 2.5–4.5 tons per ha and cane yields of 30–50 tons per ha. Sugar beet are assumed to have a yield of 55–75 tons per ha.

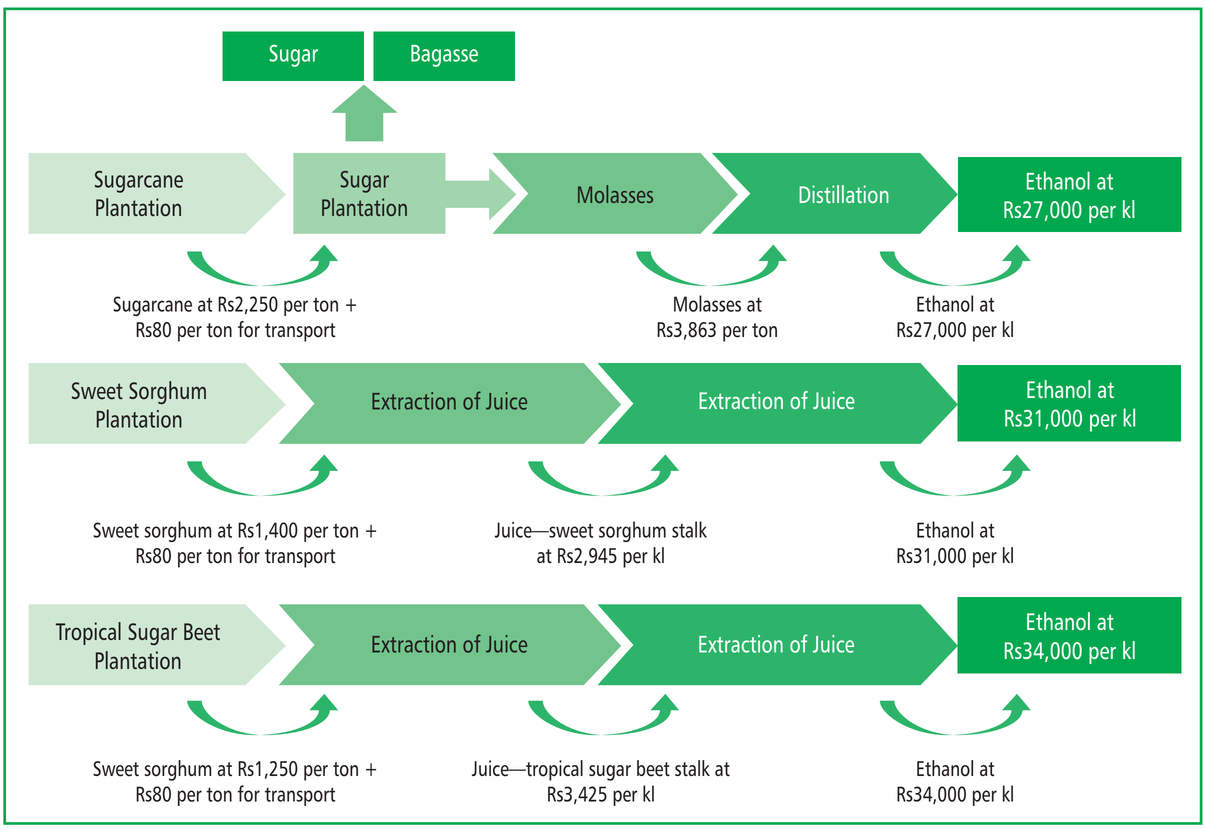
On the basis of these and assumptions concerning the costs of establishing and operating farms, the market price needs to be at least Rs1,400 per ton for sweet sorghum cane, and Rs9,000 per ton for sweet sorghum grain, to achieve minimum profitability for a farm (16%–18% FIRR). For sugar beet it needs to be Rs1,250 per ton. These prices are used to provide a picture of the rest of the supply chain for bioethanol.

The analysis on the financial viability at the processing stage was done for four alternative feedstocks: molasses, sugarcane juice, sweet sorghum grain and cane, and tropical sugar beet.

Figure 5 summarizes the price structure across the value chain for producing bioethanol from alternative sources.

Molasses. In India, bioethanol is largely produced using molasses. Realizing economies in production, most sugar mills have integrated ethanol distilleries. Typically, distilleries are set up with a capacity of 50–100 kl per day. For the production of bioethanol, the financial analysis shows that across the life of the facility, molasses is the largest cost, accounting for more than 60% of total costs. Given the cost structure and 2010 market price of molasses—(Rs3.0–Rs3.6 per kilogram)—a reasonable price would be Rs27–Rs28 per liter of bio ethanol to provide acceptable rate of return. The recent move by the government to set a price of Rs27 per liter may ensure the financial sustainability of the sector.

Figure 5 **Price Structure for the Ethanol Supply Chain across Alternative Feedstocks**



kl = kiloliter, Rs = Indian rupees.

Source: Compiled by the author.

Sugarcane juice. In addition to using molasses, bioethanol can be produced directly from sugarcane. It is important to consider the possibility of using sugarcane juice to complement molasses in producing bioethanol, because it is unlikely that sufficient molasses will be available to meet the government's 20% blending targets. However, producing ethanol from sugarcane juice is viable only if the producer realizes a minimum market price of Rs40 per liter. This is well above the current Rs27 per liter.

Sweet sorghum or sugar beet: Typically, the processes for converting juice into bioethanol using either the stalk of sweet sorghum or the root of the sugar beet are the same, and they use the same basic machinery. For sweet sorghum, the cost including transport is assumed to be Rs1,480 per ton; for sugar beet, the cost is Rs1,330 per ton. At these prices, the bioethanol price needs to be about Rs31–Rs34 per liter, which is higher than both the August 2010 trading price and the price needed to produce bioethanol from molasses.

The Impact of Biofuels on the Environment

Biofuels have the potential for reducing environmental problems associated with fossil fuels, especially lowering greenhouse gas (GHG) concentrations in the atmosphere. This is discussed below along with the impact of biofuels on water pollution. There are other positive outcomes for the environment from the use of biofuels, including lowered risks of petroleum spills and reduced air pollution, especially particulates. Importantly, biodiesel can be a positive force in reclaiming wasteland or degraded land. Putting wasteland into production for biodiesel plantations will result in the creation of tree cover for a minimum period of 20–30 years in the case of jatropha, and 30–40 years for pongamia, probably enhancing biodiversity.

Water Pollution

Most of the negative environmental impacts of biofuels in India emanate from sugarcane cultivation, primarily due to its large demand for water but also due to the use of chemical fertilizers and pesticides. High levels of chemical nutrients in the runoff from agricultural land have led to excess levels of organic nutrients in waterways in some regions. Chemical nutrient pollution could become a serious problem in India, considering that fertilizer consumption is projected to double by 2020. The impact of the expansion of biofuel production should be seen with this picture in mind.

On this issue, a clear distinction should be made between bioethanol and biodiesel feedstocks. Bioethanol feedstocks are usually grown in irrigated, row-crop agriculture, whereas biodiesel crops, such as jatropha and pongamia, are drought tolerant plants grown using little irrigation water. Biodiesel crops would have little impact on water resources if irrigation were limited to periods of prolonged drought and at the early stage of crop development.

In this assessment, it is clear that bioethanol from sugarcane does not pose inherent risks to the environment. Rather, current agricultural and manufacturing practices do not always meet standards that would protect the environment and sustain the industry. For instance, the common practice of burning sugarcane fields at harvest adds to local air pollution. Mitigation mechanisms are at hand, and often involve simply following local laws and regulations. It is important to make determined efforts to address this, otherwise the positive environmental impacts of biofuels could be lost.

Climate Change Impacts of Biofuels

Biofuels have the potential to reduce GHGs primarily because the crops themselves are carbon neutral. However, this is not a simple issue and there is considerable debate about the net energy and carbon balance of biofuels. The following sections provide a perspective on this question, especially on the potential for India receiving carbon financing through the United Nations Clean Development Mechanism (CDM), or a similar mechanism.

Carbon and Energy Balances of Biofuels

GHGs are emitted at various stages of cultivation and in the processing of biofuels. Biodiesel has a strong impact at the farm level where new plantations of jatropha and pongamia would act as carbon sinks, sequestering carbon in the growing trees.

In contrast, increased bioethanol from sugarcane is less likely to provide this type of carbon saving, as feedstocks need to be grown on arable land, all of which is already under cultivation. Even with biodiesel, fuel is used in planting, harvesting, and transport, as well as in the production of fertilizer and herbicides. This results in the release of GHGs.

At the consumer level, both biodiesel and bioethanol can reduce net carbon emissions through their substitution for petroleum products. The burning of a plant-based fuel introduces carbon into the atmosphere, but this is the carbon sequestered in the growing of the feedstocks and the use of biofuels can be considered carbon neutral. Petroleum fuels have no such offset in their production, so the use of biofuels instead of petroleum results in less carbon emissions in this respect.

The energy balance of products like biofuels, which use a variety of energy inputs at different points in the supply chain, is assessed by a net energy ratio. This is the ratio between the life cycle energy output and input. Similarly, the net carbon balance would mean how much carbon is being sequestered in comparison to the carbon emissions released in the product cycle. While there are a number of studies that have calculated the energy and carbon balances of biofuels, it is a contentious subject.

One useful recent study was a collaborative work between the Department of Biotechnology and the Confederation of Indian Industry estimating energy and carbon balances in India for biofuels. Table 11 provides a summary of the results. Sweet sorghum has a better net carbon balance than molasses, but jatropha is a far superior feedstock from the standpoint of the net carbon balance.

Carbon Financing Opportunities

Because biofuels can reduce carbon emissions, some projects can qualify to receive United Nations sanctioned Clean Development Mechanism (CDM) funding. Across the world, from 2005 to early 2010, in excess of $300 billion has been paid for carbon credits.[36] Given the uncertainties involved in the CDM which will end in 2012, the carbon financing should be viewed with some caution. In this assessment we used very conservative carbon prices to reflect this concern.

India's biodiesel plantations may qualify for carbon credits under the United Nations Land Use, Land Use Change and Forestry project category. A typical forestry project of reforestation implemented in barren, waste, or degraded land could have an average carbon credit of up to 7 tons per ha per year of certified emission reductions (CERs) for 30 years. The planted species (jatropha and pongamia), baseline soil conditions, and the package of farm practices will determine the actual carbon credit from a specific site. By taking a conservative estimate of 5 tons per ha per year of CERs, the total CERs generated by 32 million ha of oil seed plantations can be estimated as high as 160 million per year, perhaps yielding as much as Rs36 billion per annum.[37]

Table 11 **Estimates of Biofuel Net Energy and Carbon Balances**

Biofuel Type	Feedstock	Net Carbon Balance
Bioethanol	Molasses (sugarcane)	1.1
	Sweet sorghum	1.4
Biodiesel	Jatropha	4.0

Source: Department of Biotechnology and the Confederation of Indian Industry, 2010.

36 Donovan (2010).

37 The current market price per ton of avoided carbon dioxide, priced in Euros, is approximately €12 or $16.78, or Rs737.65. This report uses a far more conservative price of $5 for estimates of potential revenue flows. The calculations in this section use Rs45 = $1.

In addition, blending biodiesel with petroleum fuels avoids carbon emissions at the consumer stage. Targeted 20% blending of biodiesel would reduce carbon emissions by approximately 83.9 million tons annually. This represents a potential revenue flow of perhaps as much as Rs18.8 billion annually. The total carbon financing opportunity for biodiesel is thus Rs54.8 billion per annum.

Unfortunately, the certification process is not simple and not just any project will qualify. Feedstock for biodiesel production needs to be from a new plantation on degraded or degrading land that has been dedicated to the production of biodiesel feedstock. The credits would only be for biodiesel produced and used within the host country and for vehicles that are part of a "captive fleet" (the vehicle fleet is owned and operated by an entity which is included in the CDM project boundary). This is to ensure that the actual biodiesel consumption can be verified. One further problem is that currently this methodology is only applicable for blend levels above the mandated level in the host country. This stipulation may limit its use in India.

Moreover, in the plantation sector transaction costs are high due to the involvement of many small farmers. There are available instruments which could reduce transaction costs, including bundling of small-scale projects together under a public sector agency. The government will have to take the lead in this effort and a programmatic CDM project should be developed to reduce transaction costs.

At 20% blending for bioethanol, the avoided carbon is estimated to be 6.51 million tons annually. This would provide an annual carbon financing revenue of about Rs1.5 billion per annum. Note that bioethanol qualifies only for the blending portion of carbon credits.

Conclusions and Recommendations

Conclusions

The economic assessment shows that molasses-based bioethanol is worthwhile at the current price of oil if it does not displace alternative uses in industry or as potable alcohol. In contrast, the cost of sugarcane juice based bioethanol exceeds the benefits in most likely circumstances, therefore sugarcane-based bioethanol is not economically worthwhile. The use of sugarcane juice to produce bioethanol also compromises food production. Alternative feedstocks, such as sweet sorghum and tropical sugar beet, are not economically feasible at 2010 oil prices and their supply chains face major technical barriers. These energy crops also conflict with food security policies. Therefore, the first-generation ethanol industry has only a limited scope in India. At the current level of productivity, the most optimistic level of bioethanol blending would be 5%. India's ambitions for bioethanol largely rely on second-generation technologies, and research on these should continue.

The economics of biodiesel are very different from those of bioethanol, as jatropha and pongamia provide acceptable returns at 2010 oil prices. An increase in the price of diesel makes biodiesel more attractive. If confined to wasteland with limited irrigation only at the beginning of the planting season, biodiesel will not compete with food crops for land or water in any significant manner. The employment generation and CDM benefits of biodiesel are significant. The expansion of biodiesel production is desirable and this report supports an aggressive biodiesel program for India.

About 32 million ha of wasteland are required for biodiesel production, and yield improvements will be needed if the 20% blending target is to be realized. Unlike the case with sugarcane-based bioethanol a lot more groundwork needs to be done to realize the potential of biodiesel. Nurseries and plantations need immediate support because without high-yielding varieties and a proper understanding of suitable agronomic practices the industry cannot take off as a commercially successful national-scale venture.

An assessment of the social and environmental impacts of large-scale bioethanol and biodiesel production shows they are quite different. Biodiesel has the potential to bring significant environmental benefits. In both areas negative environmental impacts can be mitigated using available technologies.

The financial analysis shows that biodiesel production has not been profitable under the government's administratively determined pricing regime. The results clearly demonstrate that the biodiesel industry will not take off under the 2010 prices.

Biofuels have potential to reduce GHG emissions and receive significant carbon financing. However there are problems in obtaining carbon financing. Especially for biodiesel, small plantations or facilities face large transaction costs to successfully gain certification. Equally important is that current rules may not allow the receiving of CDM benefits if blending is mandatory. Innovative approaches are required to ensure that the carbon benefits of biodiesel are received.

The analysis of the possible economy-wide impact of biodiesel in India showed that this effort could provide India with an opportunity to enhance economic growth and employment prospects for rural workers. A national biodiesel program has the potential to create about 18 million jobs with significant real wage increases. While the economic prospects of biodiesel are promising, they are based on a major assumption that about 32 million ha of wasteland can be brought under cultivation. The biodiesel industry in India is at an early stage of development and an enormous amount of work on land allocation, selection and breeding, nursery development, and agricultural research has to be undertaken.

The analyses in this report assume that there is no impact of biodiesel crops on food security. This assumption is realistic so long as oil seed plantations are established only on waste or fallow lands. Their economic feasibility, encouraging economy-wide impacts, and positive environmental and social impacts provide justifications for public sector support for biodiesel in India. However, assured profitability may induce the farmers to convert crop lands for biodiesel production, adversely affecting food security in India. Therefore, oil seed plantations should remain a regulated industry and a land certification program should be implemented to ensure that subsidies and other incentives will be given only to oil seed plantations established on waste and fallow lands. If oil prices increase to a very high level in the future, the biodiesel sector should be taxed to reduce its profitability. Some of the tax revenues could also be used to provide incentives for the food crops sector to ensure that arable lands will not be converted for biodiesel production. A mixture of market-based instruments (taxes and subsidies) and regulatory measures should be designed and implemented to avoid potential impacts of the biodiesel sector on food security.[38]

There is convincing evidence that oil prices may trend higher over the next 2 decades. Higher oil prices will have significant negative impacts on the Indian economy, and biodiesel interventions have the ability to offset these impacts. Bioethanol, however, has minimal or no offsetting effects. The expansion of biodiesel is one policy response India can adopt to counteract the economic impact of oil price hikes. Combining supply-side energy solutions, like biodiesel development, together with demand-side energy management and productivity improvements in agriculture could have a much bigger impact. Even modest assumptions about energy efficiency and food productivity gains can reverse negative shocks to the economy, providing India with energy security without affecting food security.

The analyses of this report clearly show that sugarcane-based bioethanol and biodiesel are quite different in their performance. Table 12 summarizes the key differences. These differences call for separate policies for bioethanol and biodiesel.

Table 12 **Comparison of Performances of Bioethanol and Biodiesel**

Performance Attribute	Bioethanol	Biodiesel
Economic viability	Mixed, only excess molasses ethanol is viable	Viable, expansion will increase social welfare
Macro effects, ability to off-set energy price shocks	Minimum offsets	Significant offsets
Employment	0.12 million per year	18.3 million per year
Food security	Adverse effects if sugarcane juice ethanol is produced	No adverse effects if oil seed plantations confined to fallow and waste lands
GHG reduction	6.5 million tons per year	244 million tons per year
Carbon benefits	Rs1.5 billion per year	Rs55 billion per year
Sector readiness	Ready to meet 20% blending target, if sugarcane juice ethanol is produced	Need major public sector intervention for the sector to take off

GHG = greenhouse gas, Rs = Indian rupees.

Source: Compiled by the author.

[38] A cautious approach should be followed in designing regulatory measures to avoid adverse impacts of regulatory measures such as delays, corruption, and high transaction costs.

Recommendations

Based on the findings of the study the following key recommendations are offered:

(i) **Separate policies for ethanol and biodiesel.** Separate policies would serve the two sectors better given the difference in performance and issues.

(ii) **Focus on molasses-based ethanol.** Ethanol production should be limited to molasses-based ethanol.

(iii) **Research on second-generation biofuel.** There is limited scope for first-generation ethanol in India. However, there seems to be a large potential for second-generation ethanol. Therefore, research efforts on second-generation ethanol should continue.

(iv) **Public sector support for biodiesel.** The main focus of public support, at this point in time, should be for biodiesel. The following specific areas require immediate attention:

  (a) land-use mapping and land allocation studies and the taking of necessary legal, institutional, and other measures to make wasteland available for biodiesel production;

  (b) revision of biodiesel and oil seed prices and provision of a stable policy environment for the biodiesel sector to develop;

  (c) an accelerated research program on agronomy, selection and breeding, pest and diseases control, other management practices, and the propagation of high-yielding planting materials for plantation development;

  (d) incentive packages for the private sector to mobilize private investment for the development of the biodiesel sector;

  (e) further studies to examine the potential synergy between India's rural development programs and biodiesel sector development, particularly focusing on the long gestation period of biodiesel crops; and

  (f) establishment of a national agency with branches in relevant states to design and implement the public support program described above, oversee and monitor the biodiesel industry, periodically review the cost of production and prices, and design and recommend subsidies and taxes based on changes in oil prices.

(v) **Further studies on the incentive packages for biodiesel.** It is necessary to incorporate a combination of tax, subsidy, and regulatory measures to ensure that the incentives given to the biodiesel sector do not lead to expansion of biodiesel cultivations into arable lands.

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Food Security, Energy Security, and Inclusive Growth in India
The Role of Biofuels

This report summarizes the findings of the Asian Development Bank's technical assistance project TA-7250: Cross-Sectoral Implications of Biofuel Production and Use in India. Implementation of its national biofuel policy will help offset the effects of oil price increases on the economy of India in the next 2 decades. The advantages of biodiesel, as a supply-side response to counter the adverse impacts, are significant. Bioethanol, in contrast, will not generate sufficient economic benefits to justify social costs. Therefore, first-generation bioethanol has limited scope in India. As these biofuels compete for agricultural resources and compromise food security, a combination of policies—biodiesel expansion, energy efficiency improvements, and food productivity increase—will provide India with better energy security, food security, and opportunities for inclusive growth and carbon emission reduction.

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