Working Paper No. 136
October, 2014

# Reduction of GHG Emissions and Attainment of Energy Security through Sustainable Production of Biofuels: Is it a Viable Option?

*A Review of Experiences*

Dr. M. Gopinath Reddy
Dr. B. Suresh Reddy
Steven Raj Padakandla

CENTRE FOR ECONOMIC AND SOCIAL STUDIES
Begumpet, Hyderabad-500016

**Acknowledgments**

This study is a part of Indo-US bilateral JCERDC project for Development of Sustainable Advanced Ligno-cellulosic Biofuels Systems (SALBS). We profusely thank our Director, Prof. S. Galab for his constant support to the project. Thanks are due to Prof. G. Pakki Reddy, Founder and Executive Director of Agri Biotech Foundation for giving constructive comments and suggestions for this study. The authors also wish to acknowledge the constant guidance provided by JCERDC US partners, Janaki Alavalapati, Professor and Head, Department of Forest Resources and Environmental Conservation, VirginiaTech University and Dr. Pankaj Lal, Montclair State University at every point of this work. We wish to acknowledge the encouragement by IUSSF, research staff, New Delhi. Thanks are also due to Prof. Ahmed Kamal (IICT) Consortium chief and other partners for their support. We also thank the faculty members CESS and support staff and the libraries of CESS and University of Hyderabad for giving access to various journals and data sources.

Authors

## CONTENTS


| | |
|---|---|
| Acknowledgments | 2 |
| List of Tables | 4 |
| List of Figures | 4 |
| Abbreviations | 5 |
| Abstract | 6 |
| Review Study | 7-34 |
| References | 35-39 |

## List of Figures


| Sl. No | Description | Page No |
|---|---|---|
| 1 | India's Crude Oil Imports | 8 |
| 2 | Crude Oil Prices (brent) | 8 |
| 3 | India's CO2 Emissions 1990-2012 (Bntonnes of CO2) | 10 |
| 4 | Biofuel demand and production in selected regions | 14 |


## List of Tables


| Sl. No | Description | Page No |
|---|---|---|
| 1 | Impact of climate change on crop yields in different regions of India in PRECIS A1B scenario 2030 | 11 |
| 2 | Bio fuels classification | 13 |
| 3 | Technical properties of Biodiesel | 14 |
| 4 | Biodiesel emissions compared to conventional diesel | 15 |
| 5 | Biofuel consumption in road transport (bioethanol and biodiesel), 2005-2012 (in TJ) | 17 |
| 6 | Projected demand for petrol and diesel and the biofuel requirements of India | 18 |
| 7 | Etanol and Biodiesel Consumption in road transport by region in the New Policy Scenario (mboe/d) | 19 |
| 8 | Waste land status in India | 21 |

## Abbreviations

| | | |
|---|---|---|
| $CO_2$ | : | Carbon Dioxide |
| CPR | : | Common Property Resources |
| EBPP | : | Ethanol Blended Petrol Programme |
| EU | : | European Union |
| R&D | : | Research and Development |
| GDP | : | Gross Domestic Product |
| GHG | : | Greenhouse Gases |
| GOI | : | Government of India |
| GTAP | : | Global Trade Analysis Project |
| HSD | : | High Speed Diesel |
| ICAR | : | Indian Council of Agriculture Research |
| IEA | : | International Energy Agency |
| IPCC | : | Intergovernmental Panel on Climate Change |
| ISO | : | International Standards Organization |
| JCERDC | : | Joint Clean Energy Research and Development Center |
| LCA | : | Life Cycle Analysis |
| MNRE | : | Ministry of New and Renewable Energy |
| NBCC | : | National Biofuel Coordination Committee |
| NOx | : | Nitrogen Oxide |
| NRSA | : | National Remote Sensing Agency |
| OECD | : | Organization for Economic Co-operation and Development |
| PAH | : | Polycyclic Aromatic Hydrocarbons |
| PRECIS | : | Providing Regional Climates for Impacts Studies |
| RFS | : | Renewable Fuel Standard |
| SIWI | : | Stockholm International Water Institute |
| TERI | : | The Energy and Resources Institute |

# Reduction of GHG Emissions and Attainment of Energy Security through Sustainable Production of Biofuels: Is it a Viable Option?

## *A Review of Experiences*

Dr. M. Gopinath Reddy[*] Dr. B. Suresh Reddy[£] Steven Raj Padakandla[$]

## ABSTRACT

Depletion of fossil fuels at an alarming rate coupled with ever growing challenges due to anthropogenic induced climate change stress has attracted increasing attention to blending bio-fuels worldwide. India's primary energy use is projected to expand massively to deliver a sustained GDP growth rate of 9per cent through 2031-32. With self-sufficiency levels in crude oil a distant dream, there is a growing interest/need in development and commercialization of a bouquet of alternative fuels. In addition to providing energy security and a decreased dependence on oil imports, bio-fuels offer significant benefits such as reduced emission of pollutants and green-house gases. Climate change is one of the most important problems faced around the world and most importantly in developing countries like India. The National Policy on Biofuels sets an indicative target of 20per cent blending of biofuels by 2017 to tackle the twin problem of energy security and climate change. Although biofuels seem to be the most suitable solution, the perceived competition for land and the risk of displacing production of human and animal food pose substantial risk. The objective of this working paper is to review the sustainability of large scale biofuel projects from the existing literature. The review projects a mixed picture about the economic, environmental and social viability of biofuels. The justification of promoting large scale biofuels also hinges to a large extent on the question of how to avoid negative social impacts and how to obtain positive impacts. Though India has scope for developing biofuels for substitution of conventional fuels, review points out that R&D development, suitable policy support and most importantly global market balances are needed for avoiding negative externalities.

[*] Dr. M.Gopinath Reddy is Professor at Centre for Economic and Social Studies (CESS) and Principal Coordinator of Division for Sustainable Development Studies (DSDS) at CESS. *email: mgopinathreddy@gmail.com*

[£] Dr. B.Suresh Reddy is Associate professor in the Division for Sustainable Development Studies, CESS. *email: srihithasuresh@yahoo.com*

[$] Steven Raj Padakandla is Senior Research Associate at CESS. *email: pstevenraj@gmail.com*

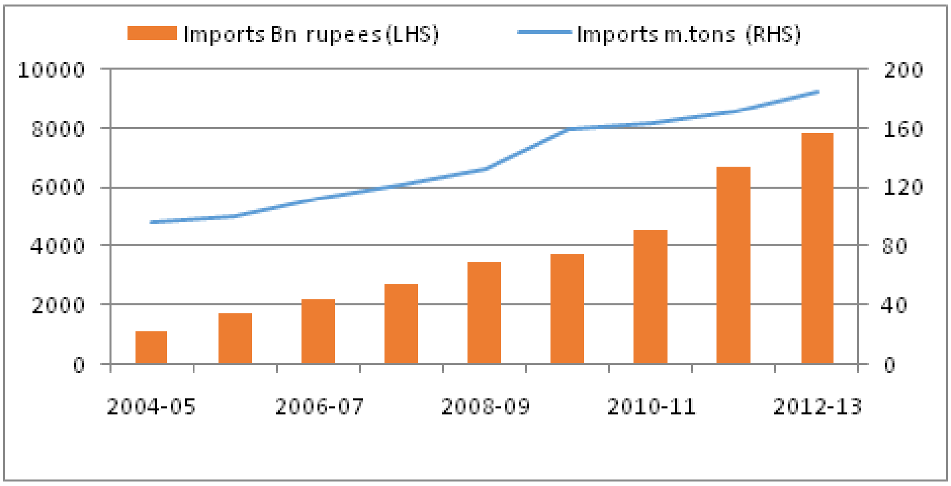
## I. Introduction

Depletion of fossil fuels at an alarming rate coupled with ever growing challenges due to anthropogenic induced climate change stress has attracted increasing attention to blending bio-fuels worldwide. India's energy demand is expected to grow at an annual rate of 4-5 times over the next couple of decades. According to the International Energy Agency, India will become the largest single source of global oil demand growth after 2020. India needs energy security along with environmental sustainability so that the eco-capacity of the conserved and environmental uncertainty arising from events such as climate change is mitigated. Of the total primary energy supplied to Indian economy in 2008, 73.6 per cent was from commercial fuels and 26.4 per cent from non-commercial fuels. Out of total commercial energy, Coal constitutes - 57.1 per cent followed by oil (31.65 per cent), natural gas (8 per cent) and from carbon free hydro, nuclear and other new renewable resources (3.3 per cent) (IEA 2010). Despite coal being the country's major resource endowment, the major source of India's energy insecurity is the heavy and growing dependence on oil imports. Off late, there have been sharp rising trends in crude oil prices coupled with volatility. India's transportation fuel requirements are unique as it consumes almost six to seven times more diesel fuel than gasoline, whereas in the rest of the world, almost all the other countries use more gasoline than diesel fuel. The National policy on Biofuels (2009) has an ambitious target of mainstreaming the use of biofuels-bioethanol and biodiesel by 20 per cent blending with petrol and High speed Diesel (HSD) by 2017. However the policy centers around the plantations and production of Jatropha on wastelands for the achievement of this target.

As discussed earlier most of the energy requirements are currently satisfied by fossil fuels - coal, petroleum-based products and natural gas. As domestic production can only bridge the gap by 25-30 per cent this has serious effects on the energy security of the country added to the burgeoning burden of imports. In 2012-13, the country imported 185.0 million tons of crude oil which amounts to nearly 80 per cent of its domestic crude oil consumption and accounting to nearly 30 per cent of the country's total imports.

India's primary energy use is projected to expand massively to deliver a sustained GDP growth rate of 9 per cent through 2031-32 even after allowing for substantial reduction in energy intensity. In order to fuel this on a sustained basis, the growth of around 5.8 per cent per year in primary energy supply including gathered non-

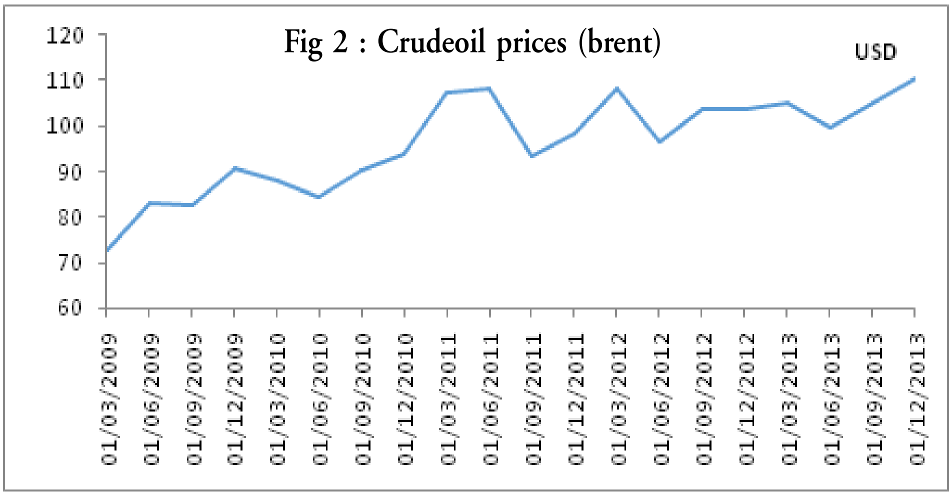
**Figure 1: India's Crude Oil Imports**




Source: *IndiaStat*

commercial such as wood and dung would be required. Commercial energy supply would need to grow at about 6.8 per cent per annum as it will replace non-commercial energy, but this too involves a reduction of around 20 per cent in energy use per unit of GDP over a period of ten years. India is confronted with energy crisis due to the depletion of resources and increased environmental problems. Diesel is the primary transport fuel of the country and comprises around 42 per cent of the total fuel market, majority of which comes through import market.

The rate at which the energy needs are growing demands either a greater reliance on imports (which is strain on depleting fiscal resources and foreign exchange) or a shift



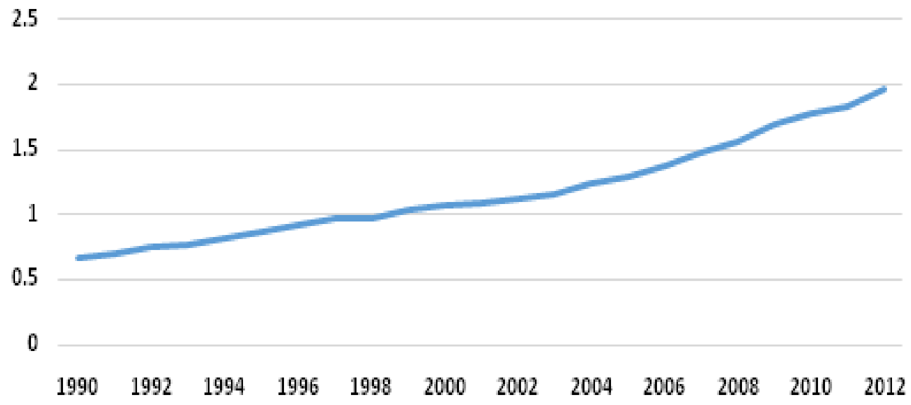

Source: *iea.gov*

to alternative energy sources. With self-sufficiency levels in crude oil a distant dream, there is a growing interest/need in development and commercialization of a bouquet of alternative fuels. This necessitates the change of focus towards bio-fuels as a favorable alternative option. In addition to providing energy security and a decreased dependence on oil imports, bio-fuels offer significant benefits such as reduced emission of pollutants and green-house gases. Most importantly the industry has a potential to create avenues to raise farmer incomes, restore degraded lands while at the same time contributing to climate change mitigation.

Climate change is one of the most important problems faced around the world and most importantly in developing countries like India. According to the IPCC AR 4, temperature has increased by 0.74°C in the last hundred years with the bulk of the warming occurring in the last 50 years. Temperatures rose at a rate of approximately 0.13°C per decade from 1956 to 2005 (IPCC, 2007). Agriculture is the largest employer in the world and the most vulnerable to weather and climatic risks. In developing countries, around 70 per cent of total population is dependent on agriculture. Majority of the total annual croplosses in the world agriculture are mainly due to direct weather impacts like droughts, floods, untimely rain, frost, heat and cold waves and severe storms (Folley, J.A, *et al.*, 2005, Hay, J, 2007). India accounts for only about 2.4 per cent of the world's geographical area and 4 per cent of its water resources, but has to support about 17 per cent of the world's human population and 15 per cent of the livestock. Climate change may alter the distribution and quality of India's natural resources and adversely affect the livelihood of its people. With an economy closely tied to its natural resource base and climate-sensitive sectors such as agriculture, water and forestry, India may face major threat because of the projected changes in climate (GOI, 2008). Hence, the country has reasons to be concerned about climate change as a vast population depends on climate sensitive sectors like agriculture, forestry and fishery for livelihood in the country.

According to the GOI report, climate change is likely to impact agricultural land use and production due to less availability of water for irrigation, higher frequency and intensity of inter and intra-seasonal droughts and floods, low soil organic matter, soil erosion, less availability of energy, coastal flooding which could impact agricultural growth adversely (GOI, 2013). Crop specific simulation studies, though not conclusive due to inherent limitations, project a significant decrease in cereal production by the end of this century. Parts of Western Rajasthan, Southern Gujarat, Madhya Pradesh, Maharashtra, Northern Karnataka, Northern Andhra Pradesh, and Southern Bihar are likely to be more vulnerable in times of extreme events. The impact of climate change on crop productivity is significant and diverse as its impact differs even across

Fig 3: India's $CO_2$ Emissions 1990-2012 (Bn tonnes of CO2




*Source:* Jos G.J. Olivier et al (2013), Trends in Global $CO_2$ Emissions report

different agro climatic zones within a state, thus making implementation of mitigation strategies very difficult (Steven Raj P, 2014).

Hence, in order to tackle the twin problem of burdening energy security and mitigate effects of climate change on the Indian economy, the Union Cabinet of Government of India approved National Policy on Biofuels on December 24, 2009, which stresses on mainstreaming of bio-fuels in India to meet its ever increasing energy requirements and to limit the carbon foot print of the country. The policy calls for setting up of National Biofuel Coordination Committee (NBCC) headed by prime minister to provide over all coordination, effective end-to-end implementation and monitoring of biofuel programme. Another Biofuel steering committee would be set up to tend to more regular and day-to-day of the same which would be chaired by cabinet secretary (GOI, 2009). National biofuel policy aims at ensuring that the next generation of technologies is based on non-food feed stocks so as to avoid conflicts with food security. The policy aims at mainstreaming of biofuels and therefore, envisions a central role for it in the energy and transportation sectors of the country in coming decades. It also aims at bringing about accelerated development and promotion of the cultivation, production and use of biofuels to increasingly substitute petrol and diesel for transport and be used in stationary and other applications, while contributing energy security, climate change mitigation, apart from creating new employment opportunities and leading to environmentally sustainable development. The policy sets an indicative target of 20 per cent blending of biofuels, both for biodiesel and bio-ethanol, by 2017. Presently the ethanol blending with gasoline was 2.9 per cent in 2013.

**Table 1: Impact of climate change on crop yields in different regions of India in PRECIS A1B scenario 2030***

| | Western region | Coastal Region | North East Region |
|---|---|---|---|
| Rice (Irrigated) | Likely to be reduced by 4%, however irrigated rice in parts of southern Karnataka and northern-most districts of Kerala is likely to gain. | Decrease by 10% - 20%, buy some coastal districts of Maharashtra, northern Andhra Pradesh and Orissa are projected to marginally increase by 5% with respect to the 1970s | Irrigated rice yields in this region may decline between 5-10%, |
| Rice (Rain-fed) | All areas in the region are likely to lose yields by up to 10%. | Projected to increase up to15% in many districts in the east coast but reduce by 20% in west coast | Decline 5-35% with respect to 1970s |
| Maize / Sorghum | Likely to impact yields by 50% depending on the region | Yield loss between 15% and 50% Rain-fed maize loss is up to 35%. AP to reduce by 10% | Projected to reduce by about 40% |
| Coconut | Likely to increase yields by 30%. South-west Karnataka, parts of Tamil Nadu and parts of Maharashtra may show reduction in yields up to 24%. | Increase by 30% in West coast (provided water level is same). In East coast increased yields by 10% esp. in north coastal districts of AP | |
| Livestock [1] | THI > 80 during September-April to reduce productivity | THI >80 throughout the year | THI > 80 during months of April-October |

Source: *Indian network for climate change assessment, MOEF*

* Assessed through a simulation model called InfoCrop

[1] The Temperature Humidity Index (THI), an index used to represent thermal stress due to combined effects of air temperature and humidity. THI > 80 severely impacts livestock health and productivity.

## II Biofuels

Sustainable development which ensures protection of resources and the environment for the future has become one of the important part of life. According to the Burndtland report (1987) sustainable development is a process which satisfies the need of the present with-out decreasing the ability of the future generations to supply their own demand. Given that environment is one of the most important pillars of sustainable development; the others being society and balanced treatment of the economy (Gathy, 2005), the focus shifts to renewable energy sources like biofuels, which aim to preserve the environment in a better way by substituting traditional fuels that are considered to be one of the biggest contributors of global environmental decay. Biofuel is a non-polluting, locally available, accessible and reliable fuel obtained from renewable sources. It is seen by many as "clean" form of energy as the amount of $CO_2$ released when it is burned is generally equivalent to the amount of $CO_2$ captured during the growth of the crop that produced it. Since biofuels can be produced from diverse set of crops each country can also adopt its local/regional/country specific strategy in order to achieve comparative advantage. Liquid bio-fuels that are being considered world over fall in to the following categories:

i) Alcohols - produced by fermentation of sugar and starchy crops, and quite recently from cellulosic bio-mass

ii) Plant seed oils - which comprises of triglycerides of long chain saturated and un-saturated fatty acids. Bio-diesel is vegetable oils modified by trans-esterification to replace the glycerol molecules by methyl or ethyl groups

iii) Bio-crude and synthetic oils - low molecular weight non-polar constituents of plant, which can be directly extracted from bio-mass and are generally a complex mix of lipids, triglycerides, waxes, terpenoids, polysterol and other modified iso-perenoids that can be catalytically upgraded for use as liquid fuels.

Globally these different liquid fuels can be obtained from four different categories of biomass sources

a) Plantations especially raised for producing energy or energy and food

b) Agricultural residues and wastes including manure, straw, bagasse and forest wastes

c) Uncultivated biomass such as weeds

d) Organic urban or industrial wastes

**Table 2: Bio fuels classification**

| **First generation Biofuels**<br>(from grains, seeds, sugars) | **Second generation biofuels**<br>(from lingo-cellulosic biomass, such as crop residues, woody crops or energy grasses) |
|---|---|
| Petroleum-gasoline substitutes<br>- Ethanol or butanol by fermentation of starches (corn, wheat, potato) or sugars (sugar-beets, sugarcane) | Biochemically produced petroleum-gasoline substitutes<br>- Ethanol or butanol by enzymatic hydrolysis |
| Petroleum diesel substitutes<br>- Biodiesel by trans-esterification of plant oils, also called fatty acid methyl ester (FAME) and fatty acid ethyl ester (FAEE)<br>- From rapeseed (RME), Soybeans (SME), sunflower, coconut, palm, Jatropha, recycled cooking oil and animal fats | Thermo-chemically produced petroleum-gasoline substitutes<br>- Methanol<br>- Fischer-Tropsch gasoline<br>- Mixed alcohols |
| Pure Plant oils (straight vegetable oil) | Thermo-chemically produced petroleum-diesel substitutes<br>-Fischer-Tropsch diesel<br>- Dimethyl ether (also a propane substitute)<br>- Green diesel |

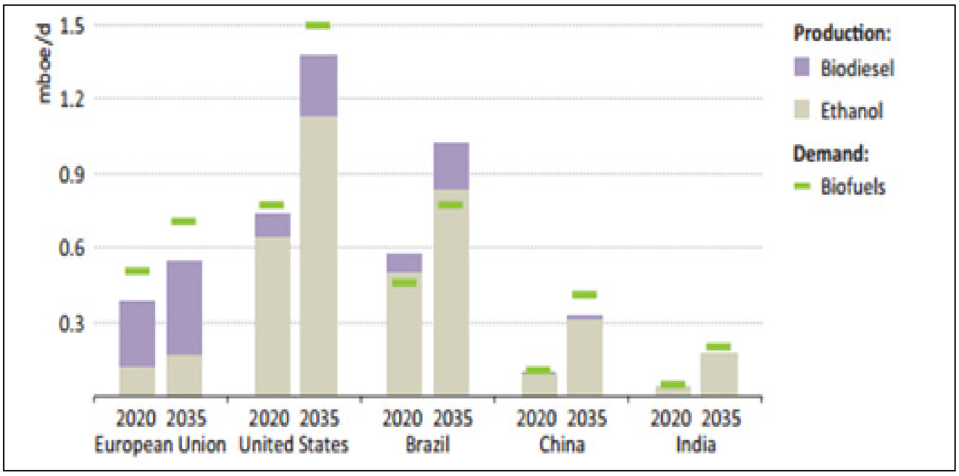
Source: *UNCTAD, 2008*

Consumption of biofuels is projected to rise from 1.3 million barrels of oil equivalent per day (mboe/d) in 2011 to 2.1 mboe/d in 2020, and 4.1 mboe/d in 2035. By 2035, biofuels meet 8% of total road-transport fuel demand, up from 3% today. Ethanol remains the dominant biofuel, making up about three-quarters of global biofuels use throughout the period. Consumption of biodiesel in road transport more than triples over the outlook period to 1.1 mboe/d in 2035. Combined United States, Brazil, the European Union, China and India account for about 90% of world biofuels demand throughout the outlook period, with government policies driving the expansion in these regions. In addition to the use of biofuels in road transport, its use in aviation begins to make inroads over the projection period (IEA 2013).

**Advantages**

Added to its uniqueness as an environmentally friendly fuel compared to either gasoline or petroleum diesel, biofuel is also recognized due to its portability, ready availability, renewability, higher combustion efficiency, lower sulfur and aromatic content, and higher biodegradability (Ma F, 1999; Konthe *et al.,* 2006). Bio-diesel has higher flash point temperature (>1000C), higher cetane number and lower aromatics than that of

**Figure 4: Biofuels demand and production in selected regions**




Source: *World Energy Outlook, 2013*

conventional fuels. Added to this biodiesel can be used in any diesel engine without any modification. Blends up to 20 per cent biodiesel mixed with petroleum diesel fuels can be used in nearly all diesel equipment and are compatible with most storage and distribution equipment.

**Table 3: Technical properties of Biodiesel**

| | |
|---|---|
| Common name | Biodiesel |
| Common chemical name | Fatty acid (m)ethyl ester |
| Chemical formula range | C14-C24 methyl esters or C15-25H28-48O2 |
| Kinematic viscosity range (mm2/s, at 313 K) | 3.3-5.2 |
| Density range (kg/m3, at 288 K) | 860-894 |
| Boiling point range (K) | >475 |
| Flash point range (K) | 420-450 |
| Distillation range (K) | 470-600 |
| Vapor pressure (mm Hg, at 295 K) | <5 |
| Solubility in water | Insoluble in water |
| Physical appearance | Light to dark yellow, clear liquid |
| Odor | Light musty/soapy odor |
| Biodegradability | More biodegradable than petroleum diesel |
| Reactivity | Stable, but avoid strong oxidizing agents |

Source: *Demirbas, 2009*

The clamor for shift to biofuel driven energy, especially in the transportation sector is gathering ground, off late more in developing countries like India, given its potential to reduce the dependency on imported fuel and thus reducing the burden on the exchequer. More over given that biodiesel can be manufactured from domestically cultivated crops would also contribute to better farm level incomes and also increased employment generation both at the field and factory level.

**Disadvantages**

Despite their appeal as an alternative to fossil fuels, biofuels are also subject of considerable controversy. The major disadvantage of biodiesel are its higher viscosity, lower energy content, higher cloud point and pour point, higher nitrogen oxide (NOx) emissions, lower engine speed and power, injector coking, engine compatibility and high price. The specific fuel consumption values of biodiesel are greater than those of commercial diesel fuel, while the effective efficiency and effective pressure values of commercial diesel fuels are greater than those of biodiesel. Biofuel production is not considered truly as carbon-neutral because the stages of production needs non-renewable energy while transporting and processing.

**Table 4: Biodiesel emissions compared to conventional diesel**

| Emissions regulated emissions | B100 (100 per cent biodiesel) | B20 (20 per cent biodiesel) |
|---|---|---|
| Total unburned Hydrocarbons | -93 per cent | -30 per cent |
| Carbon Monoxide | -50 per cent | -20 per cent |
| Particulate Matter | -30 per cent | -22 per cent |
| NOx | 13 percent | 2 per cent |
| Non-regulated emissions | | |
| Polycyclic Aromatic Hydrocarbons (PAH) | -80 per cent | -13 per cent |
| NPAH (Nitrated PAH) | -90 per cent | -50 per cent |
| Life cycle emissions | | |
| Carbon Dioxide (LCA) | -80 per cent | |
| Sulfur Dioxide (LCA) | -100 per cent | |

Source: *GOI, 2003*

The primary concern is that the substitution of agricultural crops to produce biofuels may be inherently unsustainable (Peer *et al.*, 2008) as crops require land and water to grow and this would inadvertently in the long run result in the shift from food to non-food/fuel crops given higher incentives. Crops of any nature in industrialized agriculture require synthetic inputs such as fertilizers and pesticides, both of which are produced and transported using fossil fuel energy. This fact adds to the overall energy required to produce crops that provide energy and raises questions about whether the finished product provides more energy than is spent to produce it (Giampietro *et al.,* 1997). Another issue of concern is the impact on food security in the context of diversion of land to biofuel crops. It is interesting to note that the soaring food inflation during 2002-2008 is attributed to shift of food commodities to biofuels. Though increase in internationally traded food prices during 2002-2008 is attributed to a confluence of factors, it is chiefly attributed to increase in biofuel production from grains and oilseeds in the U.S and EU. The IMF estimated that the increased demand for biofuels accounted for nearly 70 and 40 per cent of the increase in Maize and Soyabean prices respectively (Lipsky, 2008). Land use changes in Wheat exporting countries in response to increased plantings of oilseeds for biodiesel production limited expansion of Wheat production. Impact of food prices on developing countries like India is much pronounced given that they spend nearly half of their household income on food (Donald Mitchell, 2008).

There is also considerable debate questioning whether the end fuel product will truly be better for the environment than fossil fuels when subjected to a Life Cycle Analysis (Heintzman and Solomon, 2009; Puppán, 2003). LCA is defined by the International Standards Organization (ISO) as "a compilation and evaluation of inputs, outputs and potential environmental impacts of a products system throughout its life cycle" (Guinée *et al*., 2001).

Experiences worldwide suggest that the conventional fuels can be successfully substituted with biofuels. There are many successful experiences the world over from Canada, USA in North America; Brazil, Argentina and Columbia in South America; France, Germany and the European Union, India, China, Indonesia, Malaysia and Thailand in Asia and Australia. Over the last decade, between 2000 and 2009, biofuel production has increased dramatically from 16.9 to 72.0 billion liters, while biodiesel grew from 0.8 to 14.7 billion liters. The United States remains the largest biofuels market, spurred on by the Renewable Fuel Standard (RFS) through 2022 and assumed continuation of support thereafter, with consumption increasing from around 0.7 mboe/d to 1.5 mboe/d in 2035, by which time biofuels meet 15% of road-transport energy needs. Driven by blending mandates and strong competition between ethanol and gasoline, Brazil remains the second-largest market and continues to have a larger share of biofuels in its transport fuel consumption than any other country. In 2035, biofuels meet 30% of Brazilian road-transport fuel demand up from 19% today. Supported by the Renewable Energy Directive and continued policy support, biofuels use in the European Union more than triples over the period to 0.7 mboe/d in 2035, representing 15% of road-transport energy consumption. In China, government plans for expansion lead to demand for biofuels reaching 0.4mboe/d in 2035, many times the current level.

India established an ambitious National Mission policy on biofuels in 2009, but the infancy of the ethanol industry and difficulty in meeting current targets constrains future demand growth in the projections (IEA, 2013)

Of all the biofuel experiences, Brazil using sugarcane based ethanol has been regarded as the most successful one as all gasoline sold in Brazil is a blend of 18 to 25 per cent ethanol. The Brazilian national ethanol program Proalcool, was, launched in 1975. After the second oil crisis in 1979, Brazil launched to shift to cars powered by entire hydrous ethanol. This was very successful as by 1985, 95 per cent of the light vehicles produced in Brazil were built to use hydrous ethanol. In 2003, flex fuels vehicles were launched and currently account for 90 per cent of the new sales constituting the high point of Brazilian ethanol success story in the present decade. Brazil ethanol program is more consolidated because -

a) gasoline contains 25 per cent of ethanol

b) ethanol is available in all gas stations and

c) 50 per cent of the car fleet and 90per cent of new car sales are of flex fuel.

This was all possible due to the strong sugarcane sector that is already established in the country. Brazil produced 717 million tons of sugarcane, which yielded 36.1 million tons of sugar and 27 billion liters of ethanol. Most of the ethanol produced is absorbed in the domestic market where it is sold as either ethanol fuel or blended with gasoline.

**Table 5: Biofuel consumption in road transport (bioethanol and biodiesel), 2005-2012 (in TJ)**

| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|
| USA | 337,941 | 473,793 | 601,146 | 819,755 | 928,090 | 1,012,973 | 1,068,621 | 1,070,660 |
| EU27 | 130,415 | 230,762 | 283,830 | 397,878 | 495,048 | 554,991 | 580,531 | 598,371 |
| Brazil | 291,533 | 270,201 | 373,039 | 502,514 | 550,826 | 588,900 | 521,186 | 517,495 |
| China | 0 | 42,200 | 39,056 | 49,188 | 51,742 | 50,696 | 63,217 | 63,217 |
| India | 4,556 | 5,038 | 5,601 | 6,191 | 6,861 | 7,611 | 11,736 | 11,736 |
| Global | 777,605 | 1,039,354 | 1,354,706 | 1,855,104 | 2,143,083 | 2,377,504 | 2,482,683 | 2,498,870 |

Source: *Trends in Global CO2 Emissions: 2013*

### III Biofuels in India

The two prominent biofuels in India are bio ethanol (or simply ethanol) and biodiesel made from biomass containing sugar like molasses and vegetable oil like non-edible Jatropha oil respectively. The policy document on biofuels defines biomass as "biodegradable fraction of products, wastes and residues from agriculture, forestry and related industries as well as the biodegradable fraction of industrial and municipal wastes" (GOI, 2009).

Ethanol is manufactured in India by fermentation of molasses, which is by-product of sugar industry. India is fourth largest producer of ethanol in world after Brazil, the United States and China, with distillation capacity of 2,900 million liters per year. Government of India made 5 per cent blending of ethanol with petrol mandatory in nine sugarcane producing states in September 2002. However, due to supply shortage the mandate was made optional in October 2006. In October 2007, the government again made it mandatory 5 per cent ethanol blend in petrol across the country with exception of J&K, the Northeast and island territories. Now, the policy on biofuels has an ambitious target of 20 per cent blending by 2017 (See table 6).

**Table 6: Projected demand for petrol and diesel and the biofuel requirements of India**

| Year | Petrol demand in Mt | Ethanol blending requirement (in metric tons) | | | Diesel demand in Mt | Biodiesel blending requirements (in metric tons) | | |
|---|---|---|---|---|---|---|---|---|
| | | @ 5 per cent | @ 10 percent | @ 20 per cent | | @ 5 per cent | @ 10 per cent | @ 20 per cent |
| 2006-2007 | 10.07 | 0.50 | 1.01 | 2.01 | 52.32 | 2.62 | 5.23 | 10.46 |
| 2011-2012 | 12.85 | 0.64 | 1.29 | 2.57 | 66.91 | 3.35 | 6.69 | 13.38 |
| 2016-2017 | 16.40 | 0.82 | 1.64 | 3.28 | 83.58 | 4.18 | 8.36 | 16.72 |

Source: *Planning commission, Government of India.*
*Report of the committee on development of Biofuel,16th April 2003.*

Unlike in the US, Brazil and EU, the biodiesel industry, however, is not as mature and is still in incubation stage. The demand for diesel is four times the demand of petrol in India. Keeping this and other cost associated with conventional diesel fuel, GOI formulated National Biodiesel Mission in 2003. According to the Planning Commission report, by 2016-17, the demand for diesel is estimated to be around 84 million tones and with a 20 per cent blending requirement, the need for biodiesel would be around 17 million tones, cultivated over 14 million hectares in the country.

Indian bio diesel mandate is driven by multiple motivations. Biofuels are seen as a source of renewable energy with potential to create a new industry, to raise farmer incomes and to restore degraded lands, while promoting independence from oil imports and contributing to climate change. Second generation biofuel crops are seen as a possible solution to the biofuel driven land use change that has raised concerns in both developed and developing countries. The potential diversion or displacement of food crops is now considered a serious problem. Though Indian policy makers were careful and sensitive on this aspect, by envisaging bio-fuel cultivation only on uneconomic lands, the government has not accounted for the displacement of existing resource gathering and grazing activities by assuming them as waste land.

**Table 7: Etanol and Biodiesel Consumption in road transport by region in the New Policy Scenario (mboe/d)**

| | Ethanol | | Bio diesel | | Biofuels total | | Share of road transport energy use (in Per cent) | |
|---|---|---|---|---|---|---|---|---|
| OECD | 0.7 | 1.5 | 0.2 | 0.8 | 0.9 | 2.3 | 4.0 | 12.0 |
| Americas | 0.6 | 1.3 | 0.1 | 0.3 | 0.7 | 1.6 | 4.0 | 13.0 |
| United States | 0.6 | 1.2 | 0.1 | 0.3 | 0.7 | 1.5 | 5.0 | 15.0 |
| Europe | 0.0 | 0.2 | 0.2 | 0.5 | 0.2 | 0.7 | 4.0 | 12.0 |
| Non-OECD | 0.3 | 1.4 | 0.1 | 0.4 | 0.4 | 1.8 | 2.0 | 5.0 |
| E.Europe/Eurasia | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.0 |
| Asia | 0.0 | 0.7 | 0.0 | 0.1 | 0.1 | 0.8 | 1.0 | 4.0 |
| China | 0.0 | 0.4 | 0.0 | 0.0 | 0.0 | 0.4 | 1.0 | 4.0 |
| India | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 4.0 |
| Latin America | 0.3 | 0.8 | 0.1 | 0.2 | 0.4 | 1.0 | 10.0 | 20.0 |
| Brazil | 0.2 | 0.6 | 0.0 | 0.2 | 0.3 | 0.8 | 19.0 | 30.0 |
| World | 1.0 | 2.9 | 0.4 | 1.1 | 1.3 | 4.1 | 3.0 | 8.0 |
| European Union | 0.0 | 0.2 | 0.2 | 0.5 | 0.2 | 0.7 | 5.0 | 15.0 |

Source: *World Energy Outlook, 2013*

India has a mature ethanol industry, however the country is the world's largest sugar consumer, coupled with the fact that the manufacturing costs of ethanol is similar to that of petrol/diesel. The higher cost of cultivation of sugarcane/beets, highly sensitive molasses rates, and the resultant instabilities in the prices has created a ground to search for shift to other bio-diesel options.

Due to ethanol shortage during 2004-05, the blending mandate was made optional in October 2004, and resumed in October 2006 in 20 States and 7 Union Territories in the second phase of EBPP. These ad-hoc policy changes continued until December 2009, when the Government came out with a comprehensive National Policy on Biofuels formulated by the Ministry of New and Renewable Energy (MNRE) which targeted a 20 per cent blending of biodiesel and bioethonal with mineral diesel and gasoline respectively.

**IV National Biodiesel Mission 2009**

National Biodiesel Mission was proposed in a Planning Commission report of the Committee on Development of Bio-fuel, with an aim of meeting 20 per cent of fuel requirements of the country with biodiesel by 2011-12. The Policy aims at mainstreaming of biofuels and, therefore envisions a central role for it in the energy and transportation sectors of the country in coming decades. The Policy will bring about accelerated development and promotion of the cultivation, production and use of biofuels to increasingly substitute petrol and diesel for transport and be used in stationary and other applications, while contributing to energy security, climate change mitigation, apart from creating new employment opportunities and leading to environmentally sustainable development.

The scope of the policy encompasses bio-ethanol, bio-diesel and other biofuels, as listed below:-

i. 'bio-ethanol': ethanol produced from biomass such as sugar containing materials, like sugar cane, sugar beet, sweet sorghum, etc.; starch containing materials such as corn, cassava, algae etc.; and, cellulosic materials such as bagasse, wood waste, agricultural and forestry residues etc. ;

ii. 'biodiesel': a methyl or ethyl ester of fatty acids produced from vegetable oils, both edible and non-edible, or animal fat of diesel quality; and ,

iii. other biofuels: bio-methanol, biosynthetic fuels etc. (GOI, 2009)

The key aspect of this policy is to employ non-edible oil seeds cultivated on marginal and waste lands to achieve this target. After extensive research Jatropha seed was considered feasible for oil extraction in Indian Biodiesel mission. It would concentrate on producing enough feedstock for production, testing the viability of processes and to inform and educate the potential participants. The Indian government initially intended to plant Jathropa on 11.2 million hectares of wasteland by 2012 and achieve a 10% blending target. However, biodiesel production costs surpassed its purchasing price (which is predetermined by national regulators on a six month basis), thus effectively hindering the ambitious targets proposed by the government. Jathopra has been never grown as a commercial crop and its long term response to drought conditions and poor soil fertility is uncertain. Added to this very little is known about its seed and oil yields when grown in relatively dense block plantations (Achten *et al*, 2008). The plant response to fertilizers, water and pruning has not been well established in planting and management practices that vary widely. Annual growth and biomass production are highly variable - even between adjacent plants in the same filed - because the plant material has not yet been defined (Divakara *et al.*, 2009). Large scale cultivation of Jatropha must be established before biodiesel production can meet even a 5 per cent blending requirement nationally. But, amid reports of un-availability of Jatropha seed and overall negative energy balance of biofuel processes the National Biofuel mission and policy recommendations seems to hang in jeopardy (Negi *et al.*, 2006; Gonsalves, 2006; Singhal and Gupta 2012).

**Table 8: Waste land status in India**

| Sl No | Report Waste land | (m.ha) |
|---|---|---|
| 1 | Dept of Agriculture and Cooperation | 38.4 |
| 2 | National Remote Sensing Agency | 75.5 |
| 3 | National Bureau of Soil Survey and Land use | 187 |
| 4 | National Waste Land inventory Project (200) | 63.85 |
| 5 | National Waste Land Updation project (2003) | 55.64 |
| 6 | Ministry of Rural Development (2010) | 47.3 |
| 7 | Wasteland Atlas of India 2010 | 63.85 |

Source: *Mohan Dharia Committee (1995) and Wasteland Atlas of India*

The target set by the commission to achieve through Jatropha cultivation on waste lands led to several unanswered questions. In India, the true availability of waste land is highly uncertain, a situation largely caused by the overlapping and improper classification of common land, waste land and pasture land (Agoramoorthy *et al.*, 2009). The classification of wasteland in India is very ambiguous, with several reports coming up with several different estimations (Table 8). Mohan Dharia Committee on waste lands (1995) say that land use statistics available for 305 million hectares out of the 329 mha land in the country there is much confusion regarding wastelands in India ranging from 38.4 mha reported by Department of Agriculture and Cooperation to 75.5 mha reported by National Remote Sensing Agency (NRSA-1995) to 187.0 mha reported by National Bureau of Soil Survey and Land Use Planning (ICAR). According to TERI (2005) report they note that about 5.6 mha of wastelands have been allotted to many poor families under various programme, in addition to a large part of land being encroached for which there is no proper record. Given wide spread poverty among developing countries that there is no such non-productive or waste land as the marginal people are more likely to dependent on land for their livelihood and day to day survival. A government's definition of degraded or waste land is perhaps informed by the lands previous productivity or by the current absence of agricultural systems that produce commodities for the world market i.e bring in foreign currency and/or tax revenue, which is in odd with the view by local people (Dan Van der Horst and Saskia Vermeylen, 2011). Estimates of biodiesel capacity based on waste land availability are therefore likely to be inaccurate, which may create misleading cost-benefit analyses. When combined with highly variable seed yields, the displacement of informal land uses creates large uncertainties when determining the implications of widespread Jatropha plantation development.

In the longterm, lingo-cellulosics are likely to become the primary source of biofuels. It is important in each particular case to evaluate the sustainability of raw material production to ensure that biofuels are developed in areas that do not affect the use of the basic resources of agricultural ecosystems such as soil water air and biodiversity (World Energy Council, 2010). Although biofuels for aviation and shipping seem to be the most suitable solution, the implications for land use are enormous for the development of road transport biofuels (Philp *et al.*, 2013). A major debate continues world over about biofuels production and its impact on traditional agriculture, i.e., the perceived competition for land and the risk of displacing production of human and animal food by biofuels. Although land devoted to fuel production could reduce land available for food production, this is at present not a serious problem.

It is against this back ground an Indo-US bilateral JCERDC project for Development of Sustainable Advanced Ligno-cellulosic Biofuels Systems was initiated in America and India with multiple partners in consortium in each country. The consortium was led by University of Florida (UF) in America and Indian Institute of Chemical technology (IICT) in India. Centre for Economic and Social studies was associated with the work package component of Sustainability, Marketing and Policy and is looking into socio-economic and ecological impacts of biofuels cultivation in India. As a part of our work we conducted baseline survey in Madhya Pradesh state of India to know the existing scenario with reference to the proposed biofuel crops Jowar (Sorghum) and Bajra (Pearl Millet). Baseline survey also looked into different socio-economic aspects related to the sampled farmers. The objective of this working paper is to study the review of experiences from existing literature both at the global and specifically in the Indian context. This review study also looks at the sustainability of large scale biofuel projects and their impact in delivering twin benefits of energy security and environmental sustainability from the existing literature.

**V Review of literature**

Mario Giampietro *et al.*, (1997) assessed the feasibility of biofuel production as an alternative to oil by relating the performance of the biofuel energy system to the characteristics of both the socio-economic and environmental system in which the biofuel production and consumption takes place. They highlighted that specially, biofuel can substitute for fossil energy only if the large-scale production of biofuel is biophysically feasible (i.e not constrained by the availability of land and fresh water sources of energy crop production), environmentally sound (*i.e* does not cause significant soil degradation, air and water pollution, or biodiversity loss); and compatible with the socio-economic structure of the society (i.e requires labor productivity that is consistent with the existing labor supply and per capita energy consumption in the society). They observe that biofuel system must deliver a sufficiently large amount of net energy to society per hour of labor employed in the cycle of biofuel production to make the process economically convenient for society while generating a sufficiently low environmental loading per unit of net energy supplied to keep the process environmentally sound. They conclude that large scale biofuel production is not an alternative to the current use of oil and is not even an advisable option to cover a significant fraction on it.

George Francis *et al.*, (2005), in their article "A concept for simultaneous wasteland reclamation, fuel production and socio-economic development in degraded areas in India: Need, potential and perspectives of Jatropha plantations" highlights the need for alternative energy for India in the wake of ever growing transport needs. Noting that there is more than potential mismatch between the demand and supply of energy needs, they pitches for producing biofuel from Jatropha on eroded soils as it promises to achieve both wasteland reclamation and fuel security goals which is in line with Government of India's policy of national development. The authors pitch forth the cultivation of Jatropha given its advantages to achieve the triple benefits of transportation substitution fuel, soil protection and economic development. Citing the example of Soy bio-diesel, they say that the life cycle analysis show that it can reduce $CO_2$ and $SO_2$ emissions by 80 and 100per cent respectively compared to petro-diesel. They opine that the life-cycle carbon dioxide emissions, resulting from the production of bio-diesel from low-input, no-tillage, perennial Jatropha plantations (no application of chemicals) would be lower and is likely to be less than 15per cent compared to petro-diesel.

The study centers on preliminary economic analysis of the production system over a period and is based on the productivity of plants on degraded and currently unusable land with poor soils that have no opportunity costs. While an estimated net internal return of 21.8 per cent can be generated per hectare of Jatropha plantation, 16.0 per cent internal return is expected for a small scale biodiesel production plant with processing capacity of 2,000 tons of raw vegetable oil per year. At the same time the cost of producing a liter of biodiesel stands at 0.50 dollars. Though the results seem to be very viable option, they are not done under the assumption of steady yields and large scale cultivation which however proved to be impractical under Indian circumstances.

Domac J *et al.*, (2005), pointed that monetary gains and employment generation are viewed as the prime drivers of the present bio-energy projects. The authors ascertain that given the extreme complex nature of bio energy and its linkages with a number of aspects, the bio energy debate should not just be focused on the net return and employment but in effect look in to the different other aspects which include social, cultural, institutional and environmental issues. The paper clearly depicts significant contribution of bioenergy as a labor intensive technology, having the potential of creating employment at national, regional and local levels. However the employment depends on different processes employed and the different stages of conversion process. The authors also ascertain that there is a huge difference between bio-energy sector in the developed and the developing countries given its various linkages and complexities in it. In developing countries though bio energy can provide positive employment and income particularly during off-harvest season, the current practices employed would make it unsustainable and hence there is a need for modernizing traditional practices.

Larson (2006), summarizes the results of literature published on LCA studies of liquid biofuels in the transport sector. The review chiefly focuses on the impacts that production and use of biofuels might have on emissions of GHGs relative to conventional petroleum based fuels. The study highlights the drawback of lack of proper LCA analysis done in the developing countries. He notes that almost all biofuel LCA studies have been undertaken in European or North American context, while only one good study was available for Brazil and India (both based on Ethanol based from sugarcane). The author rightly observes that though European and North American context studies provide indicative results, but given the context specific variability and uncertainty around input parameter values in LCA analysis, country-or at least region specific studies are needed for providing quantitatively more meaningful results. The review also highlights the wide range of results in terms of net energy balances and net greenhouse gas emissions (expressed in terms of equivalent CO2) reported for a given biofuel and originating biomass. Quoting Quirin *et al.*, (2004), he says the results for any single biofuel pathway span a large rage in per-km savings relative to the use of fossil fuels. The authors notes that it is difficult to arrive at an unequivocal conclusions regarding the precise quantity of energy and environmental benefits given the diversity of LCA results. He ascertains that in order to understand the diversity there is a need to examine he details of each study regarding analytical boundaries, numerical input assumptions and methodologies used to generate the results. He concludes that higher GHG savings with biofuels are likely to be achieved only when there are high and ecologically sustainable biomass yields are there.

Muller *et al.*, (2007), perceives that the food vs fuel debate regarding biofuels is unwarranted as there is no imminent global shortage of land and water to grow a substantial amount of biomass for both food and bio-energy production. Though the growing demand for bio-energy will have a negative effect on food as higher food prices increases food insecurity among poor, on the positive side higher prices and more marketable production can stimulate agriculture sector by creating better employment opportunities. However, the authors agree that uneven distribution of natural resources resulting in regional differences would continue to have negative consequences unless trade related areas are addressed.

Rajagopal (2007) highlights the drawbacks in India's biofuel policy given India's dependence of rural poor on wastelands for diverse purposes. The national biofuel mission emphasizes cultivation of biofuel crops on waste lands, however majority of these lands are classified as common property resources (CPR), meaning that the community owns the resources collectively. Quoting Gundimeda H, (2005) the authors establish that CPRs contribute between 12 - 25 per cent of poor household income, and poorer the household the greater the dependence on CPRs. The study also highlights the loopholes in the categorization of land as wasteland in India given the change in parameters according to the regions and crops grown. The author states that conflicts are bound to exist if appropriation of wastelands without involvement of local communities in decision making, in addition to the problems of the lack of prior experience and absence of minimum support prices for biofuel crops. The author suggests multi-purpose short duration crops that can simultaneously yield food/fodder fuel can be cultivated in rotation with food crops as an alternative approach such that even small private farmers can benefit from the opportunities that come from biofuel crops.

Sunil Kumar *et al.*, (2008) in their study on "Economic sustainability of Jatropha biodiesel in India", assess the feasibility of bio-fuel production in terms of cost factors. They highlight the necessity of biofuel with reference to fuel shortages and international crude price fluctuations that frequently affect the country. The study also assesses the productive opportunities that are supposed to be created by bio fuel industry with reference to employment generation, and reclamation of waste and degraded land. It is estimated that crops like sunflower, rapeseed and tree borne oil seeds like Jatropha Curcas provide rich biomass and nutrients to the soil and check degradation of land - a major problem affecting nearly 65 million hectares in the country. Quoting Planning Commission report they estimate that out of 130 million hectares of wasteland in India, about 33 million are available for reclamation through tree plantation. Economic analysis of feasibility of biofuels in the country done using both primary and secondary data in Bhopal industry data show that while the cost of bio-diesel (specific gravity of 0.85) per liter stood at 30.91 rupees, while the retail price stood at Rs.37.81, much lesser than the international crude prices. Considering the economics, the authors conclude that Jatropha bio diesel can be more economical than petroleum diesel in the Indian scenario. However they opinion that though bio fuel blending is the need of the hour, nobody in the country is in favor of the implementation of a high tech agrarian methods that need maximum inputs to deliver bumper crops.

Pradip Kumar Biswas *et al.*, (2010), in their research article "Biodiesel from Jatropha: Can India meet the 20 per cent blending target?" attempts to make an assessment of the state of India's biofuel programme and to identify the hurdles that policy makers need to overcome to achieve the goal of 20 per cent blending. Due to the non-feasibility of using edible oils in India; as the domestic consumption demand often exceeds domestic production, Jatropha presents a viable option given its shrubby nature and short gestation period that makes harvesting easier. Added to that seed collection of Jatropha does not coincide with rainy season when most agricultural activities takes place, hence making it possible for people to generate additional income in the lean season, not to forget the general advantage of the plant vis-à-vis pest resistance and ability to survive on less fertile land. The authors discuss the important question of availability of land for Jatropha cultivation and the methods to bring land under it. While addressing the bottlenecks of biofuel programme and as conclusion present the state of commercial production of biodiesel in the country. The first important bottleneck with reference to large scale production of biodiesel using Jatropha is the different and divergent opinions about the identification and estimation of wastelands/ fallow lands in the country. In order to meet the Planning Commission estimated target of 20 per cent blending by 2016-17, the authors project that the need of the hour is economies of scale or large scale production that reduces prices. Planning Commission estimates that 20per cent blending requires 17 million tons of biodiesel that has to be cultivated over 14 mha. However, availability of waste land, issue of ownership, capital investment, long gestation period, risk of mono-culture, yield fluctuations in different climatic zones, handicaps with regarding extraction technology and most importantly the issue of price fluctuations large scale production of biofuel using Jatropha is not feasible in the country. Referring to the approach paper to the mid-term appraisal by TERI (2005) they note that in both forest and government owned wastelands, local communities are not willing to participate unless land ownership is given to them. The authors conclude that success of biofuel programme in India depends on solving various problems ranging from land identification, identification of farmers, diffusion of high yielding crops, and scale of processing plants, prices and subsidies to provide incentives to various stakeholders.

Giovanni Sorda *et al.*, (2010) reviews the national strategy plans of world's leading producers over the last decade, with particular attention to blending targets, support schemes and feedstock use. The article aims to identify the driving forces behind the recent growth of biofuel production, while also focusing on the agricultural products that are directly affected by local support schemes. The authors note that the last ten years (2000-2009) witnessed an increase of fuel ethanol output from 16.9 billion liters to 72.0 billion liters., while that of biodiesel grew from 0.8 to 14.7 billion liters. This is chiefly driven by government interventions like mandatory blending targets, tax exemptions and subsidies. In addition to production and consumption driven interventions, the government has also intervened on the production chain by supporting intermediate inputs (feed stock crops) and subsidizing value adding factors like capita and labor, not to forget the import tariffs that protect the domestic industries.

The authors note that without the government intervention, production is unprofitable and need to be driven by external incentives in the form of tax exemptions, subsidies or other form of financial incentives. In addition to these strongly distorting policies and criticism on food security, the biofuel life cycle assessment highlighted a negative net contribution to a reduction in GHG emissions. Hence the need for second generation of fuel crops is necessitated, which focuses on nonfood crops. Given these new challenges and concerns many countries are adopting new legislations. While U.S and EU now require substantial reduction in GHG life-cycle emission, the impact on bio-ethanol and biodiesel production on indirect land use has also been taken in to consideration as manufactures have to now certify the origin of the feedstock. Germany on the other hand has set its future biofuel targets in terms of GHG reductions rather than output volumes. However the authors note that it would a demanding task to couple capacity expansion with environmentally substantial production, while at the same time limiting biofuel burden on the state budgets.

Pere Ariza Montobbio and Sharachandra Lele (2010), study on "Jatropha Plantations for biodiesel in Tamil Nadu, India: Viability, livelihood trade-offs and latent conflict", focuses on the dimensions of productivity, economic viability and distribution and latent conflict of biodiesel plantations both the farm level and household levels. They also study how these observations vary across different socio-economic classes. They argue that integrated assessment of large scale biofuel production has a very low energy return on investment compared to fossil fuels while at the same time imposing heavy demand on land, water and labour per net GJ delivered. They observe that the government promotion of cultivation on private lands using state supported and corporate supported contract farming approaches in regions of poverty, agrarian distress and water scarcity have the potential to spark unanticipated conflicts. Citing Fargione *et al.*, 2008, they say that the claimed positive GHG emissions balance will be compromised by the "biofuel carbon debt" of converting forest or shrub ecosystems to energy crops.

The results of the primary study conducted in Tamil Nadu found that the yields are much lower than expected and its cultivation is currently unviable and even it potential viability is strongly determined by water access. Rather than alleviating poverty the crop impoverishes farmers particularly the poorer and backward sections and also promotes conflict between state and farmer and between different socio-economic classes. Agronomic assessment found that Jathopra requires at-least three years to start giving consistent economic yields. Though survival rates are high, they differed between rain-fed and irrigated areas, with plots in the irrigated areas reporting better survival. In accordance to existing literature the study found that Jatropha has high water footprint, as per unit consumption of this plant is 1.5 times more than Soyabean and 5 times more than Sugarcane/Maize. The highest yield in 3 year old plantation ranged from 450 kg/ha in rain-fed areas to 750 kg/ha in irrigated areas while globally reported yields show high variability ranging from 0.4 to 12 t/ha.

The economic viability of the plantations studied under three different scenarios of plots - irrigated with electricity pumpset, plots irrigated with diesel pumpsets and rain-fed crops, showed that, taking current yields net returns are always going to be negative even for irrigated farmers, when assumed that the best case results are at 3 year plant maturity (which however is not the reality). When the economic viability of Jatropha is compared taking in to consideration the opportunity cost of cultivating groundnut, it yielded unprofitable scenarios even under the assumptions of generating experimental level yields and non-factoring of interest burden. Given these poor agro-economic performances close to 30 per cent of the plantations were removed and other 50 per cent were kept without maintenance.

Impact on livelihoods has also been assessed considering the changes in the items that are valued outside formal markets. It has been noticed that the even when the cultivation becomes economically viable it benefits only large land holders and not people from lower sections of the society. Crop choice has complex implications for labour demand. Many of the activities in the livelihood portfolio are complementary and address different needs of the household; hence they cannot be conceptually aggregated into a single measure of income. The study also found a significant negative impact on food security as 82 per cent of the respondents were cultivating food crops in the plots which have been now shifted to Jatropha and 50 per cent of total land holding of household converted to this cultivation. A negative tradeoff has been noticed when the opportunity cost of not cultivating groundnut is taken in to consideration - an additional 3500 per year per household is incurred with regard to expenses for food (cooking oil), wage labour and fodder (from biomass of ground; one acre of groundnut or paddy yields cart load of paddy feed bullocks for 2 months).

Martin Banse *et al*., (2010), in their research article, "Impact of EU biofuel policies on world agriculture production and land use", discuss the impact of EU biofuel policies by extending the global general equilibrium model Global Trade Analysis Project (GTAP) by including biofuel crops in to the analysis. Though the extension does not present biofuels as separate products for final consumption, it enables analysis of the impact of targeted policies such as tax exemptions and obligatory blending for the petrol sector for individual regions and countries. The authors say that though biofuels provide additional income for farmers in an otherwise saturated market there are also concerns as they tend to increase the volatility of agricultural world prices by linking them with crude oil prices.

The results of the analysis show that enhanced demand for biofuel crops under the EU mandate has strong impact both at the global and regional level. The long term trend of declining real world prices of agricultural products slow down or may even be reversed for feedstock used for biofuels. At the same time increased incentive to produce also tends to increase land prices in many regions, especially in the South and Central Americans. However the results depend on the fluctuations of global crude oil prices on the higher side; the higher the crude oil prices, the more competitive the biofuel crops become. The analysis also establishes that the projected changes in production of biofuels would have environmental side effects. As biofuel crops are dependent on scare resources like land, water and other agricultural inputs, they tend to effect $CO_2$ balance, soil erosion and biodiversity. Also long run investments in R&D, higher yield varieties, better conversion technologies, coupled with strong government intervention is needed for the industry to be competitive. The study also ascertains the need for spatially explicit analysis at the regional level to measure the actual effect biofuel crop cultivation.

Study by Findalter and Kandilkar (2011), about second generation biofuel stocks in Rajasthan observed the specific local impact of rapid jathopra plantation development on both government and private lands on rural livelihoods. The study is based in Jhadol Tehsil of Rajasthan, a predominately semi-arid district and demography dominated by scheduled tribes. Jatropha grows naturally in this Tehsil and the villagers have traditionally planted it as a protective fence, while at the same time also using its seeds to make soap. Given the relative abundance of wasteland, prior association of the plant to this region, a plantation boom has developed after the launching of National Mission for Biodiesel in 2003, making this tehsil a frontrunner in national biodiesel programme.

In Rajasthan most of the waste land to be leased in Jatropha development is government or common land previously accessible to farmers and villagers for grazing, forage collection and resource gathering. The study observes that since the poorest villagers typically have the smallest land holdings - if any - the disappearance of common grazing land affects them disapportionately, as the use of accessible common land for plantation development may therefore have unintended local consequences by displacing grazing and forage collection. The study also found that the yields have been much less than anticipated and they have been handicapped in making use of public or private land, due to the reduction of grass levels on Jatropha planted land. The most severely impacted farmers and villagers are those with the smallest landholdings - typically the poorest as they tend to be more heavily dependent on public land for forage. None of the participants reported substantial income from the selling of seeds. Added to this there is an additional burden on them as all the villagers indicated that they had to buy additional fodder in years of low rainfall.

The study done by Peter Karacsony *et al.*, (2011) examined to what extent EU biofuel production and utilization can contribute to sustainable development of environment while at the same time produce long term socio economic effects. The study notes that to achieve the EU agreement dated 2007, which specifies a 10 per cent component of biofuel mix for 2020 within total fuel consumption, the basic ingredients will have to be cultivated on 38 per cent of the EU soil area with the remaining shared between plant cultivation for food and fodder purposes. The study notes that food supply, biofuel industry and environmental protection influence each other tightly, with safe supply of food being the most important. In the above connected system, the three factors namely, food, energy and environment compete with each other. Citing Gallagher report, they report that biofuel production impacts on safe supply of food which is already skewed due to the imbalance distribution of resources in the world. Added to the pressure on land, increase in cereal prices due to biofuels will have a direct impact on developing countries, while in developed countries where the higher added animal meat is consumed, there is an indirect impact. The study also notes that the decrease of $CO_2$ and other GHGs by using biofuel depend on raw materials, applied agricultural and production technology. Citing IEA report on biofuels for Transport's Life Cycle Assessment, they study notes that the best result was reached by the cellulose based second generation bioethanol (60-100 per cent GHG saving compared to conventional fuel), compared to 80-90 per cent of first generation sugarcane based ones.

Dan Van der Horst and Saskia Vermeylen (2011), in their article "Spatial scale and social impacts of biofuel production", provides a critical examination of the impact of biofuel policies within the framework of social impact assessment for both developed and developing countries. The paper explores how the social impacts of biofuel production may be at odds with the push to increase the production of liquid biofuels as global commodities. The authors also try to find out when and why negative social impacts are likely to occur and under what circumstances more positive impacts might be expected. The authors note though biomass energy has the potential to fulfill multiple objectives of environmental social, developmental/economic and supply security, in practice the choice of specific policy designs and project types often privileges the achievement of one policy objective at the expense of another. They argue that policies that are designed for a narrowly defined purpose of security of supply cannot be realistically expected to yield high social or environmental benefits. The production and use of biofuels is never carbon neutral, and at best it is less carbon intensive than petroleum products it displaces. Hence the justification of promoting biofuels hinges to a large extent on the question of how to avoid these negative social impacts and how to obtain positive social impacts.

The authors assess the social impact of biofuels in relation to the Inter-organizational committee on guidelines and principles for social impact assessment (IOCGP), which define social impact as the "consequences to human populations of any public or private actions that alter the way in which people live, work, play, relate to one-another, organize to meet their needs and generally cope as member of society. They maintain that SIA guidelines can be more easily implemented in a more participatory process, leading to no negative social impacts, even though when a project causes social impacts beyond national boundaries this tends to have negative impacts. The article highlights the social impacts of large scale biofuel among developing countries under three heads namely, land used for increased production, distribution of the different benefits among different sections of society and impact of large scale cash crops on rural livelihoods. They conclude that none of them have a positive social impact.

They rightly note that the displacement effect is also not included in the LCA analysis of liquid biofuels, given that they require a much more interdisciplinary and multi-method approach. The study envisages that involvement of rural communities in the production of liquid biofuels cannot be evaluated through simplistic proxies such as the number of jobs on the plantation or the average pay per worker. What is required is a much more detailed analysis of how the livelihood strategies and outcomes of rural communities and individuals are transformed by changes in land ownership, land management and land use associated with the switch toward production of biofuel. The major finding of the study is that though, production of transport biofuels could bring positive social impacts, these are very unlikely to emerge as automatic by-products of the large scale production of bio-ethanol or biodiesel, without strict regulation of the entire supply chain. Large scale and globalized production models are much more likely to result in negative social impacts, caused or exacerbated by the geographical, cultural and power divided between the governments and large companies who are driving this agenda forwards and the individuals and communities affected on the ground.

Umesh Babu M. S and Sunil Nautiyal (2012), in a study done on "Socio economic and Ecological Consequencesof Biofuel Development in India" highlight that biofuels and their production have failed to address challenges like supply of water and food security for the growing population in India as well as many other developing countries in the world. Added to the shortcoming like food security and lack of market linkages, the article notes that biofuels which are made from crops require enormous amounts of water which is already getting scarce. Bio energy is definitely an alternative energy for fossil fuels but it will compete with water which is required for food production. Referring to the Stockholm International Water Institute (SIWI) report the authors note that by 2050, the amount of additional water needed for bio energy production could be equivalent to the amount required by the agricultural sector. The biofuels are not 'the' solution but one of the solutions, and its production could be a great competitor to food production.

Meyer P. M *et al.*, (2013), assessed the Brazilian renewable sector which is considered as a pioneer not only in biofuel (sugar based ethanol) production but also in the use of ethanol as motor fuel. While highlighting that ethanol substitutes for a little over half of all the gasoline that would otherwise be consumed in Brazil, they assess how the bio-ethanol industry has affected livestock and agriculture production as well as environmental and social economic issues. They note that the success of Brazil's biofuel programme is due to greater consolidation as the gasoline contains 25 per cent of ethanol and its availability at all gas stations Added to this about 50 per cent and 90 per cent of existing and new car fleet being "flex fuel" (dual fuel, running on any proportion of ethanol and gasoline). The authors argue that the lack of structural regulations created greater instability in the production and consumption of alternative fuels leading to cycles of fuel substitution with negative effects to all stakeholders. For example the sector which grew at the rate of 10 per cent per year between 2000 and 2008, slowed down to 3 per cent after the financial crisis, creating supply constraints for ethanol based cars.

Comparing different studies based on the regional scenarios of both ethanol and cattle industry in Brazil over 1997 to 2006, they conclude that the pressure exerted by the sugar-ethanol industry on livestock is negative given the appreciation of land prices especially in the areas with high agricultural potential characterized by fertile and well drained soils and flat topography. In addition to this, given the bias of sugar-ethanol industry to large urban centers further aggravating the problem and leading to shifting of lands from cattle cultivation to sugarcane cultivation. As of a result of this livestock activity and the people who depended on this experienced three different situations 1) local migration where the farmers, abandoned livestock cultivation due to inadequate knowledge of sugarcane cultivation there by leasing out their lands. This phenomenon of rural exodus is more observed for small and medium farmers in southeast region who migrated mostly Sao Paulo. 2) Regional migration which affected medium farmers mostly, who exchanged their farms in southeast region for extensive areas at the agricultural frontier in Midwest and North regions, that resulted in clearing of native forest areas to move cattle to untouched areas. 3) Technological migration - pressure exerted by bioethanol industry on livestock by rising land prices resulted in technological migration as it led to change from extensive production system to intensive production system that require highly specialized techniques.

**Conclusions:**

Liquid fuels from biomass have already entered commercial markets in many countries especially as blends with gasoline and diesel. Though India has scope for developing biofuels for substitution of conventional fuels and achieving energy security due to availability of raw material, review of existing literature points out that R&D development, suitable policy support and most importantly global market balances are needed for avoiding negative externalities. Given that a vast majority of the population and livelihoods are interlinked to the agriculture and its surrounding environmental balances, a fine blend of policy decisions and technological break throughs are the need of the hour for achieving positive social impacts or at least negate the negative social impacts. Achieving the energy security of the country by alternate ways is an important area being focused by the Indian policy makers. However any attempt, to promote the use of major staple food crops such as Jowar and Bajra for biofuels production has long lasting impact on the food, fodder and nutritional security of millions of people and livestock in India. Cultivation of high biomass Jowar and Bajra varieties on a large scale could pose a serious threat to existing rich diversity in these crops. Hence even for trying out these crops at research level, it is very essential to have a dialogue with the farmers of dry-lands where these two crops are predominantly grown. Voice of small and marginal farmers and women should be heard before moving further in utilizing these crops for biofuel production. More importantly, we should learn from our earlier experiences of Jatropha cultivation. Large-scale biofuel production is not an alternative to the current use of oil and is not even an advisable option to cover a significant fraction of it (Giampietro *et al.*, 1997).The production of feed stocks for biofuels would put additional pressure on agricultural resources such as land and water. Therefore it is quite important that policies, plans and strategies for energy security do not conflict with other aspects of critical national importance like food security.

The review projects a mixed picture about the economic, environmental and social viability of biofuels. Except experiences related to Jatropha no literature is available with reference to biofuel production from food based crops in India. Experiences from Europe and other South American countries however provide opportunities to learn from prior experiences with regard to policy, technology barriers, especially with regard to conversion, problems associated with trade linkages and most importantly long run economic viability. A strong synergy of rationales like prospect of reduction in external dependence, better environment and creation of additional employment opportunities make a strong case for promotion of biofuels in India. However reviews suggest that it is difficult to achieve all of the objectives simultaneously and it would be a demanding task to couple capacity expansion with environmentally substantial production, while at the same time limiting biofuel burden on the state budgets. The outlook for biofuels is also highly sensitive to possible changes in government subsidies and blending mandates, which remain the main stimulus for biofuels use. Over the past year much uncertainty has developed about how biofuel policies in several key markets will evolve (IEA, 2013).

The production and use of biofuels is never carbon neutral, and at best it is less carbon intensive than petroleum products it displaces.There is also a huge difference between bio-energy sector in the developed and the developing countries given its various linkages and complexities in it. In developing countries though bio energy can provide positive employment and income particularly during off-harvest season, the current practices employed would make it unsustainable and hence there is a need for modernizing traditional practices. Most of the alternative energy policies are designed for a narrowly defined purpose of security of supply and cannot be realistically expected to yield high social or environmental benefits. The important barriers for successful implementation of biofuels come from farmers - the chief stakeholders, and given India's majority livelihoods linked and re-linked to agriculture, caution must be exercised in promoting biofuel production from food based crops. Hence the justification of promoting large scale biofuels hinges to a large extent on the question of how to avoid negative social impacts and how to obtain positive social impacts.

## References

Acthen *et al.*, 2008, "Jatropha bio-diesel production and use", *Biomass and Bioenergy*, 32, 1063-1084

Agoramoorthy G, *et al.*, 2009, "Can biofuel crops alleviate tribal poverty in India's dry lands?" *Applied energy*, 86, Pp S118-S124

AninditaKarmakar *et al.*, (2010), "Properties of various plants and animals feed stocks for biodiesel production", *Bioresource Technology*, 101 (2010), Pp 7201-7210

Basavaraj G, *et al.*, "A Review of the National Biofuel Policy in India: A critique of the need to promote alternative feed stocks", Working Paper Series No.34, ICRISAT, Hyderabad

Dan Van der Horst and SaskiaVermeylen (2010), "Spatial scale and social impacts of biofuel production", *Biomass and Bioenergy*, 35 (2010), December 2010, Pp 2435-2443

Demirbas, A(2009) "Progress and recent trends in biodiesel fuels", *Energy Conversion and Management*, 50:14-34

Divakar BN, *et al.*, 2009, "Biology and genetic improvement of Jatrophacurcas L: a review". *Applied Energy* 87, Pp 732-742

Domac J *et al.*, (2005), "Socio-economic drivers in implementing bioenergy projects", *Biomass and Bioenergy*, 28 (2005), Pp. 97-106

Donald Mitchell (2008), "A Note on Rising Food Prices", Policy Research Working Paper 4682, The World Bank, Development Prospects Group

FangruiMaa and Milford A Hanna (1999) "Biodiesel production: a review", *Bio-resource Technology*, Volume 70, Issue 1, October 1999, Pp 1-15

Findlater K.M and Kandlikar M. (2011), "Land use and second-generation biofuel feed stocks: The unconsidered impacts of Jatropha biodiesel in Rajasthan, India", Energy Policy, 39 (2011), Pp 3404-3413

Foley, J.A., *et al.*, (2005) "Global consequences of land use", *Science*, 309, Pp 570-574

Gathy A (2005), "Agri- environmental problems of the enlargedEuropean Union member states and national sustainable developmentstrategies", *Agricultural Sciences Publications*, 16 (special issue), Pp346-353

George Francis *et al.*, (2005), "A concept for simultaneous wasteland reclamation, fuel production and socio-economic development in degraded areas in India: Need, potential and perspectives of Jatropha plantations", Natural Resources Forum 29 (2005), Blackwell publishing, Pp 12-24

Giampietro, M., Ulgiati, S and Pimentel, D (1997) "Feasibility of large-scale biofuel production" *Bioscience*, 47(9), Pp587-600

Giovanni Sorda *et al.*, (2010) "An overview of biofuel policies across the world", *Energy Policy*, 38 (2010), Pp 6977-6988

GOI (2003), "Report of the committee on development of Biofuels", *Planning Commission*, New Delhi

GOI (2008), "National Action Plan on Climate change", *Prime Minister's Council on Climate Change*, 30 June, available at http://pmindia.nic.in/pg 01-52.pdf, Pp 1

GOI (2009), "National Policy on Biofuels", Ministry of New and Renewable Resources, NewDelhi

GOI (2010), "Wasteland Atlas of India", Ministry of Rural Development and National Remote Sensing Centre, New Delhi

GOI (2013), State of Indian Agriculture 2012-13, *Department of agriculture and cooperation*, Ministry of Agriculture New Delhi, Pp 1

Gonsalves, B. J (2006) "An Assessment of the Biofuels Industry in India", United Nations Conference on Trade and Development/DITC/TED/2006/6

Guinée, J. B., Huppes, G., Sleeswijk, A. W., Gorrée, M., Heijungs, R., Kleijn, R., *et al.* (2002) "Life cycle assessment: An operational guide to the ISO standards", Kluwer Academic Publishers

Gundimeda H (2005), "Can CPRs generate carbon credits without hurting the Poor?" *Economic and Political Weekly*, Vol - XL No. 10, March 05, 2005, Pp. 973-980

Hay, J., (2007)"Extreme weather and climate events and farming risks", in Srivakumar, M.V.K., Moth. R, (eds), "Managing weather and climate risks in agriculture", *Springer*, Berlin, Meidelberg, Pp-1-19

Heintzman, A, and Solomon, E. (2009). "Food and fuel: Solutions for the future", House of Anansi Press,Toronto

IEA (2013), "Renewable Energy Outlook", *World Energy Outlook* 2013, Chapter 6, Pp 197-232

IPCC (2007) Solomon, S., et.al., (eds.), "Climate Change 2007: The Physical Science Basis", Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Joseph B. Gonsalves (2006), "An Assessment of the Biofuels Industry in India", United Nations Conference on Trade and Development, UNCTAD/DITC/TED/20066

Lipsky, John (2008), "Commodity Prices and Global Inflation", Remarks at the Council of Foreign Relations", New York City

Knothe, G, Sharp, C.A and Ryan, T.W. (2006) "Exhaust emissions of Biodiesel, Petrodiesel, NeatmethylEsters, and Alkanes in a new technology engine". *Energy Fuels*, 2006;20: Pp 403-408

E. Larson (2006), "A review of LCA studies on liquid biofuels for the transport sector," *Energy for Sustainable Development*, Volume X No. 2, June 2006, Pp109-126

Mario Giampietro *et al.*, (1997), "Feasibility of Large-scale biofuel production - Does an enlargement of scale change the picture"? *BioScience*, Vol. 47, No.9 (Oct 1997), Pp 587-600

Muller Alexander *et al.*, (2007), "Some insights in the effect of growing bio-energy demand on global food security and natural resources", Paper presented at the International Conference "Linkages between energy and water management for agriculture in developing countries", Hyderabad, 28-31, January 2007

Martin Banse *et al.*, (2011) "Impact of EU biofuel policies on world agriculture production and land use", *Biomass and Bioenergy*, 35 (2011), Pp 2385-2390

Meyer P. M *et al.*, (2013), "Impact of biofuel production in Brazil on the economy, agriculture and the environment", *Animal Frontiers*, April 2013, Vol. 3, No.2, Pp 28-37

Negi, K., Komal, JK and Ranjan, P (2006) "Promotion of Biofuel in India: Issues and Prospects", Society for Promotion of Wastelands Development (SPWD), New Delhi

Jos G.J. Olivier *et al.*, "Trends in Global CO2 Emissions: 2013 Report", Netherlands Environment Assessment Agency (2013), The Hague

Puppán, D. (2002) "Environmental evaluation of biofuels", *Periodica Polytechnica Ser. Soc. Man. Sci.*, 10, No (1), Pp 95-116

Peer *et al.*, 2008, "Second Generation Biofuels: High-Efficiency Micro algaefor Biodiesel Production" *Bioenerg. Res.* (2008), Pp 1:20-43

Pradip Kumar Biswas *et al.*, (2010), Biodiesel from Jatropha: "Can India meet the 20per cent blending target?" Energy Policy 38 (2010), Pp 1477-1484

Pere Ariza Montobbio and Sharachandra Lele, (2010), "Jatropha Plantations for biodiesel in Tamil Nadu, India: Viability, livelihood trade-offs and latent conflict", *Ecological Economics* 70 (2010), pp 189-195

Peter Karacsony *et al.*, (2011), "The role of biofuels in sustainability of the environment" in Mohammed Behnassi *et al.*, (eds) "Global Food Insecurity: Rethinking agricultural and rural development paradigm and policy", Springer 2011, Pp245-256

Philp, J.C., Guy,K and Ritchies, R.J. (2013) " Biofuels development and the policy regime"*Trends in Biotechnology*, Vol.31,No.1, January 2013, Pp 4-6

Rajagopal, D. 2007, "Rethinking current strategies for Biofuel production in India", paper presented at International Water Management Institute conference, Hyderabad, India, 29-30 January 2007, accessed on 18th September 2014, http://Jatropha.pro/PDFper cent 20 bestanden/Rethinking per cent 20 current per cent 20 strategies per cent 20 for per cent 20 Biofuel per cent 20 production per cent 20 in per cent 20 India.pdf

Singh B.R and Singh, Omkar (2006), "Necessity and potential for biodiesel use in India", Proceedings of International Conference on Bio Fuels Vision 2015, October 13-15, 2006, College of Engineering., Bikaner, Rajasthan, India, Paper no. 023

Sunil Kumar *et al.*,(2008), "Economic sustainability of Jatropha biodiesel in India", *Journal of Environmental Research and Development*, Vol.3 No.1, July-September 2008, Pp 292-300

Singhal, R and Gupta Ramprasad Sen(2012) "Energy security and Biodiesel -Implications for Land use and Food Security", *Economic and Political Weekly*, Vol. XLVII No.40 Pp66-73

Steven Raj Padakandla (2014), "Climate Sensitivity and Crop Yields: A Study of Agro Climatic Zones in Andhra Pradesh", Unpublished Thesis, Andhra University, Vishakapatnam

TERI (2005), "Liquid biofuels for transportation: India country study on potential and implications for sustainable agriculture and energy", New Delhi

Thomas W Hertel *et al.*, (2010), "The Global Impacts of Biofuel Mandates", *The Energy Journal,* Vol. 31, No. 1, Pp 75-100

UmeshBabu M. S and Sunil Nautiyal(2012) "Socioeconomic and Ecological Consequencesof Biofuel Development in India", NUPI Working paper No. 807, Norwegian Institute of International Affairs 2012

UNCTAD (2008), "Biofuel Production Technologies: Status, Prospects and Implications for Trade and Development" UNCTAD/DITC/TED/2007/10