

PROCEEDINGS OF

SAARC
Regional
Training
Workshop
on

Bio fuels



Heritance Hotel, Kandalama, Sri Lanka
22 to 26 September 2008

Organised by
SAARC Energy Centre
&
Sri Lanka Sustainable Energy Authority

In technical collaboration with
Sri Lanka Energy Managers Association

Proceedings Published by

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ON BIOFUELS**

**22-26 September 2008
Kandalama, Sri Lanka**

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SAARC Energy Centre, Islamabad
&
Sri Lanka Sustainable Energy Authority**

Workshop Organizing Committee

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Mr. Lalith Gunasinghe, Manager (Project)

Foreword

SAARC Energy Centre (SEC) under its Technology Transfer program organized a one-week SAARC Regional Training Workshop on Biofuels, in cooperation with Sri Lanka Sustainable Energy Authority (SEA) on 22-26 September 2008 at Dambulla, Sri Lanka. The objective of the Workshop was to provide latest in-depth knowledge on the technology, status and prospects of biofuels to the professionals of the SAARC region. The Workshop was attended by 49 participants including official nominees of the SAARC Member States (Bangladesh, Bhutan, Nepal, Pakistan and Sri Lanka), professionals from SEC, SEA and other energy sector organizations of Sri Lanka. The resource persons included eminent professors and high profile professionals from India, Sri Lanka, Sweden and USA.

SEC pursues a policy of seeking cooperation and support of energy institutions of the Member States to implement its program activities. We are grateful to the Government of Sri Lanka and Sri Lanka Sustainable Energy Authority for having set an example for others by jointly organizing the Biofuels Workshop with SEC. We also thank Sri Lanka Energy Managers Association (SLEMA) for their strong professional support to our activities.

It is a matter of great satisfaction that pursuant to the Workshop on Biofuels, we are now publishing its proceedings in cooperation with the Sri Lanka Sustainable Energy Authority. I hope that it will provide useful information on various aspects of biofuels to policy makers, professionals, entrepreneurs and other stakeholders.

Islamabad, May 2009

Hilal A. Raza
Director
SAARC Energy Centre

Introduction

A one-week SAARC Training Workshop on Biofuels was organized by SAARC Energy Centre (SEC) and Sri Lanka Sustainable Energy Authority (SEA) in technical cooperation with Sri Lanka Energy Managers Association (SLEMA) on 22-26 September 2008 at Dambulla, Sri Lanka. It was attended by 49 participants including nine official nominees of the SAARC Member States; professionals from SEC, SEA, academic institutions and energy sector organizations of Sri Lanka. The Workshop was organized with the following objectives:

- Impart training to the participants selected from the Member States to acquire knowledge on present global and regional status and future prospects of biofuels;
- Provide knowhow on the latest trends and technologies to produce and use biofuels from the available resources;
- Provide a platform for sharing experience with each other;
- Help Member States to reduce their import dependence on oil; and
- Promote regional cooperation in biofuels.

The inaugural session held in Taj Airport Hotel, Seeduwa, was presided over by Mr. W.B. Ganegala, Secretary Ministry of Petroleum and Petroleum Resources Development. The Hon. A.H.M. Fowzie, Minister for Petroleum and Petroleum Resources Development sent a message wishing the success of the Workshop. The participants, resource persons, key government officials, academics and professionals from the local industries of Sri Lanka attended the inaugural session. The inaugural session was addressed by Mr. Ananda S. Gunsekara, Chairman SEA; Dr. Muhammad Pervaz, Program Leader, Technology Transfer, SEC; Mr. Chandana Samarasinghe, Director General, SEA; Mr. Harsha Wickramasinghe, Deputy Director General, SEA; and Mr. Wickramnayake, Director, Pelwatte Sugar Industries limited, Sri Lanka.

Three international resource persons were invited for the Workshop including Prof. Shang-Tian Yang, Professor of Chemical and Bio-molecular Engineering of Ohio State University and Director, Ohio Bio-processing Research Consortium, USA; Dr. Francis Xavier Johnson, Research Fellow, Climate and Energy Programme, Stockholm Environment Institute Sweden; and Mr. Phani Mohan Kancharla, Independent Consultant and Expert on Sugar and Ethanol Industry, India. In addition, eleven resource persons including professors and energy professionals from Sri Lanka made presentations on different aspects of biofuels with special reference to Sri Lanka.

The working sessions of the Workshop were held in Heritance Kandalama Hotel at Dambulla. The team of international and Sri Lankan resource persons covered wide range of topics related to biofuels in 25 technical sessions of the Workshop. Prof. Shang-Tian Yang also introduced his recent research on production of Butanol from cellulose in biorefinery. Butanol can be used in gasoline engine without any modification which could be

a better replacement of gasoline than ethanol. The participants and resource persons enriched the discussion by sharing the practical experiences and knowledge on biofuels. The country representatives from Bangladesh, Bhutan, Nepal, Pakistan and Sri Lanka presented the country reports highlighting the status and initiatives of biofuels in their respective countries. A field visit was also arranged to Jatropha plantation for bio-diesel production in Sri Lanka. Certificates of participation were awarded to all participants and resource persons. Participants expressed high level of satisfaction over the deliberations of the resource persons, selection of topics, selection of venue, arrangements and supports provided by the organizers. It is expected that they could now be in a better position to help their governments in efforts to introduce or enhance use of biofuels.

The proceedings of the Workshop contain papers presented by international and Sri Lankan resource persons, country representatives, highlights of discussions during technical sessions etc. It includes regional and international perspectives, biofuels plantation (issues and options), technical, environmental, regulatory and legal aspects of production, distribution and consumption, economics and applications of biofuels, research and development and case studies. Proceedings provide deep insight into the opportunities and impediments regarding the development of biofuels in South Asia. For wider dissemination, the proceedings have also been uploaded to the SEC website: www.saarcenergy.org.

SAARC Energy Centre appreciates and acknowledges the sincere support and cooperation of the Sri Lanka Sustainable Energy Authority and Sri Lanka Energy Managers Association in co-organizing the Workshop and compiling its proceedings.

Dr. Muhammad Pervaz
Program Leader, Technology Transfer
SAARC Energy Centre

Islamabad, May 2009

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A. Regional and International Perspective

Summary of the Regional Status

Prof. R.A. Attalage
University of Moratuwa, Sri Lanka

Countries in the South Asian region have recently shown great interest on liquid biofuels falling in line with the international scenario of this sector. Almost all countries have paid much attention at the national level expressing their commitment and interests by way of policy formulation, strategy development, and financial mechanisms strengthening together with the participation of the private sector into the equation. The recent initiative through the ProBios program has thrown light on the topic and thus fuelling the related activities.

Nepal being an agricultural country has potential for ethanol from sugarcane and oil from seeds with reference to biofuels. Due to the economies of scale and productivity reasons, it seen that cost of sugar production in Nepal is high compared to those of neighbouring countries and has resulted recently to the closure of some sugar mills. A cabinet decision was taken in 2004 to mix 10% ethanol into gasoline. However, this has not come into effect due to a difficulty in agreement for a price for ethanol between the state owned oil company and sugar mills. The oil company itself is facing a financial crisis because of state regulated low oil prices. Moreover, private entrepreneurs have been discouraged from entering the biofuels business due to lack of favourable policies related to the sector.

In Bangladesh even though the contribution from biomass to the national energy requirement is more than 50%, awareness on liquid biofuels appears to be rather low. Even though the climate for oil-seeds such as jatropha or castor-oil is favourable, it is almost impossible to establish plantations for biofuels due to its population density. There are a few regions where large-scale plantations are possible, but these are restricted due to political and other reasons. Further, small-scale plantations are not likely to be economically viable to the farmers. Some Government owned land could be an option to commence. Feasibility studies on biodiesel and identification of the suitability of plants are under way.

The transport sector of Sri Lanka is entirely dependent on imported petroleum oil. Sri Lanka has the possession of a state owned oil refinery which is at the verge of expansion. The recent energy policy of Sri Lanka has focused on biofuels even though there is no dedicated policy for biofuels as such. With the enforcement of vehicle emission standards that is going to take place shortly, biofuels can play an important role as an accelerator to supplement the fuel quality standards in this context. There is no specific ministry or agency directly responsible for biofuels, but around eight

ministries have direct or indirect relations therein.. Sri Lanka has the capacity to produce ethanol from sugar molasses at its sugar factories, although this is currently only done for the alcoholic beverage industry. Several small scale initiatives have taken place to explore the possibility of biodiesel from non-edible oil seeds such as rubber, neem, jatropha etc. Even though Coconut oil could serve as feedstock for biodiesel, edible oils would not be under consideration here. A robust roadmap for biofuels focusing ethanol, biodiesel & compgas has been established at national level in 2006.

Maldives being a country with a large number of small islands has its main source of income from fisheries, tourism and coconuts. Maldives is a net importer of petroleum. The government is conducting feasibility studies to produce biodiesel from coconut shells. Used cooking oils are another possible feedstock under consideration.

In the context of India, in view of short term alternatives for the transport sector, a significant attention is paid to biofuels with a focus on emission levels and climate change aspects. Indian government does not look upon land used for edible agriculture diverted to producing biofuels. In this connection, the biodiesel options are only waste oils and crops that can be grown on marginal lands while those for ethanol are by-products from the sugar and food industry. In 2002, India's ministry of petroleum and natural gas announced a policy indicating that 5% ethanol would be blended with gasoline from January 2003 in nine states and four Union Territories. However, the program did not start as expected due to shortage of molasses supply. The blending program was then made compulsory from November 2006 in almost all Indian states. Research is being conducted by various agencies to blend 10% ethanol with gasoline and blend ethanol with diesel. Moreover, in 2003, India's Planning Commission recommended a program for development of biodiesel. It had envisaged that in the first phase, a demonstration program would be taken up for undertaking plantations of jatropha on 400,000 hectares of degraded / waste land. It had further projected that a blend of 20% biodiesel could be achieved by 2011-12, which would require 13.4 million hectares of jatropha plantation.

The Ministry of Petroleum and Natural Gas announced a biodiesel purchase policy in October 2006. In addition, the Ministry of New and Renewable Energy Sources has drafted a national policy on biofuels.

Discussion

Mr. N de S Cooke

The exact extent of land under the cultivation of *Jatropha* in Sri Lanka is not known. *Jatropha* grows wild, but no one harnesses fuel from it. There are relatively small scale cultivators of *jatropha* doing about 400 ha (1,000 acres). There are other non-edible crops such as 'Pongamia' that can be used for production of biodiesel. But, no one cultivates on a commercial scale for the purpose of biodiesel.

Dr. Sanja Gunawardena

Sri Lanka has other non-edible oil sources and one which we do not discuss very much often is rubber seed oil. We have 118,000 ha of rubber cultivation in Sri Lanka. According to literature, we can collect about 450 kg of seeds from a ha. If oil is extracted at an efficiency of 20% and convert that into biodiesel at an efficiency of 65%, we can get about 5,000 tons of biodiesel. No one is doing this at present and we have the resources. Currently, someone is already collecting rubber seeds which they use in soap and paints industries.

Mr. M U Ranasinghe

One company in Sri Lanka is collecting rubber seeds for producing biodiesel. As far as I know, they have tons of rubber seeds collected in a warehouse.

Prof. S A Kulasooriya

Rubber seed oil also is a very important source that has not being recognised and it is readily available in Sri Lanka. But as per reports, the free fatty acid content of the rubber seed has to be removed in order to convert it to a fuel. Some researchers at the Chemistry Department of University of Peradeniya have developed methods to remove free fatty acids to use as a fuel. There is an international group right now prepared to financially support as a private – public partnership to utilise the source of rubber and Prof. Kulasooriya could facilitate the company collecting rubber seeds or any other interested parties.

Mr. N de S Cooke

Economic analysis of using rubber seed oil for biodiesel production has not known to be carried out in Sri Lanka. It is known that rubber seeds are used in the soap industry and therefore there is a necessity to compare using of rubber seeds for biodiesel production with the economics of using them in the soap industry. Although no calculations have been carried out, at the small scale, rubber seed based biodiesel production is at-least

about 3-4 times expensive due to the cost of the chemicals. The market forces would determine whether using rubber seeds for biodiesel production is viable not

Prof. S A Kulasooriya

It is too pre-matured to talk about economic analysis or break-even point calculations right now because we are working out the techniques. Once techniques have been worked out, then, we have to look at the economics and opportunity costs related to soap, paint and other industries. Demand for rubber for paint industry has gone down because no they are using synthetic material in place of rubber seeds.

Dr. C S Kalpage

The cost of production of rubber seed based biodiesel at the laboratory level is about LKR 350 per litre which is expensive. It is with methanol purchased at LKR 200 per litre whereas, when it is bought in larger quantities, it would be around LKR 60 per litre.

Mr. N Mumtaz

Since *Jatropha* is grown on waste land, the amount of irrigation water that is required has to be found as availability and diversion of irrigation water is essential

Prof. S A Kulasooriya

According to the experience, Prof. Kulasooriya has not used any irrigation water at all for cultivation of *jatropha*. If it could be planned to plant in Sri Lanka as the rainfall is such that, if plantation can be synchronised with rain, *jatropha* plantation of around 400 ha of extent can sustain without irrigation. But when it comes to 100s of ha, irrigation may be necessary. Sri Lanka has a rainfall of over 1,000 mm even in the dry zone. Although the rain is confined to a few months, a sufficient rainfall is there in Sri Lanka, and it may not be same to the rest of the SAARC region. At the moment, it can be said that Sri Lanka has a fair extent of land where *jatropha* can sustain without any irrigation.

Biofuels from an International Perspective

Prof. Shang-Tian Yang, Ph.D

The Ohio State University Columbus, Ohio 43210 USA

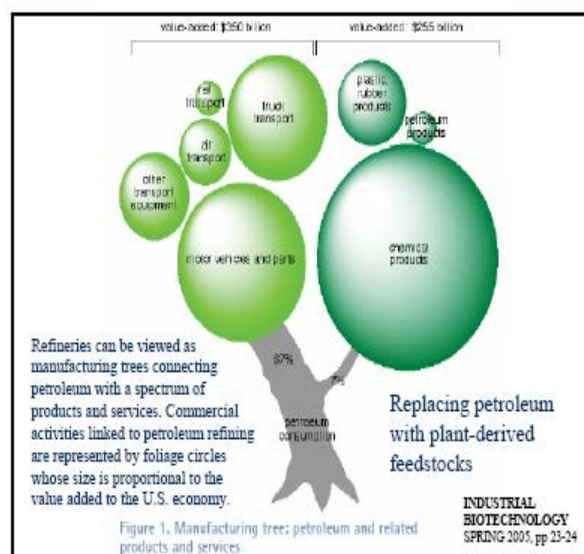
Abstract

This presentation introduces the concept of integrated biorefinery for producing biofuels, biochemicals and other value-added bioproducts from renewable biomass including agricultural residues and processing wastes. In the US, biomass represents an abundant carbon-neutral resource that can be converted to energy and chemicals to replace fossil fuels and petrochemicals. An integrated biorefinery utilizes all components of the biomass feedstock to produce fuels and chemicals to improve environmental impact, process economics and meet market needs. This paper will provide a brief review on the current status of corn ethanol and challenges facing cellulosic ethanol. Lignocelluloses, the second generation feedstock, are the most abundant biomass found in almost all plant derived materials, from wood and grass to agricultural residues. However, their uses in biorefinery for fuels production are limited by the difficulty of breaking down cellulose to fermentable sugars. Besides ethanol, butanol and hydrogen are two promising biofuels that can also be produced by microbial fermentation of carbohydrates. Although they have better fuel properties, including higher energy content, than ethanol, butanol and hydrogen are expensive to produce using conventional technologies. White biotechnology, the application of biotechnology to industrial production of fuels and chemicals, holds many promises for sustainable development, but many products still have to pass the test of economic viability. Integrated biorefinery producing high-value bioproducts and converting by-products or processing wastes to biofuels and biochemicals can significantly improve the economics of biofuels and biochemicals.

Biofuels from an International Perspective

Integrated Biorefinery – Production of Biofuels and Biochemicals from Biorenewable Resources

Shang-Tian Yang
Department of Chemical and Biomolecular Engineering
Ohio Bioprocessing Research Consortium
The Ohio State University



Industrial Markets

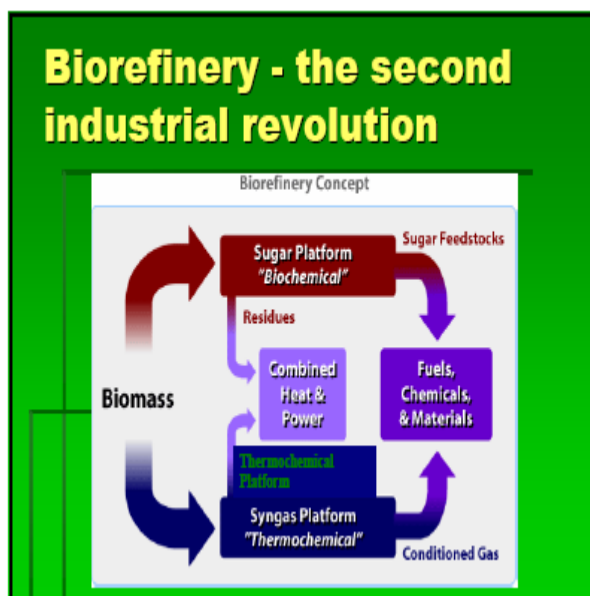
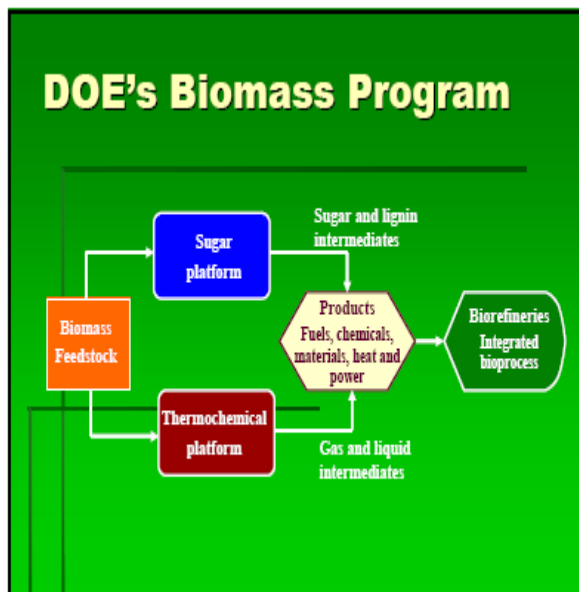
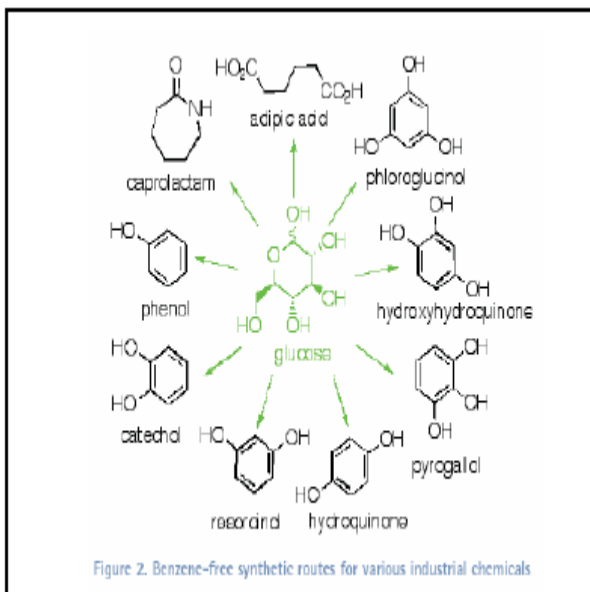
- Chemical industry – over \$2 trillion on sales worldwide
 - commodity chemicals, specialty chemicals, consumer care products, and pharmaceuticals; plastics/polymers
 - uses nearly \$24 billion worth of hydrocarbon feedstock annually in the US.
- Fuel and energy (in the US)
 - Gasoline: 160 billion gallons; Diesel: 64.3 billion gallons
 - Ethanol (mainly from corn): 12.8 billion gallons in 2008
 - Biodiesel (from soybean oil): 375 million gallons in 2007

Biofuels

- Alcohols
 - Ethanol
 - n-Butanol
- Hydrogen
- Biodiesel
- Methane (biogas)
- Microbial and algal oils and hydrocarbons

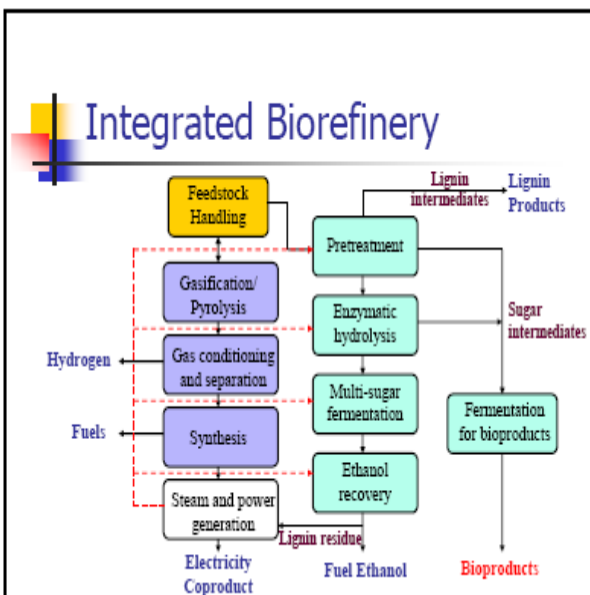


http://www.atozfilms.com/film/corn_ethanol_gas.jsp?channel&keyword&channel_rapped_from_headlines



What is a biorefinery?

- Biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuel, power and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum.



What is biomass?

- Biomass means any organic matter that is available on a renewable or recurring basis (excluding old growth timber), including dedicated energy crops and trees, agricultural food and feed crop residues, aquatic plants, grass, wood and wood residues, animal wastes and other waste materials.

Biomass Feedstock

	Biomass Production (10 ⁶ dry ton)	Heating Value (GJ/dry ton)	Energy Potential (10 ⁶ GJ)
Agricultural residues	203	17.0	3.5
Forestry residues	167	19.0	3.2
Municipal solid waste	111	12.7	1.4
Excess cropland	680–1,361	19.0	13–26
Potential cropland	405–1,087	19.0	7.7–21
Forest land	262	20.0	5.2
Total	1,828–3,190	–	34–60

Production data from: Appl. Biochem. Biotech. 39/40, 41–59 (1993)

Annual biomass potential from agricultural resources in the United States

Agricultural resources	(10 ⁶ dry tons)
Crop residues	446
Grass and woody crops	377
Municipal solid waste	111
Grains to fuels	87
Animal manures	44
Food processing residues	44
Total	998

Oak Ridge National Laboratory, Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility for a Billion-Ton Annual Supply, U.S. Department of Energy, DOE/GO-201995-2135, 2005

Annual biomass potential from forest resources in the United States

Forest resources	(10 ⁶ dry tons)
Logging residues	64
Excess biomass thinning	60
Fuel wood	51
Mill processing residues	145
Urban wood residues	48
Total	368

Oak Ridge National Laboratory, Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility for a Billion-Ton Annual Supply, U.S. Department of Energy, DOE/GO-201995-2135, 2005

Starch and Sugar Crops

Crop	Production (10 ⁶ metric tons)	Starch	Sugar	Protein	Oil	Fiber
		(dry basis, wt%)				
Corn	695	72	-	10	5	13
Wheat	628	80	-	14	-	5
Rice	619	89	-	8	1	2
Soybeans	210	16	16*	40	21	5
Sugar cane	1,290	-	55	-	-	45
Sugar beet	243	-	68	6	-	7
Sweet sorghum	59	-	50	-	-	50

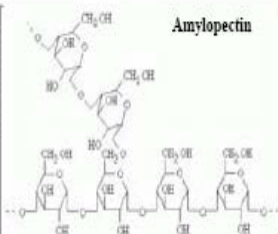
2005 data from FAOSTAT Database available at <http://faostat.fao.org/>
*including sucrose and soluble oligosaccharides

Lignocellulosic Biomass

Feedstock	(dry basis, wt%)			
	Cellulose	Hemicellulose	Lignin	Other
Bagasse	40	24	25	11
Corn stover	40	25	17	18
Corn cob	39	35	15	11
Corn fiber	15	35	8	42*
Rice straw	35	25	12	28
Wheat straw	38.2	21.2	23.4	17.2
Wheat chaff	38	36	16	11
Switch grass	45	31	12	12
Hard wood (hybrid poplar)	44.7	18.6	26.4	10.3
Soft wood (pine)	44.6	21.9	27.7	5.8
Waste paper	76	13	11	0

*including 23.7% starch.

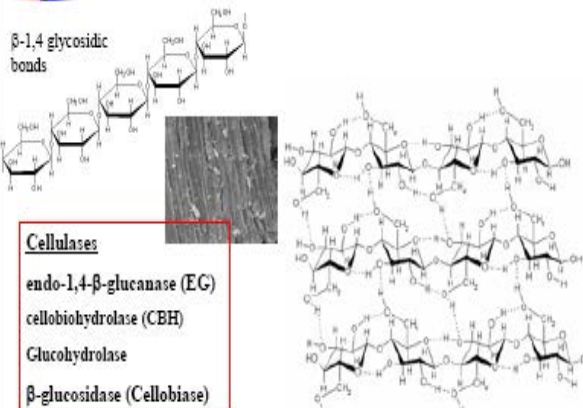
Hydrolysis of Starch

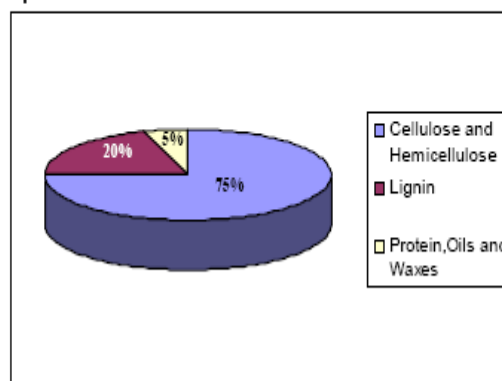
Enzymes

- Polylalanase** – debranching, cut at α -1,6-glycosidic branching bonds
- α -amylase** – starch liquifying enzyme, randomly cut
- β -amylase** – saccharifying enzyme, cleave two glucose units at a time from the non-reducing end α -1,4-linkage
- Amyloglucosidase (glucoamylase)** – cleave one glucose unit at a time from non-reducing end α -1,4-linkage

Hydrolysis of Cellulose



Composition of lignocellulosic biomass



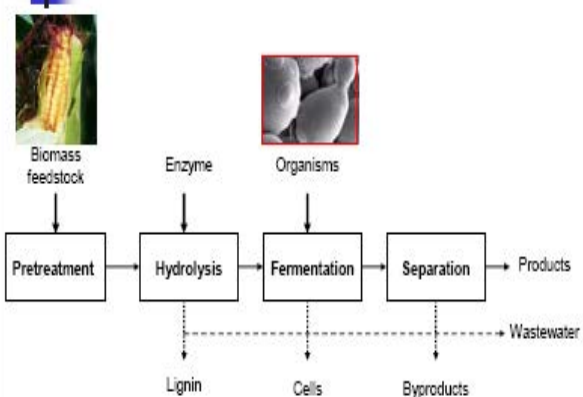
Thermochemical Platform

- Gasification (650-900 °C)
 Reacts with air, oxygen, steam, CO₂
 Product: CO, CO₂, H₂, CH₄
- Pyrolysis (450-500 °C) in absence of any reactive compounds or oxidants
 Product: Pyrolysis oil
 It converts all components of biomass including lignin, which is resistant to biological conversion, to building block.

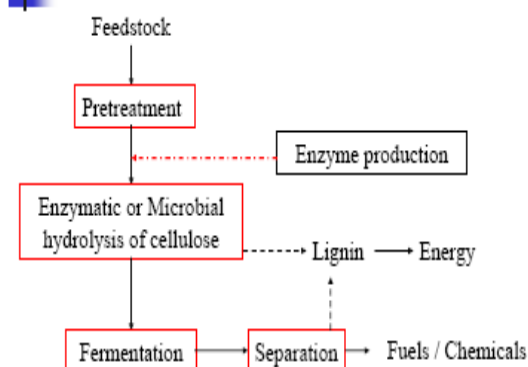
Technical Barriers for Thermochemical Platform

It cannot compete with fossil fuel in its cost. Clean syngas and pyrolysis oil represents 60% of the total capital cost. Other barriers are syngas utilization, process integration, thermal processing, feed processing and handling, sensors and controls.

General bioprocess flowsheet



Sugar Platform



Hydrolysis

Acid hydrolysis

Enzymatic (Microbial) hydrolysis

- Hemicellulose + H₂O → Xylose + Glucose
- Cellulose + H₂O → Glucose
- Sugar + acid catalyst → Furfural + H₂O

Pretreatment

- Prehydrolyze hemicellulose
- Reduce lignin content
- Decrystallize cellulose
- Increase accessible area for enzymatic hydrolysis
 - Steam explosion (200-217°C, 3.53 MPa, 2 min.)
 - Hot water pretreatment
 - Dilute acid pretreatment (HCl or H₂SO₄, 170°C)
 - Ammonia fiber explosion (AFEX)

Dilute acid pretreatment

- Toxic byproducts after pretreatment
 - Acetic acid, Formic, Levulinic acid
 - Furfural, 5-hydroxymethylfurfural
 - Phenolic compounds (vanillin, p-hydroxybenzoic acid, coniferylaldehyde, etc.)
- Detoxification
 - Sulfite, Anion exchange, Enzyme treatment,
 - Activated carbon, Wood charcoal
 - Overliming with hydroxide or oxide of alkaline metals

AFEX

(ammonia fiber explosion)

- It treats biomass with liquid ammonia under pressure followed by explosive pressure release to enhance the conversion of cellulose and hemicellulose to fermentable sugars (90-110 °C).
- The operational conditions:
T, P, biomass moisture content, ammonia loading, residence time

Biofuels

- Alcohols
 - Ethanol
 - n-Butanol
- Hydrogen
- Biodiesel
- Methane (biogas)
- Microbial and algal oils and hydrocarbons



http://www.atomfilms.com/film/canvafford_gas.jsp?channelKeyword=channel%20ripped%20from%20headlines

Ethanol



- Current production is mainly from corn and sugarcane by yeast fermentation
- Potentially can be produced from lignocellulosic biomass (switch grass, etc.)
- Low level blends (5% - 20% ethanol in gasoline)
- High level blends (85% ethanol in gasoline)
- Replacement of MTBE (methyl tert butyl ether) in gasoline
- Fuel cell

U.S. Ethanol Production

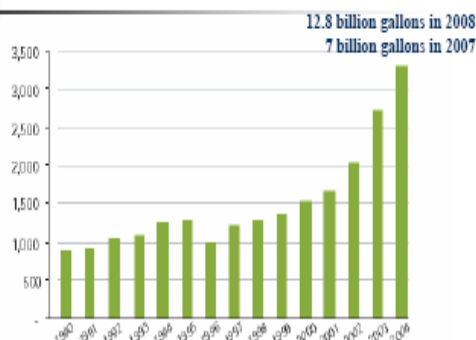


Figure 1. Annual U.S. ethanol production, 1990-2004 (millions of gallons)
Source: Energy Information Agency

U.S. Ethanol Production

Feedstock	Ethanol Capacity	
	MMG/Yr	% Share
Corn	3,372	95%
Milo	81	2%
Wheat Starch	69	2%
Agricultural Waste	20	< 1%
Whey	10	< 1%
Seed Corn	4	< 1%
Other	2	< 1%
Total	3,557	100%

Figure 4. U.S. installed ethanol capacity by feedstock (as at January 2005); MMG/Yr = millions of gallons/year

Source: BB Ethanol, Vortex Energy LLC

U.S. Ethanol Production

Rank	Company	Ethanol Capacity		Ethanol Plants	
		MMG/Yr	% Share	Number	% Share
1	Archer Daniels Midland	1,070	30.1%	2	2%
2	Cargill	118	3.3%	1	1%
3	Avertine Renewable Energy	100	2.8%	1	1%
3	NewEnergy Corp.	100	2.8%	1	1%
3	VeraSun Energy	100	2.8%	2	2%
4	ING P Ingredients	90	2.5%	3	3%
5	Abergoes Bioenergy	65	2.4%	1	1%
6	Chief Ethanol Fuels	62	1.7%	1	1%
7	A.E. Staley	60	1.7%	1	1%
8	Ag Processing	52	1.5%	1	1%
9	Midwest Grain Processors	50	1.4%	1	1%
10	Other	1,670	48.9%	72	83%
Total Capacity and Plant Count		3,557	100.0%	87	100%

Attribute	Grain Ethanol	Bioethanol
Feedstock	Primarily corn; also wheat, sorghum, other	Agricultural waste, energy crops, forest residue, municipal solid waste
Feedstock Cost	High	Low
Ethanol Conversion Process	Enzymatic hydrolysis fermentation	Acid hydrolysis fermentation Enzymatic hydrolysis fermentation Pyrolysis gasification
Scale of Production	High-volume commercial production	Pilot production
Cost Profile	Uneconomic without subsidies	Currently uneconomic; potentially competitive
Cost Reduction Potential	Modest	Significant
Greenhouse Gas Reduction (E10 fuel blend)	2%	8% - 10%
Net Energy Balance	+ 20,000 - 25,000 Btu per gallon	+ 60,000 Btu per gallon

Figure 7. Comparison of grain and cellulosic ethanol in terms of feedstock, process, cost profile, greenhouse gases, net energy balance

Fermentation Process

- Separate hydrolysis and fermentation (SHF)
- Simultaneous Saccharification & Fermentation (SSF)
 - Cellulase is added to the fermentation broth
- Simultaneous Saccharification & Cofermentation (SSCF) - Cellulase is added to the fermentation broth, slurry containing both cellulose and xylose is added to the fermentation broth. Glucose and xylose are fermented simultaneously.
- Consolidated Bioprocessing (CBP)
 - Production of cellulase, hydrolysis of biomass and fermentation of resulting sugars (Glucose and Xylose) to desired bioproducts occur in one step

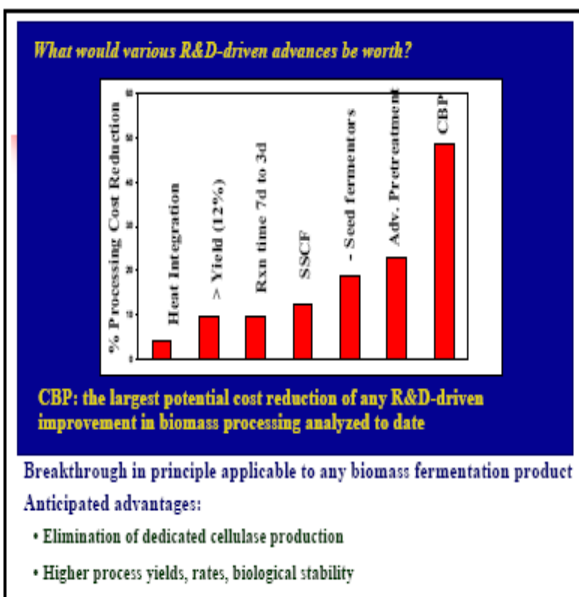
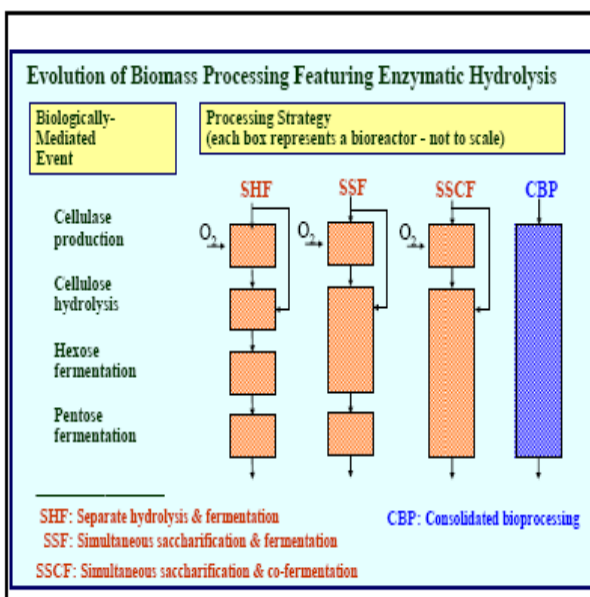
Simultaneous Saccharification and Fermentation (SSF)

Advantages:

- End-product inhibition is decreased
- Higher yield and productivity
- Low risk of contamination

Disadvantage:

- Different optimum temperatures for cellulase and microorganism



- ### Ethanol fermentation challenges:
- Yeast: use glucose with high ethanol yield and titer; but cannot use xylose
 - Bacteria and filamentous fungi: utilize both xylose and glucose, but low ethanol yield and titer
 - **Challenge 1:** Engineering strains to utilize both xylose and glucose with high ethanol yield and titer
 - Cellulase producing strains, but no/low ethanol production
 - **Challenge 2:** Engineering strains to produce both cellulase and ethanol



U.S. Department of Energy
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Biomass

Top Value Added Chemicals from Biomass

Building Blocks
1,4 succinic, fumaric and malic acids
2,5 furan dicarboxylic acid
3 hydroxy propionic acid
aspartic acid
glutaric acid
glutamic acid
itaconic acid
levulinic acid
3-hydroxybutyrolactone
glycerol
sorbitol
xylitol/arabinitol

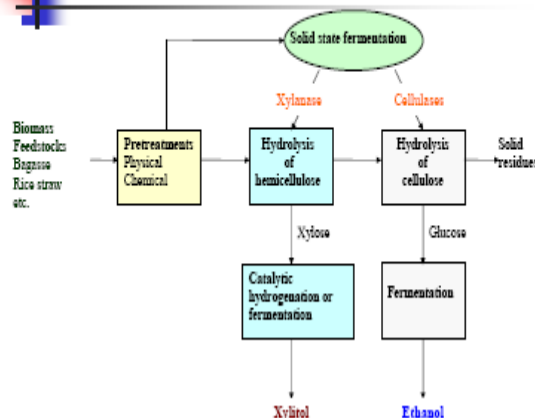
This report identifies twelve building block chemicals that can be produced from sugars via biological or chemical conversions. The twelve building blocks can be subsequently converted to a number of high-value bio-based chemicals or materials. Building block chemicals, as considered for this analysis, are molecules with multiple functional groups that possess the potential to be transformed into new families of useful molecules. The twelve sugar-based building blocks are 1,4-diacids (succinic, fumaric and malic), 2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, aspartic acid, glutaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol.

- ### Technical Barriers for Sugar Platform
- Pretreatment: thermochemical prehydrolysis of biomass
 - Yield of hemicellulosic sugars (60%-70%)
 - Solid concentration (19%)
 - Impurities of the sugar solutions
 - Enzymatic hydrolysis
 - Enzyme cost
 - Thermostability of enzyme and sugar end-product inhibition
 - Dosage (g enzyme/g biomass)

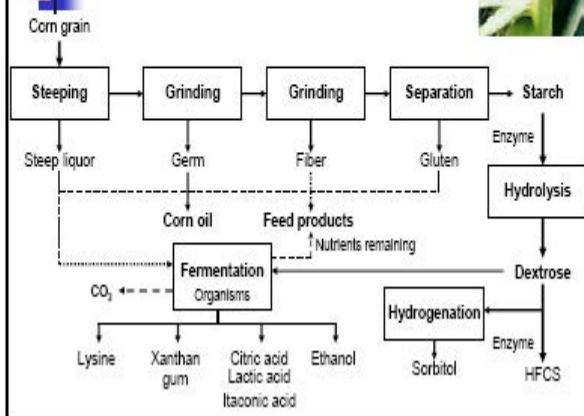
Biotransformation to Chemical Building Blocks

- Fermentation pathway (may be unknown)
- Improving microbial biocatalyst to 1) reduce other acid coproducts, 2) increase yields and productivities
- Lower costs of recovery process to reduce unwanted salts
- Scale-up and system integration issue

Integrated Biorefinery



Corn refinery



Refining Use of Corn in USA (2004)

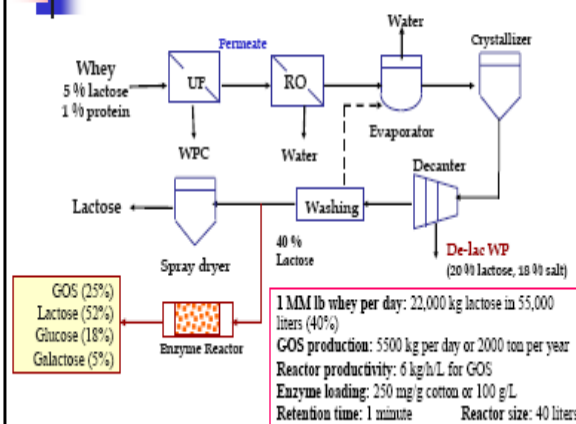
- Corn production – 11.8 billion bushels (300 million tons)
 - ~500 million bushels in Ohio;
 - 56 lbs corn kernels per bushel
- Corn refined – 2.669 billion bushels
 - HFCS: 515 million bushels; 23.5 billion lbs
 - Glucose & Dextrose: 222 m.b.; 9.34 b. lbs
 - Starch: 280 million bushels; 6.68 billion lbs
 - Fuel alcohol: 1,325 m.b.; ~2 billion gallons
 - Beverage alcohol: 133 m.b.
 - Cereal & other products: 189 m.b.
- Corn refining byproducts - ~17 million tons
 - Corn gluten meal, corn fiber, steep water
 - 25% to 30% weight of the corn refined

Cheese Manufacturing in USA

(2005)

- Milk production - 177 billion lbs
- ~91 billion lbs milk used in cheese production
- Generating ~82 billion lbs liquid whey
 - 7% T.S. - ~5.7 billion lbs whey solids
 - 5% Lactose - ~ 4.1 billion lbs lactose
- Less than 50% of whey solids has economical use
- Surplus whey must be treated to reduce BOD before discharge to environment

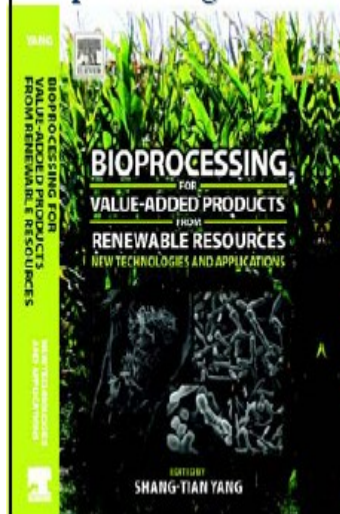
Whey Processing



Economic Production of Bio-based Products

- Low-cost feedstock
- Efficient fermentation process
 - Productivity
 - Final product concentration and purity
 - Product yield
 - Process stability and scalability
- ❖ Microbe or cell factory
- ❖ Bioreactor
- ❖ Product recovery and purification

Bioprocessing for value-added products



- Higher-value products from agricultural commodities
- Better uses (disposal) of processing wastes
- Natural, healthier consumer products
- Environmentally more friendly products
- Zero-emission or non-polluting processes

Conclusions and Summary

- White biotechnology: The application of biotechnology to industrial production holds many promises for sustainable development, but many products still have to pass the test of economic viability
- Some biofuels and biochemicals can (will) be economically produced from biomass to replace oil-derived fuels and chemicals
- Integrated biorefinery with value-added products can significantly improve economics and sustainable development

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Discussion

Mr. Xavier Johnson

It has taken a long duration that expected for enzyme development to bring down the cost of lignocelluloses.

Prof. Shang- Tian Yang

United States Department of Energy has invested tremendous amount of money to enzyme companies to bring down the cost and improve the cellulase performance and they have some degree of success. Currently, the enzyme costs consist of about 30-40% of the raw material cost. It is too expensive and if you want to buy them from an enzyme company, they want to make money. The performance is not getting yet to be economically competitive with coal and starch based or sugar

based material. So, this is an area which is still being heavily researched. People are looking at consultative process instead of producing cellulase. Cellulase is a separate process, than using in the fermentation since you can combine 2 processes into one, then you can potentially reduce the cost using the lignocellulose material in an economic way.

The sugar is the way to go to be sustainable. There is a transition period. Because you already have so many refineries already in place and the technology, you only need to do is to change the feedstock. There are also a lot of barriers to do this because the composition of the Biomass is lot more complicated and also collection of the feedstock is a big issue. Coal or oil come in large quantities, so they can be processed in a

Dr. Sanja Gunawardena

You mentioned Corn steep liquor is used in many fermentation processes to make the fermentation faster and more efficient. The micro organisms need not only the carbohydrates and sugar, but also elements like Phosphorous.

Prof. Shang- Tian Yang

Corn steep liquor is used in many fermentation processes to make the fermentation faster and more efficient. The micro organisms need not only the carbohydrates and sugar, but also elements like Phosphorous.

Md. L Rahman

From the statistics given by you, particularly from the USA, it is seen that the crops for bio-energy are the ones used as food and its uses is on the increase. Don't you think this creates a major constraint on the food at least in the foreseeable future?

Prof. Shang Tian- Yang

The point is well taken. Corn price has been staying low in the last 10-15 years in the USA. It was about US\$ 2.00 to 2.50 per bushel. The only way to increase the price for the farmers is everyone using corn. Corn is exported to Europe and Asia etc by the USA. Because of the advanced technology and the large land availability, USA produces more corn than meat. That is why even 5 years ago, Ethanol or Biodiesel is not economical. Petroleum was very cheap at that time. Agricultural lobby is the largest push for Ethanol use, so they can maintain good price for corn. Of course everything changed since 2 years ago with crude oil prices escalating from US\$45 per barrel to nearly US\$ 150 per barrel (Though during last few weeks it fell below US\$ 100 per barrel).

With the quick rise in the oil prices, everyone jumped into Ethanol production for a bigger profit. That also jumped the corn prices from about US\$ 2.50 per bushel to about US\$ 8.00 per bushel. Suddenly everyone realised that is not the way to go because we need to eat and before we eat the beef steak, we need to feed the cow. Everyone complain that food prices have increased by 100% in the last year or 2, and that is why the government is saying that it is not sustainable. The problem is that energy is important for daily life of the Americans or other people of the world and here we can walk, you can ride a bike, but in the USA, in many cities, you can't survive if you don't drive. This means you have to have gasoline or biodiesel for transportation. So you have to produce some kind of biofuel. Affordable feedstock for society is required. That is why the research on feedstock has become a priority for the

Department of Energy today, looking into alternative or other crops.

Dr. Muhammad Pervaz

I would ask rather a policy question. Have you produced Butanol from the route proposed? How do you see the future? When or in how many years we would see a bio refinery producing Butanol for fuel purposes?

Prof. Shang-Tian Yang

Bio Butanol is economical today to produce from corn or crop for the chemical market. The Butanol price increased almost double to about US\$ 6.5 per gallon. This makes the fermentation process economically attractive. However, to use Butanol as biofuel, you need to further lower the cost to be competitive with Ethanol and other Biofuels. That requires more work. There are 1000s of Biofuel companies funded by the Venture Capitals in the last few years for the production of bio Butanol. For many investment groups we were talking to, they all were having a very promising future because Ethanol is not really Biofuel, it is a transition from petroleum fuel gasoline to Biofuels and Butanol is much better. Only this can be produced economically and used for Biofuel.

Mr. N Mumtaz

This is more of a comment. The USA has done a lot of research. One model that can be attributed to be that is just giving subsidies to farmers. It has raised the price of corn. Further more, at the WTO, it faces a lot of criticism from agriculture subsidies. Even WTO talks collapsed due to the resistance to do away with the subsidies despite having surplus of food, they would dump it than export or give it to food deficient countries. It is possible that the technologies which the USA is introducing or using may not be cost effective in other countries. There are dangers if we straight away adopt or try to replicate the same technologies with other (SAARC) countries. Their technology may not be workable because the technology in the USA is subsidy based.

Prof. Shang- Tian Yang

5-10 years ago, corn Ethanol had government subsidy in order to be economically attractive for investors. There was a large profit for the corn Ethanol producers in the last 3 years. On the other hand, the stock market price went up a lot because corn prices also went up. I agree with you that the governments should not subsidise corn Ethanol and it should be governed by the free market based on demand and supply. Many people invested in it and they want to cover their investments. So they continue to lobby the government to subsidise the fuel Ethanol.

B. Biofuel Plantation: Issues and Options

Agronomic Realities and Opportunity Costs of Biofuel Plants

Prof. S. A. Kulasooriya

Emeritus Professor of Botany, University of Peradeniya, Sri Lanka

Biofuel is defined as solid, liquid or gas fuel derived from recently dead biological material and is distinguished from fossil fuels which are derived from biological material that have died millions of years ago and undergone decomposition under anaerobic conditions. These conditions will not be repeated in nature and hence fossil fuels are considered to be non-renewable.

Theoretically, biofuels can be produced from any (biological) carbon source including animal fats, although the most common sources are photosynthetic plants. Biofuels are currently classified as 1st generation (vegetable oils, biodiesel, bioalcohols, biogas, solid biofuels and syngas), 2nd generation derived from cellulosic material from non-food material and/or crop residues (biohydrogen, biomethanol, mixed alcohols, wood diesel), 3rd generation (algal biofuels) and 4th generation (waste vegetable oils, pure plant oils and straight vegetable oils).

The first diesel engine demonstrated by the German engineer Rudolph Diesel was run on peanut oil. This indicates that diesel engines were originally made to operate on vegetable oils. Therefore any oil of plant origin has the potential to be converted to a fuel suitable to run diesel engines. Similarly many simple carbohydrates like sugar can be converted to ethanol either microbiologically or chemically and this can be used as fuel for petrol engines. Thus biofuels can be made from edible oils such as soya oil, corn oil, sorghum oil, palm oil, coconut oil etc., as well as from non-edible oils like *Jatropha* oil, *Pongamia* oil and rubber seed oil.

It is important to realize the negative impacts of converting edible oils or food sources such as sugarcane to biofuels because this could lead to a battle between food and fuel. This is especially relevant to countries of the SAARC region where poverty is prevalent as the 1st victims of such a battle would be the less endowed poor people. As the President of Sri Lanka declared, we should avoid converting edible oil to fuel and refrain from utilizing lands suitable for crop production to grow phyto-fuel plants.

Among the non-edible oil producing plants, *Jatropha curcas* has gained worldwide recognition as a drought resistant perennial plant capable of growing well in impoverished soils with minimum

inputs and it also has the advantage of not being browsed by herbivores. These features make this plant an ideal contender for the production of biofuels with little or no competition with food crops.

With its origin in the Central American region *Jatropha curcas* was most likely introduced to Sri Lanka by the Portuguese some 500 years ago and has been well naturalized. It can be seen in most parts of the country except in the high elevations, but is predominantly found in the lowland dry zones commonly as a fence post plant and its local names *Weta Endaru* and *Pala Ini* denote this meaning. Though people are familiar with the plant and the ease with which it grows, there had been no attempts to grow it on a plantation scale until recently. With renewed interest in *Jatropha* as a biofuel plant several requests have been made to the Government to obtain State land for the large scale cultivation of this plant. On a request made by the Honourable Minister for Environment and Natural Resources, the author undertook the responsibility of examining the possibility of large scale field cultivation of *Jatropha curcas* in Sri Lanka.

This presentation would mainly deal with a project initiated by the Department of Forest Conservation under the guidance of the author to examine the field cultivation of *Jatropha curcas* in the intermediate and dry zones of Sri Lanka. As an extension of the program a large scale cultivation of *Jatropha* on a 100 acre land in collaboration with a private investor is also included. Through a series of photo illustrations the steps taken and the progress so far made in these activities would be presented. While the photos would illustrate the successes achieved, the difficulties, pitfalls and problems that were encountered during project implementation and the possible solutions tested would be discussed.

Based on data obtained from other countries particularly India, certain projected calculations on biodiesel production to meet the demand for diesel in Sri Lanka would be presented.

With regard to opportunity costs a brief treatment on the basis of a more generalized biofuel production would be attempted in relation to 1st, 2nd and 3rd generation feed stocks. While a discussion on opportunity costs on global attempts to introduce biofuel usage is presented it was found premature

to discuss this aspect in the Sri Lankan scenario as a State Policy on the use and marketing of Bio-fuel in Sri Lanka is yet to be declared

Discussion

Dr. Muhammad Pervaz

For South Asia, do you recommend that the first step in using Biofuels is for power generation and then for transportation sector?

Prof. S A Kulasooriya

South Asia will be producing relatively small quantities of Biofuels compared to fossil fuels. Therefore, always it is useful to have a priority in terms of its usage. Although, we must take them to the world market, the countries should look inwards, and evaluating what is better. It is a decision the policy makers should take. In my opinion, in terms of usage, it has to be prioritised. We should first go for power generation in small scale where there is no national grid electrification. And then, if you also allow the use of these fuels, to farmers as the next priority because they are producing the food (water pumping, tractors and alike) and then the fishermen for their out boat motors as they also bring food. Other vehicles come only next.

Mr. Buddika Gunaratne

You have shown plantations done in different parts of the country. Are those from local *Jatropha* varieties? We also have done some field trials where we have got the seeds from India. India has apparently done a lot of research in developing better varieties of *Jatropha*. We clearly noticed that the Indian varieties are much better in giving the yield and a growth. We had two similar plantations under similar conditions. As a country, shouldn't we look at this since India has already developed the seeds which can give better a crop? Shouldn't we look at getting down those seeds and cultivate rather than doing research on Sri Lankan varieties?

Prof. S A Kulasooriya

The seeds we used are entirely local. Unfortunately, the approach by the private sector (like yours) is something that I would not subscribe to very much. The immediate response of the Indian delegate who is present here with us who is a private entrepreneur is that *Jatropha* is a failure in India. You can get more information about more *Jatropha* work in India from him. A yield of 1.5 – 2. kg of *Jatropha* seeds per plant is on the lower side, which is the Indian yield average. Although you have got some seeds and they have shown some growth initially, it has to be tested for the

not have a solution. At the same time, you have to realise that these seeds that come from foreign countries whether it is India, Indonesia or Australia could carry certain micro organisms & eggs of certain pests that could damage your plants in Sri Lanka. So any imported seed variety should have been subjected to quarantine or they should at least be supported with a sanitary certification from the origin to say that these seeds are safe. The damage is if you bring in some unexpected and unknown pathogens, pests, fungal, bacteria or insects. We should never depend on foreign germ-plasms entirely

Prof. S Subasinghe

Regarding your mono crop plantations, your calculations were based on 2,500 plants per hectare. Once we do a sole plantation, definitely you have to go for private sector because the community based farmers would not take an interest as they have to wait for some time. In our experiments at Nikaweratiya over the last 2 years, when we asked the communities to grow *Jatropha*, they refused in the first instance. They suspected that the soil fertility would reduce and they needed quick yield and an income, within a season, within few months of time. My question is, if we go for these larger scale plantations, what are the benefits to the community? Other question is on biodiversity. If we go for larger plantations in the scale of 1,000 hectares of *Jatropha*, what would happen to biodiversity?

Prof. S A Kulasooriya

As a botanist, I never go for monoculture. Even these plantations are not really monoculture. We are intercropping by growing *Gliricidia*. I also have a plan to introduce *Pongamia*. We have not planted the entire 100 acres there. So that will also act as a biological barrier in case of there is a pest infestation. Even for small scale farmers, we will be advising not to use monoculture in any case. Upto 2 years, we can go for short term crops such as *mun*, *cowpy*, chillies, tomatoes to get a short term income and that will keep them away from weeds. After 2 years of course, it would depend on the markets. Right now the market for *Jatropha* is not attractive. I don't think that anybody in this audience could say how much a kg of *Jatropha* seeds will fetch in Rupees. We have no market or a market price today. Once a market is established, all these comparisons will be made. Therefore, the community based activities have to be developed in an area where we are productive. In your case, my personal view is that we should encourage the communities to reintroduce *Jatropha* as a fence based plant. The yield predicted of a fence based *Jatropha* is something between 0.8 – 1.0 kg per tree. But even then it is protecting their

property. Some thing that they don't have to do is to direct much attention. They can grow all the crops in their territory.

Mr. Anwar Sadat

Does Jatropha seeds need any further processing?

Prof. S A Kulasooriya

Jatropha has a hard shell that you can de-shell. There are some small machines that do it. The hard shells are used for other forms of energy such as burning or what ever. You get the kernel and get a higher percentage of oil. When I went to South India, Tamil Nadu to Chennai and Coimbatore, they have machines to grind the shells. That is easier in terms of commercial larger scale where you just take the seed and crush it with the shell. The shell goes as an organic fertilizer. But, otherwise, without the shell, you get a higher yield of oil extraction. After you esterify to convert oil into Biodiesel, you get Glycerine as a by-product which also has got a market. You can use the oil for heavy machinery and generators without any further processing. However, if you want to use fuel injection engines, then you have to esterify, that is converting the acids into esters and reducing water. That is the only processing I am aware of.

Biofuel Plantations: Issues and Constraints

Prof. S. Subasinghe
University of Ruhuna, Sri Lanka

Abstract

The most current problem of the country is facing the fuel crisis and a large sum of money is spent on importing petroleum to Sri Lanka. It has increased from Rs. 80.2 billion (US\$ 991 million) in 2003, Rs. 270 billion (US\$ 2.5 billion) in 2007 and projected to exceed Rs. 324 billion (US\$ 3 billion) in 2008, which is 400% increased with compared to 2003. Therefore there is an urgent need to find out alternatives for petroleum fuel and one such alternative is Bio-fuel. Therefore the aim of the paper is to discuss the possibilities of growing bio-fuel plantation in Sri Lanka, and their issues and constraints. Studies conducted in many countries have found a number of alternatives to petroleum. Vegetable oils are such alternatives for diesel, which can be extracted from oil bearing crop/plant species such as *Jatropha*, Rubber (seed oil), Neem, Oil palm, Coconut, Soybean etc. which are grown in Sri Lanka.

The other major promising area is Algaeculture, which is comparatively new area of producing bio-fuels especially in developing world. More recent studies conducted using a species of algae with 50% oil content have concluded that 250 times higher bio-diesel from algae can be produced than the amount per acre of soybean produced. Ethanol is most widely used alternative fuel, which can be made from high starch containing crops such as cassava and maize, or high sugar containing crops such as sugarcane which are also grown in Sri Lanka.

At present, around 12 million litres of alcohol are produced annually at Pelwatta and Sevanagala sugar factories, which can be used to blend petrol. Those are some possible alternatives for bio-fuel production in Sri Lanka, but the government policy of not to use food crops for bio-fuel production is a problem for using food crops to produce bio-fuel. Then only non food crops and by-products of food crops can be used to produce bio-fuels. At the same time when expanding the bio-fuel plantations resulting over-fertilization, over use of pesticide, degradation of biodiversity etc. will be some environmental problems. Also it is important to find out whether these bio-fuel plantations are economically sound as an alternative for the available lands where other crops can be grown or marginal lands where other crops can't be grown or as a component crop for the existing cropping systems since no studies have been conducted in Sri Lanka in this regard.

Lack of information on land use, degraded/waste/marginal lands are major constraints when designing biofuel plantation. Lack of sound government policy on Biofuel production, lack of coordination among responsible government and private sector organizations, lack of scientific information on suitable management practices, lack of high yielding cultivars for large scale plantations, lack of low cost multiplication practices for planting material production etc also negatively affect on development of biofuel industry in Sri Lanka. Therefore preparation and implementation of sound government policy, identification of suitable crop/tree species to produce biofuel in Sri Lanka, identification of suitable lands for biofuel, proper coordination among all agencies/institutions which are directly involved in biofuel production, conducting detailed research on development of management practices, high-yielding cultivars, mass multiplication techniques, suitable development models for increasing supply of raw materials for bio diesel production etc. are major concerns on developing biofuel industry especially plantation aspects of biofuel in Sri Lanka

Keywords: Algaeculture, Bio-fuel, Bioethanol, Biodiesel, Degraded lands

1. Introduction

The most current problem of the country is facing the fuel crisis and a large sum of money is spent on importing petroleum to Sri Lanka. It has increased from Rs. 80.2 billion (US\$ 991 million) in 2003, Rs. 270 billion (US\$ 2.5 billion) in 2007 and projected to exceed Rs. 324 billion (US\$ 3 billion) in 2008, which is 400% increased with compared to 2003. Therefore there is an urgent need to find out alternatives for petroleum fuel

Therefore the major objective of the paper is to discuss the present situation, find out possibilities of expanding bio-fuel plantation and discuss their issues and constraints [1].

Bio-fuels are liquid or gaseous fuels made from plant matter and residues, such as agricultural crops, municipal wastes and agricultural and forestry by products. Ethanol, biodiesel and biogas are the most cultural sources. Studies conducted in many countries have found a number of alternatives to

petroleum fuel such as,

Biomass

Biodiesel
Bioethanol
Biogas

2. Biomass

Biomass, including by-products from the timber industry, agricultural crops and raw material from the forest has been identified as a sustainable source of renewable energy (Table 1). Intensive use of biomass as a renewable energy source could reduce dependency on fossil fuels and significant advantage lies in net carbon dioxide emission to atmosphere leading to less green house effect.

The increase use of biodiesel has been particularly rapid growing from essentially zero in 1995 to more than 1.5 billion litres in 2003 [3]. Biodiesel is a renewable diesel fuel substitute that can be made by chemically combining any natural oil (vegetable oil) or fat with an alcohol such as methanol or ethanol. Methanol has been the

the most economically used alcohol in the commercial production of bio-diesel, which can be used as an alternative fuel for petroleum production.

Biofuel potential in Sri Lanka is yet to be identified. Potentially However, some plants present in Sri Lanka have been identified in the global market as viable liquid biofuel sources but the government policy of not to use any food crops for producing biofuels, following crop/crop by-products may be considered as possible biofuel crops in Sri Lanka (Table 2).

Table 2 Possible biofuel crops in Sri Lanka

Feedstock	Litres/Hectare
Soybean	375
Rapeseed	1,000
Mustard	1,300
Jatropha	1,590
Palm oil	5,800
Algae	95,000

Table 1 Biomass availability in Sri Lanka

Type of Biomass	MT/Year	%
Rice husk available in commercial mills	179,149	6.2
Biomass from coconut plantation available for industrial use	1,062,2385	3.7
Sugar Bagasse	283604	8.3
Biodegradable garbage	786840	27.4
Saw dust	52,298	1.8
Off cuts from timber mills	47,938	1.73
Biomass from home gardens (Glyricidia)	505,880	17.6
Total	2,873,880	100%

2.1 Jatropha (Jatropha Curcus)

Jatropha curcus is a drought-resistant perennial, growing well in marginal/poor soil. It is easy to establish, grows relatively quickly, producing seeds for 50 years. Oil content of the seeds is 30-37% and oil can be combusted as fuel without being refined. It burns with clear smoke-free flame, tested successfully as fuel for simple diesel engine. The by-products are press cake, a good organic fertilizer, oil has also insecticidal properties. A good crop can be obtained with little effort. Not browsed by cattle, goats and sheep and easily propagated either through seeds or cuttings. Depending on soil quality and rainfall, oil can be

extracted from the jatropha nuts after two to five years. The annual nut yield ranges from 0.5 to 12 tons. The kernels consist of oil to about 60 percent; this can be transformed into biodiesel fuel through esterification. The current distribution shows that introduction has been most successful in the drier regions of the tropics with annual rainfall of 300-1000 mm. It occurs mainly at lower altitudes (0-500 m) in areas where average annual temperatures well above 20°C but can grow at higher altitudes and tolerates slight frost. It grows on well-drained soils with good aeration and is well adapted to marginal soils with low nutrient content.

Fruit production is seasonal, or it may produce several crops during the year if soil moisture is good and temperatures are sufficiently high. Each inflorescence yields a bunch of approximately 10 or more fruits. Seeds become mature when the capsule changes from green to yellow, after two to four months.

Even though *Jatropha* may be economically viable biofuel crop when growing in arid and marginal lands, Sri Lanka doesn't have much arid lands with compared to global scenario. Therefore replacing other crops with *Jatropha* plantation in monoculture may not be economically viable since most of the lands and climatic conditions are favourable for growing more economical crops. According to the topography, soil profile and prevailing agro-climatic conditions in an area, *Jatropha* can be combined with other suitable species comprising the agricultural, horticultural, herbs, pastoral and/or silvicultural components to result in an ecological viable, economically profitable and socially acceptable agro-forestry system. It is possible to improve the socio-economic conditions in rural areas and to transform the national energy scenario and ecological landscape. Medically it is used for diseases like cancer, piles, snakebite, paralysis, dropsy etc.

No systematic cultivation of *Jatropha* found in Sri Lanka but trees can be seen every where in Sri Lanka in natural habitat and plant in boundary fences. One Sri Lankan company (DSI) is planning to establish commercial plantation of 5000 acres. *Jatropha* can be easily intercropped with wide range of crop/tree species such as vegetables, field crops, tuber crops, grasses, fruit crops, medicinal plants, mixed plantation with Teak/Neem etc. for more economically sound system. Also *Jatropha* can be used for Biofencing, support plants, as shade trees etc. Germination needs between 5 and 7 days depending on the ambient temperature. No seed treatment is essential but germination can accelerate by clipping the seed coat (Scarification). Planting can be done by direct planting through seeds, planting through cuttings and planting through saplings. The best result is saplings from seeds raised in a nursery in poly bags (about 3-4 months). These should be planted just before the rainy season. Plants from cuttings are not so resistant to drought as well as water logged conditions, because they don't develop tap root, which reaches deeper in to the soil. *Jatropha* seeds are oily and do not store for long. Seeds older than 15 months show viability below 50% (Kohiks, 1989). But our findings shows that seed viability is lost drastically after 6

Months under normal arir temperature (30-32°C) and can extend even after one year under refrigerator.

Benefits to be received from Kyoto Regime, for example when growing *Jatropha* plantations, One *Jatropha* plant can offset 0.15 tons of CO₂/year and then 1000 plants can survive in 1 ha (assuming 10% mortality). One hectare of *Jatropha* can fetch 270 CERs (1 CER = 1Tons of Carbon mitigated) and CER can be traded with the countries who are signatories to Kyoto protocol and this would further offset biodiesel price rise.

2.2 Neem (*Azadirachta Indica*)

Neem is a medium to fairly large tree with dense rounded crown which is widely distributed in dry and intermediate zones of Sri Lanka. Deep rooted drought resistant plant, which can be grown in dry zone areas easily and salt resistant plant. Neem seed contain 40% oil; can be used for fuel for lamps. Since the seeds can be used to extract insecticide, competitive ability for biodiesel seems to be high. But still no information available on tree counts in Sri Lanka and potential seed availability for biofuel production.

2.3 Oil Palm (*Elaeis Guineensis*)

Palm oil have used as fuel in diesel engines for many years. High viscosity may be a problem but good results can be achieved by mixing 50:50 palm kernel oil and petrol as diesel fuel and otherwise higher oil yield per hectare can be obtained from oil palm. It was the second-most widely produced edible oil, after soybean oil. However, it may have now surpassed soybean oil as the most widely produced vegetable oil in the world.

The palm fruit is the source of both palm oil (extracted from palm fruit) and palm kernel oil (extracted from the fruit seeds). Malaysia has already begun preparations to change from diesel to bio-fuels by 2008, including drafting legislation that will make the switch mandatory. From 2007, all diesel sold in Malaysia must contain 5% palm oil. Being the world's largest producer of crude palm oil, Malaysia intends to take advantage of the rush in finding cleaner fuels.

It was introduced to Sri Lanka in 1969 and there are little more than 2000 ha of lands under oil palm cultivation. In recent past, oil palm cultivation was expanding and even rubber plantations were replaced with oil palm. With low rubber price and higher oil palm yield, oil palm plantations were highly profitable. But some

environmentalists protested against the negative impacts on environment. Bio-diversity in oil palm plantation is very much less. People in the oil palm growing areas, always complained that water table of their wells are decreasing and also they complain about some skin diseases for human as well as animals in the area such as dogs. But recent studies proved that it was not affected significantly on ground water table. But at present, due to higher prices of rubber and lower prices of palm oil, oil palm plantations are not much profitable as in the past. Therefore there is a potential to convert palm oil in to bio-diesel in Sri Lanka.

2.4 Soyabean

Soyabean (*Glycine max*) is an annual legume; vary in growth habit and height. Beans are classed as pulses whereas soybeans are classed as oil seeds. The oil and protein content together account for about 60% of dry soybeans by weight; protein at 40% and oil at 20%. The remainder consists of 35% carbohydrate and about 5% ash. Soybean cultivars comprise approximately 8% seed coat or hull, 90% cotyledons and 2% hypocotyls axis or germ.

Cultivation is successful in climates with hot summers, with optimum growing conditions in mean temperatures of 20 °C to 30 °C (68°F to 86°F); temperatures of below 20 °C and over 40 °C (68 °F, 104 °F) retard growth significantly. They can grow in a wide range of soils, with optimum growth in moist alluvial soils with a good organic content. Soybeans, like most legumes perform nitrogen fixation by establishing a symbiotic relationship with the bacterium *Bradyrhizobium japonicum* (syn. *Rhizobium japonicum*; Jordan 1982). However, for best results inoculums of the correct strain of bacteria should be mixed with the soybean seed before planting. Modern crop cultivars generally reach a height of around 1 m (3 ft), and take between 80-120 days from sowing to harvesting.

In Sri Lanka, soybean has been growing from several decades, especially in dry zone area (i.e. mainly in Anuradapura). But farmers are facing marketing problems. They are getting lower prices and cannot compete with imported soybean. Therefore area of cultivation is getting decreased. Since this is short age crop and harvest within 3-3.5 months, this crop can be incorporated in to current paddy based cropping system. Most of the paddy lands under rain fed condition in dry zone area are not cultivated in Yala season due to water shortage and these lands can

be easily used to cultivate soybean. Also in between Yala and Maha season (Meda season), this crop can be grown easily if cropping calendar is planned properly. Since this crop is a legume and can fix N, soil fertility also can be improved by growing soybean. Therefore cultivation of soybean for bio-diesel has still a huge potential but again government policy may negatively affect on expanding soybean cultivation for biofuel.

2.5 Rubber

Agro-technology aspects of rubber have been perfected. In Sri Lanka, there are about 180,000 ha [4] of rubber plantations and annually produce a large quantity of rubber seeds and most of the seeds are wasted, which can be used easily for oil production. World annual capacity of Rubber Seed Oil (RSO) is 130,000 tons and 200,000 tons of oil cake. In Sri Lanka, annual contribution is only 4,500 tons of RSO (for emulsion paint industry) and 7000 tons of oil cake (as Animal feed and N rich fertilizer). It is planning to expand the rubber cultivation in Monaragala and Eastern province and with this future prospect for rubber, seed oil extraction for biodiesel is promising. No exact information available on amount of rubber seeds available in Sri Lanka.

2.6 Coconut

This is the major oil producing crop in Sri Lanka but it has multiple uses. The total land area under coconut is about 395,000 hectares and produces 2869 million nuts annually [4]. Generally coconut lands are not much productive in Sri Lanka and only part of the lands is used for the intercropping and other lands are just monoculture plantations and wasted the natural resources. According to the available figures, about 50% of the coconut lands are in the intermediated zone and only less than 50% are intercropped while more than 50% lands (nearly 100,000 hectares) are still available for intercropping including sugarcane, *Jatropha* etc. The experiments conducted by the Coconut Research Institute proved that coconut cultivations in intermediate zone can be used for intercropping with sugar cane successfully. Therefore, nearly 100,000 hectares of coconut lands are available in intermediate zone for intercropping with sugarcane especially plantation below 5 years and over 20 years. With regards to *Jatropha*, instead sole crop plantation, intercropping with some crops is more economically viable. In this regard, *Jatropha* can be intercropped successfully under coconut.

3. Ethanol Producing Crops (Bioethanol)

Carbohydrates (hemi-cellulose and cellulose) in plant materials can be converted to sugars by hydrolysis process. Fermentation is an anaerobic biological process in which sugars are converted to alcohol by the action of micro organisms, usually yeast.

In 2004, 3.4 billion gallons of fuel ethanol were produced from over 10% of the corn crop in the world. Ethanol demand is expected to more than double in the next 10 years. The world ethanol production is about 60% from feedstock from sugar crops. The America's (North and South) including Brazil, produced 65%. Ethanol is a well-established bio-fuel for transport and industry sectors in several countries, notably in Brazil. All petrol sold in Brazil contains around 25% ethanol. USA has used ethanol produced from maize in fuel blends since the 1980s, which was about 2821 million gallons in 2003 and is projected to increase to 4544 million gallons in 2025.

The major ethanol producing crops grown in Sri Lanka are Maize, Cassava and Sugarcane. But again due to government policy of not to use food crops for producing biofuels, we can consider only by-products of food crops.

There are few potential crops in Sri Lanka which can be used to extract ethanol.

3.1. Maize (*Zea Mays*)

Maize crop can be grown easily in most part of the country and gives good yield, which is about 5-6 tons/ha under good management practices. There is a huge potential to expand this crop in Sri Lanka since wide range of soil and agro-climatic areas are suitable to grow this crop. 1 ton of dried corn would yield about 370 kg of ethanol. But government policy of not to use any food crop for extract biofuel and still we are importing huge amount of corn for livestock feed, the possibility of using maize crop to extract biofuel is very limited.

3.2 Cassava (*Manihot Esculentus*)

Cassava has become an important biofuel crop. Apart from its traditional role as a food crop, Cassava has increased its value as a fuel commodity. The technology for converting cassava into the biofuel, Ethanol is being perfected and, in time that technology could be used here to convert cassava into Ethanol.

In Sri Lankan condition, Cassava can be grown almost all parts of the country, from wet zone to driest area as well as from low country to up country. Compared to other crops even in low fertile marginal lands, cassava can be grown well and gives huge tuber yield. In Sri Lanka, about 23,460 ha of Cassava in 2005 were grown and produced 223,380 tons of tubers. National average yield is very low (8.6-9.2 t/ha) even though potential yield is much higher (about 20-30 T/ha).

The farm gate prices of Cassava are very low and therefore this crop also has huge potential to use as energy plantation to produce bioethanol since there are several varieties with wide range of maturity periods. But still there is a problem to use this crop due to government policy of not using food crops for extracting biofuel.

3.3 Sugarcane (*Sacharin Officinarum*)

Brazil is a major grower of sugarcane, which is used to produce sugar and provide the alcohol used in making gasohol and biodiesel fuels. Sugarcane cultivation requires a tropical or subtropical climate, with a minimum of 600 mm of annual rainfall. It is one of the most efficient photosynthesizer in the plant kingdom, able to convert up to 2 percent of incident solar energy into biomass. Average yield is about 60 tons/ha even though sugarcane yield in Sri Lanka is much lower (about 40 tons/ha). Sugarcane is propagated from cuttings, and once planted, a stand of cane can be harvested several times; after each harvest, they cane stands up new stalks, called ratoons. Depending on agricultural practices, two to ten harvests may be possible between plantings.

In Sri Lanka, around 12 million litres of alcohol are produced annually at Pelwatta and Sevanagala sugar factories. These can be used to blend petrol. Annual petrol consumption in Sri Lanka is 500 million litres. Generally 1.5 l of ethanol is equivalent to 1 l of petrol so another 732 million litres of ethanol is needed to replace 100% petrol. Our annual sugar production was 32,000 MT in 2007 and the extent of sugarcane cultivation was 6605 ha in 2007. Balance 443,600 MT were imported in 2007. Government policy is self sufficiency of sugar and to achieve this target, we need to grow 234,727 more hectares to produce 481,000 MT of sugars. From this production, 183 million litres of ethanol from molasses (by-product from sugarcane) and thus 122 million litres of petrol, which is 22 % of petrol requirement in Sri Lanka can be produced. We need to find out these lands to extend the cultivation. Now government is planning to restart the Hingurana and Kantale sugar

Table 3 Potential land availability of Sri Lanka for bio fuel plantations

Land type	Area (ha) x 1000		Potential for biofuel plantation
	1997	2010	
Urban land	28	32	No
Agricultural land	3987	4170	Partly
Natural forest and Mangroves	1909	1614	No
Forest planted	95	119	No
Wet and barren land	410	410	Yes
Other crop land	86	170	Yes
Total land	6516	6515	

factories as well as another sugar factory at Badulla and extend the sugarcane cultivation in these areas. But still we need more and more lands to achieve this target. In intermediate zone there are about 100,000 hectares available for intercropping, which can be used for intercropped with sugar cane since coconut research Institute has proved that these lands are suitable for sugar cane cultivation

4. Environmental and Socio-economic Benefits of Biofuel Plantations

Saving foreign exchange, agricultural lands can be used more productively, low capital cost/intensity as compared to petroleum refinery, lower toxic and healthcare cost, provide cheap and locally available energy, and provide substitutes /supplemental energy for agriculture at the door step farmers.

Biofuel plantations can be successfully utilized in order to improve livelihoods on sustainable basis. It has also potential for generating the employment from plantation, harvest and processing activities, which will reduce migration of people from rural areas.

Participation of women in managing the plantations will boost their livelihoods and will empower the women.

It has both tangible benefits as well as in-tangible benefits. There are innumerable in-tangible

benefits like: potential to produce a green fuel that will reduce carbon dioxide emissions and re-circulating atmospheric carbon dioxide through the process of photosynthesis, greening waste and marginal lands, which has positive impact on hydrology, alleviate soil degradation, deforestation and conserve soil and rain water and improve ecosystem and environmental sustainability.

Potential earnings through CERs, One ton of petrodiesel released 3.2 tons of CO₂. Bio-diesel/ SVO reduces net CO₂ emission by 78.45%, compared to petroleum diesel, the use of bio-diesel therefore gives a reduction of 2.51 Tons of CO₂ and average price of CER of US \$ 10/ton of CO₂ (not including Carbon sequestration by the plantation of TBO's) Reduction of Net CO₂ emission by 100%.

5. Constraints

More traditional bio-fuels, such as ethanol from corn, cassava or sugar cane, and bio-diesel from oil seeds (oil palm, coconut, Soyabean), are produced from classic agricultural food crops that require high quality agricultural land for growth.

Following information are lacking with regards to potential of expanding bio-fuel plantations in Sri Lanka,

- Land use data,
- Secondary yield data

- Preliminary resource assessment
- As to what the maximum capacity is for expanding bio-fuel plantation
- The aspect of whether we should go for more bio-diesel producing crops (Oil crops) or bio-ethanol producing crops (starch/sugar based crops)
- The demand that can be created
- Scientific information on suitable management practices
- High yielding cultivars for large scale plantation
- Low cost multiplication practices for planting material production

Worldwide production of vegetable oil and animal fat is not yet sufficient to replace liquid fossil fuel use. Furthermore, the vast amount of farming may resulting over fertilization, pesticide use and land use conversion that would be needed to produce the additional vegetable oil, which may affect negatively on environment.

6. Suggestions/ Recommendations

It is essential to undertake detailed research for development of management practices, high-yielding cultivars, mass multiplication techniques, suitable development models for increasing supply of raw materials for bio diesel production.

It is necessary to identify the suitable existing cropping lands for intercropping, agro-forestry etc. with biofuel crops (Nearly 100,000 ha of coconut lands are available in intermediate zones for intercropping).

There is a need to have a strategy to develop/rehabilitate degraded lands through bio-diesel plantations by efficient use of existing natural resources (i.e. more than 50,000 ha of degraded tea lands are available in mid and up country).

As land requirement emerges as a major prerequisite in the bio-fuel programme, there should be proper identification programmes for wasteland and documentation of marginally productive and waste lands, which can be targeted for biofuel plantations, without compromising on food production.

One of the promoting livelihoods of poor is through promotion of biofuel plantation by user groups on common pool lands like degraded forests, community owned lands, low quality lands not suitable for annual food crop production, land

along the railway tracks, canal embankments, reservoir foreshore etc.

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8. Discussion

Dr. Muhammad Pervaz

I am just giving a situational analysis. In South Asia, if we think of using palm oil or coconut oil to use as Biodiesel, although it may be okay for a country like Sri Lanka, for countries such as Pakistan, Nepal and Bhutan etc, who import edible oil, it would be a problem. Just few years back, Pakistan's tea and edible oil imports was about ½ of the crude & petroleum products imports. Now it may have changed because of high prices. If you use edible oils for Biodiesel, it may not be sustainable. Even using of coconuts oils, its high prices cannot afforded when coconut or olive oil is used as edible oils. It is very challenging and expensive and edible oil prices in Pakistan have doubled in the past 2 years. I heard good news from Prof. Yang, who said that he is working hard on Butanol and in the next 2-3 years, Butanol will be commercially available. Even if it takes 10 years, it is worth because in our part of the world (SAARC), it takes about 5-10 years to shift from a pilot stage to commercial stage.

Prof. S Subasinghe

I am not telling to use edible oils for Biofuel production. I just mentioned here that some of the major oil bearing crops which we are grown and

some of the potential crops that we are expanding. It depends on the price. Actually we are importing a lot of vegetable oils here in Sri Lanka. Even coconuts, we sometimes import to produce desiccated coconut.

Md. L Rahman

I am rather confused over someone mentioning about the unproductive lands. A land remains unproductive as long as humans don't interfere. You showed that Jatropha having created a lot of enthusiasm. The range of yield is 0.5 to 12, which is a very wide range. It indicates a lot of uncertainty. Yesterday, we came to know that it is immune to diseases and pests, but your presentation has revealed the other way around. Algae has got a very high oil content and we have been hearing this for a long time. Algae are capable of producing oil and people from the petroleum background know that algae are one of the sources of oil and gas. Then why it is not being commercially cultivated? Can algae be cultivated with fish culture?

Prof. S. Subasinghe

Algae can be grown with fish feed. According to literature, there are some kinds of algae which can be used in waste water to extract oil. Some research in the USA has revealed that they can extract 50% of oil and that is how I have given my calculations. With regards to Jatropha, it completely depends on the management practices and agro climatic zones where we grow. Even in India, same cultivar or species grown within the same state will show the yield difference in the range of 2 to 10 times. We have got a lot of research papers and they have shown that this wide range of yield difference. A participant of this workshop from the Aitken Spence Company said that they have visited India and their plantation is very poorly grown compared to the growth in Sri Lanka, which is very promising. It depends completely on agro climatic, soil and fertilization and so on for the marginal crops such as Jatropha. If you grow the crops in good agricultural lands and if proper agricultural practices are followed such as irrigation & fertilisation, definitely we can get more yields. One of the main agricultural practices is weeding at the initial stages. If you don't weed at proper times, then you may lose the whole plantation. There are many factors that contribute to a range in the yield data. The other is the varieties. If you have promising varieties, then of course we can get a good yield. That is why there is a big range.

Farming Biofuels - A Community Based Approach

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Abstract

There is an energy and food crisis in the world at large, yet when it comes to the community level, it is more of a need to meet food and energy needs than a crisis. Large scale biofuel farming takes place commercially while many community based biofuel farming is focused towards merely meeting the local demands. For bio-diesel, community members involve in either growing (as a mixed crop or otherwise) or collecting the oil bearing seeds themselves. Oil is expelled / extracted and then converted to biodiesel at a centralized location locally or elsewhere. In the cases where community is an out grower, an intermediary would collect seeds and transport to a central processing unit.

For sustainable community based biofuel farming, priority given to farming of biofuels & energy needs by the communities compared to the other needs is vital. Economic benefits including the price in the short term, incentives & buy back guarantees given and livelihood opportunities created decide their motivation. Whatever the myths they have needs getting cleared. Existing farming patterns, land use, types of crops cultivated, climatic seasons, availability of water, type of soil, degree of returns from the efforts put in are some other considerations.

Mobilising the communities from the beginning helps gain sustainability & gives them confidence. Basic understanding of the benefits to them, working relationships with stake holders, tangible & visible infrastructure, and basic skills on operations of processing units, responsibilities given for smooth functioning of the systems and indirect benefits are other aspects in continuation of the interventions.

Use of oil for lighting has been in practice over centuries. In addition, different applications of biofuels by the community for meeting various needs maintain momentum of enthusiasm. Community based rural transport systems, water pumping and power generation using biofuel are some common applications.

1. Introduction

The agricultural sector still contributes significantly to the GDP of many developing countries. The industrial and service sectors' contribution to the GDP keeps on surpassing that by the agricultural sector. Majority of the rural poor are still engaged in subsistence farming in making a living. Land, water and other natural resources that help the agriculture sector are scarce and depleting. People tend to encroach and clear the forests to set up farm land and dwelling units. With the forests being cleared, the fertile soil gets eroded and water streams get silted. The logging business mafia rape the forests in large scale. Wild animals, including the elephants find their heritage lands lost.

In order to feed the growing population in the world, the green revolution helped by introducing the use of chemical fertilizers and pesticides, and repellents etc. This helped to increase the food production significantly, at times, producing a considerable surplus. With the oil & energy crisis of the 1970s, there was a hurry to find out alternatives to oils and attention was rejuvenated to ex-

plore possibilities of using biofuels among other options.

Use of biofuels for energy applications had been there for centuries. However, the renewed interest brought it to a different height and intensity. With the current higher prices of petroleum oils, their reserves dwindling, rate of exploration of new & economical oil resources retarding, challenge of global warming, widening of inequity and many other factors has brought back the biofuels into the limelight. Related research & development are immense and commercial interests have taken the path of going for commercial scale biofuels energy plantations. Occasionally, there exists biofuel farming as a community collective effort for mutual benefits.

2. Concept of Community Governance

The conventional top-down approach in decision making, implementation & monitoring of development activities has continued to remain within the bureaucratic systems of administration of the governments as well as the management of the private sector. This has ultimately further

marginalized the under privileged communities. This situation inculcates vulnerability among the people making them powerless while the privileged groups to continue to enjoy all the benefits. Conventional systems of administration also provide room for or already practices corruption at many levels. This results in frustration & social unrest in the community, especially among the youth.

The Community governance concept is introduced to the development sector in order to remedy this situation. By using the experience gained through many of the development interventions at grass-root level, the concept of community governance in community development adopts a participatory framework within which individuals and community organisations are strengthened & capacitated to influence the administration & authorities and facilitate greater community participation in spelling & carrying out their own development. Community Biofuels Farming interventions in Rasnayakapura, a remote area situated in the North Western Province of Sri Lanka take place within the community governance interventions implemented by the communities along with other stakeholders including Practical Action, a local organisation Sangrama and government offices.

3. Community Priorities

Needs of the communities are immense. In order to identify their priorities, participatory rural appraisals (PRAs) and focused discussion were held for the 86 villages in the 28 Grama Niladari divisions of the Rasnayakapura Divisional Secretariat area. Needs were ranked and those that could be achieved with a community approach were identified. Many infrastructure, services and capacity building interventions were carried out over 3 years prior to introducing biofuels. By this time, the communities were well mobilised and they were ready to achieve their needs on their own initiatives getting technical and other required supports from the other relevant stake holders.

Communities living in the village of Gurugoda which is situated remotely, at times being subjected to wild elephant encroachments within the Rasnayakapura Divisional secretariat area had no access to electricity or public transport at the time the community governance approach was introduced. To cater to their electricity needs, a community wind electrification scheme was set up. However, during the periods the wind is weak, they do not get sufficient electricity. It made them to think about ensuring electricity supply from

another source. Different alternatives to solve this were considered. Initially, Gliricidia was considered to go for a dendro – wind hybrid system. This did not materialise until now. Biofuels was identified as a feasible solution at a latter stage.

Electricity is not the only energy related need of the village. Since they do not have a public transport system, they were interested on a community based public transport system. Further, as some parts of the village have no access to water, particularly for drinking during the drought, pumping water was another need. During the periods they did not get electricity from the community wind scheme, they had to revert back to use of kerosene oil lamps for house lighting. Considering these, the communities agreed that they would use biofuels to meet their energy needs.

Although there is a huge debate on energy crisis and biofuels at the global scale and the food specialists claim that growing biofuels for energy leads to food crisis, when it comes to the community, they hardly understand this. For them, food is one need and energy is another need among many other needs they confront with daily. They do not visualise a crisis in the energy sector, as they are already deprived of electricity and public transport systems within the villages.

Working with the community governance systems for 3 long years had given the communities in Rasnayakapura Divisional Secretariat area confidence on collective work. On the other hand, communities were capacitated on several aspects including working with the external agencies. They demonstrated their ability in managing their own technologies such as village roads, irrigation systems, low cost housing & wind systems etc to an acceptable level. At this time, they had not heard that biofuels can meet their energy needs, except for that some oils can be used for house lighting. In order to try out the option of liquid bio fuels to meet their diverse energy needs, there was hardly any doubt in their minds on the technologies. Community based participatory village development approaches had worked for them in the past, so that they had confidence.

The idea of trying out biofuels to cater to energy needs was well taken on board by the communities. An initial investigation was carried out to find out the availability of different oil bearing seeds in the area. *Jatropha*, *castor*, *neem*, *mee* and *domba* were found from the locality. Samples of seeds were collected by the communities themselves. These trees were growing naturally on their own. There was no plantation as such. In

order to encourage the communities on the option of biofuels farming, the fence of the power house – turbine of the community wind electrification scheme was built with a mix of *Jatropha* and *Gliricidia* with community participation. This demonstrated the possibility of growing them while also showing the communities that there is preparedness for a future intervention. Considering many aspects, *Jatropha* was selected as a suitable crop to be used for farming biofuels in Gurugoda.

Although, the fence was built, when the communities were requested to go ahead with small plantation of *Jatropha* and *Gliricidia* on their own lands as fencing, there was some sort of a resistance although they did not fear to take up the biofuels technical option to solve their energy needs. This is at this stage the communities were exposed to the concept of community farming, an experience they had never faced before.

4. Community Farming

The community farming is an approach where number of people gets together and engages in farming for their mutual benefits. By this, they expect sharing of resources and risks and achieve synergy. At times, farming takes place on common land, but very often they cultivate on their own land, but for a common purpose with a common approach. In order to synchronise the efforts, an external party often provides with its coordinating inputs.

Commercial scale farming is done for sale of biofuels as a business. In contrast, community farming can be for both sales and own consumption. When it is for consumption, the yield of the farm is focused towards merely meeting the local demands. The community members involve in either growing (as a mixed crop or otherwise). In the case of Gurugoda, community members grow on their own land.

5. Motivators of the Community

Community members had experienced blackouts due to lower wind speeds not producing enough electricity to meet their daily demands. Therefore, they had a high enthusiasm to find a solution to this situation. As explained above, the communities liked the idea of using biofuels technology to meet their energy needs and the concept of community farming; yet, there was a resistance to grow biofuels. The reasons for this behaviour was attempted to be understood with participatory discussions. Subsistence farmers had the practice

of thinking in the short term. Existing farming practices was closely related to the rain seasons. Lifestyle and spending patterns were linked to it. Paddy, cereals, vegetables and ground nuts were their main crops they grew, depending on the seasons. Over the years, they have got used to a certain rhythm.

Farming biofuels is new to them and takes them to an unknown territory compared to the practices they have had over the years. Apparently, the oil bearing seeds (mentioned above) were already available in the area. They questioned as to why they should be grown. On the other hand, these seeds were not catching a good price and they were wondering whether they would get economic returns by selling although the biofuels farming here is meant for producing seeds for own consumption and not for sale. A possibility to have better livelihood options (such as paid labour) is another aspect they were considering. A good price with a buy back guarantee and higher degree of returns for the efforts put in were their expectations.

In the mean time, there was a belief in them that around the *Jatropha* trees, no other crop grows. Some had the view that after *Jatropha* trees dies, no other crop would grow where it was as the soil becomes completely infertile and toxic. No scientific data was found to prove or disprove these views. This fact again, contributed to their resistance to grow *Jatropha* as a biofuel.

Due to their existing farming patterns, land use, types of crops cultivated, some had the view that taking *Jatropha* would not keep in line with them as a biofuels crop. *Jatropha* is a non edible crop where as most other crops they cultivate are edibles. Gurugoda is situated in the dry zone and *Jatropha* was growing well in this area, but some doubted whether this crop would absorb the water in the soil and affect the availability of water in the area or prevent the growth of other crops. Therefore, whatever the myths they have needs getting cleared while lack of necessary data and information needs to be researched or investigated and found out. This shows that for a sustainable community based biofuel farming, priority given to farming of biofuels & energy needs by the communities compared to the other needs is vital.

Motivating the communities for farming biofuels had many challenges. Therefore, different approaches were adopted to convince them. Mobilising the communities from the beginning helped give them confidence. Basic understanding of the benefits to them was explained. The community

members were linked and exposed with working relationships with stake holders. Still, it was hard to push. It is then it was decided to use tangible & visible infrastructure so that by seeing them, the community will be encouraged. They were told that a biofuel processing centre would be established in the village and power generation, water pumping and running of an intermediate mode of transport system. A building was leased and renovated while the generator, vehicle and water pump were bought. In the mean time, the research continued and the other equipments were designed and fabricated. Growing biofuels continued.

6. Experience from Elsewhere

In the community based biofuels farming interventions, the seeds are supplied or found by different means. The common options adopted are collecting the seeds from the already available crops & trees, growing own crops through a dedicated plantation (mono crop, mixed crop, hedges, homestead), purchase from another out grower community or purchase through an intermediary who would collect seeds from various places. The seeds are then brought or transported to a central processing unit. It has been found from similar interventions that basic skills on operations of processing units, responsibilities given for smooth functioning of the systems and indirect benefits helps in continuation of the interventions.

In the case of Gurugoda, the community members grow their crops at the home gardens on the hedges. Already available seeds are also collected from the nearby as there is a shortfall. An out grower & intermediary system is planned with a Rural Enterprise Network who are already marketing different rural products under one brand after quality assurance.

7. Roles of Main Stakeholders

Village Community– The community is the key stake holder. They are engaged in biofuels farming with the support from the intellectuals and other partners. In addition, they are involved in the planning, implementing, monitoring the socio-economical impacts. Community roles consist of that of growers of the plantation and managers of the plantation and processing activities

Technical Advisory Board– This body acts mainly as overall advisor & providing guidance to ensure that the interventions become up to date and

keeps track with national interests. In addition, this body provides links to the main stakeholders and interested audiences in the bio-fuel sector to share the findings, outcomes and exchange experiences

Research institutions– The research aspects in engineering and agro forestry are carried out by the Universities and National Engineering Research & Development Centre. Existing knowledge gap is filled by them. Transferring the technology to the community & testing is carried out with the communities while training them and adapting to their social context.

National level & Area based coordinating bodies – It is generally hard to get an autonomous community intervention without an external input. The overall facilitation and coordination of the design and implementation of the community governance concept and the interventions on farming biofuels as a community based approach are carried out by a national developmental organisation Practical Action and a local organisation Sangrama. Wherever possible, they provide technical inputs of their expertise.

8. Key Steps

Community awareness, mobilisation & motivation -Within the community governance practices in the Rasnayakapura Divisional Secretariat area, the technology & site specific programmes were and are being carried out for Gurugoda

Establishment of energy plantations at household level - At the beginning, the scientific data related to the crops were lacking. Jatropha was seen in the area being grown at hedges and other places around. Until proper information is ascertained, seeds & sticks were collected from the locality and homestead plantation plots were established. Initially, community members were given a brief awareness. 7,000 plants, by seeds and sticks were grown. Parallel to this, research & development was carried out at University of Ruhuna.

Oil expelling and extraction – To ascertain scientific data on types of seeds, oil contents, extraction and expelling methods etc experiments were carried out at National Research & Development Centre. Based on the findings, proper oil expellers were selected and filters were designed, developed & made

Experiments on biofuel processing – A series of experiments were carried out at the University of

Peradeniya on the conversion of oil into biodiesel. Based on the findings, a proper reactor was designed & made

Testing engines & oil lamps– Engines were tested with varying proportions of biodiesel mixed with petroleum diesel at University of Ruhuna. Innovative oil lamps also have been designed and developed.

Infrastructure for Community Biofuels Processing Centre – A building was leased and renovated by Sangrama to house the community biofuels processing centre having space also for storage of seeds.

IC engines – Vehicles to be used as community intermediate modes of transport, power generator and water pumps have been bought by Practical Action

Knowledge generation and sharing – The experiences on farming biofuels as a community based approach is being documented along with the test & socio-economic survey results

9. Monitoring

A participatory monitoring system is adopted on biofuels farming. This system gets the involvement of the main partners and stakeholders within the monitoring process. This takes place at 4 levels

Village level monitoring - Technical or management issues are discussed with the community members. Plans to be implemented and progress against the plans are discussed here, and suitable corrective actions are taken. Generally, these are carried out at the village development committee that meet every month attended by the community members

Monitoring by Partner organisation - They carry out participatory monitoring every two months in addition to a regular social mobilisation process through village based social mobilisers. The officers from partner organisation Sangrama supervise, monitor and assist the community and village leaders to maintain the quality of the process and facilitate in the smooth functioning

The Technical advisory Board – This meets every quarter. At this, the technical aspects related to the main aspects related to cultivation, oil expelling & extraction, processing and applications are discussed in detail. Research and development carried out and their applications with the com-

munities are assessed and plans are made accordingly. These discussions take place on field or off-field.

Annual Planning & Reviews- At the end of the year, the Technical Advisory Board meets at a residential planning session setting the detailed plans for the next year. Activities are reviewed by all stake holders at an annual reviews session. Major decisions are taken and responsibilities are shared at these reviews.

10. Community & Research Based Renewable Energy Park

In addition to the details described above, biofuel farming intervention is integrated into a demonstration 'community and research based renewable energy park' where other renewable energy aspects such as wind turbines and biogas systems are present. There are plans to add Solar PV, Solar thermal applications and dendro.

11. Issues

The current progress indicates the cost of production of biodiesel can be around Rs 300 per litre or more where as the petroleum diesel is currently sold at Rs 110. With no mandatory blending requirements, selling biodiesel at a very high price may not become economically feasible. On the other hand, the capacity of a community biofuels process centre possesses limitations with the quantity of biodiesel such an intervention could produce. The consistency of the quality of the biofuels so produced and the ability to adhering to the required standards is yet to be proven.

Biofuels processing deals with chemicals which are dangerous to be handled by unskilled personnel and children. At the same time, these chemicals have to be imported, making to rely on foreign suppliers. With high capital and operational costs, the sustainability of a community biofuels processing scheme is at stake.

12. Conclusions

Farming biofuels with a community based approach is an uphill task under the current circumstances. A community governance approach to integrated developmental interventions of this nature can be of immense use. Prioritization of energy needs and decision to grow biofuels among many other choices by the community is vital. Community members are motivated by multiples reasons. Many stake holders will have to

together while performing many parallel functions while the research and development would continue to take place. Currently, farming biofuels with a community based approach is going to be costly with the issues of sustainability, and therefore, need to be improved to make it a more viable, environmental and people friendly option.

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14. Discussion

Dr. Muhammad Pervaz,

I would like to appreciate you for talking on behalf of those people who normally cannot speak during conferences and facilitating them. In some rural communities, the animals and people are friends where they drink water from the same pond. It is common in South Asia. What ever efforts you do and all our research & cooperation should facilitate these people. They need our help and I think what you have done is fine and if this model could be replicated and shared with other countries, I think it will be useful.

Md. L Rahman

About the community, you have said that rural community want results very quickly. I think it is the convincing of the people that is needed. They are not the impatient people. It is important that they have the opportunity to avail as far as cultivation is concerned. For example, how long it takes for coconuts to reap fruits, it is longer than *Jatropha*. Once you are able to show them that you purchase the produce or there is a certainty of markets, then they will be inspired. If you want to produce the ultimate production from the community that is from the seeds to Biodiesel it is very difficult to make things work. Rather, you can approach them where they will be producing the seeds and give them certainty that they will be getting returns from the seeds. You will process the seeds in a centralised location. If the market is there, they will be produce.

Mr. Namiz Musafer

Perennial crops like coconuts, they are grown in those areas, but overall, there is a tendency for them to look for short term results. Why we wanted from plantation, processing and applications within the village was to test the model. Because it is a new approach and we also thought we had some sort of a rush getting forward into the area and use our experience of the other sectors such as micro hydro and biogas and see as to how this model could be adopted or adapted in the Biofuels sector. So it is some sort of a test for us also to see whether it would work. If it works, then it would be documented and share with the others. So I will not say that it is the best model. We don't know. We designed and trying this model, if it succeeds, it can be replicated and if it fails, we can put it to the history.

Mr. N de S Cooke

Our company is taking a similar approach to yours. We are not doing a plantation model similar to you, but we allocate lands of farmers on which they would cultivate a mixture of crops. We provide them with the seed material like castor, neem, *Pongamia* and we also provide them with a monthly income during the gestation period, so that they have something to survive on. We provide them a buy-back guarantee, provide them with infrastructure and we take on the responsibility of their certification process with a vision to export the majority of the Biodiesel produced, because that is where the market is. We also train them with best practices providing extension services. You also raised the point about *Jatropha* being possibly toxic. From what I have understood from the studies that have been conducted by various authorities is that it is not toxic, but can be carcinogenic if consumed. So that is why most animals don't eat it or approach it, because it is not very good for them.

Mr. Namiz Musafer

Private sector also comes with Corporate Social Responsibility (CSR) and as you said, there is some sort of income that comes from external sources to them during the gestation period and also your involvement as an external agency to give a buy-back guarantee. Those are some of the things we wanted to avoid. Because we wanted some sort of an autonomy within the village for them to decide for themselves, and for them to survive on their own resources. So this is the model we wanted to try out and we do not know whether it would work or not. That is why I said that there were some assumptions from the communities for those, but we didn't want to encourage them happening. There is nothing wrong in it,

but this model is little different to that.

Mr. Xavier Johnson

Can you explain what you observed about the processes where governance structure is emerging in the community because a common perception may be that it may be getting into these types of markets? We have only a choice between private sector and government, but of course there are many different types of models that can emerge when the community is involved in. How is this governance structure merged in terms of leadership to organising the logistics and financial arrangements and so forth if it is possible to see some type of structure emerging? It may some times be spontaneous, but also based on the capabilities of people where the people are in charge of certain things and others have to follow through and that are how these structures emerge. How it might be different for the case of Biofuels compared to experience with micro hydro or bio-gas you mentioned?

Mr. Namiz Musafer

Generally, for the people to get together there should be a common interest. That is the entry point. Even for micro hydro, community governance system works when there is a need for electricity. So what happens initially is there are social mobilisation and awareness programmes held. It can be either government sector or NGO sector. Then the system works where they are themselves trying to analyse their needs, and then due to constraints in the resources prioritising the needs for action. That process takes a long time. As for Biofuels is concerned in our interventions, there was already a community governance system in place for 3 years and therefore it was not difficult. But if you are starting anew, then you have to start from community awareness and mobilising programmes. At a latter stage only you will be able to embark on a big structure like this.

Prof. S A Kulasooriya

Jatropha or Pongamia being toxic is a myth. My work has clearly shown that we could grow tomato, chillies & brinjals (common vegetables) between Jatropha. They grew, they produced with no problems. In Monaragala we are trying to introduce legumes.

Social and Environmental Aspects of Large-scale Biofuel Plantations

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Abstract

Biofuels have emerged in recent years as a strategic element in the global transition to sustainable energy, based on a confluence of factors—higher oil prices, climate change, and the need for renewed emphasis on the agricultural sector in the developing world. The economics of biofuels are, however, more complicated than almost any other class of energy sources, because they are dependent on land and water availability as well as being dynamically intertwined with the supply and prices of many agro-industrial products and socio-economic variables. They are also a class of energy resources whose implications—and in some cases—complications—have spread from the local to the national to the global. In this paper, an overview on biofuels markets will be discussed from a broad historical perspective. Some key examples are reviewed and some of the main linkages across scales and sectors are considered

1 Environmental Impacts

It is difficult to summarise environmental impacts across all the different crops, applications, and conversion processes for biomass-energy systems. In general, most of the impacts come from the land-use side rather than the industrial side of bioenergy production, due to the land-intensive nature of biomass compared to other energy sources. Environmental impacts and emissions are closely linked to the energy and other input requirements for growing biomass; the most productive options are those that have lower input requirements and require less land and/or lower quality soils. Feedstock growing costs are also strongly related to land use, and feedstock costs are generally the major cost component for bio-energy systems.

1.1 Impacts from Different Crops

Bioenergy is inherently land-intensive, meaning that the associated socioeconomic and environmental impacts are generally much more significant than those of other renewable energy systems. A comprehensive list is difficult to summarise briefly, but some key concerns relate to loss of ecosystem habitat, deforestation, loss of biodiversity, depletion of soil nutrients, and excessive use of water. In addition to the provision of a renewable energy source, some positive environmental impacts might include restoration of degraded land, creation of complementary land use options, and provision of non-energy resources and materials. Some specific issues that arise in the case of sugar crops, woody biomass, and oil-bearing crops, are outlined below.

1.1.1 Sugar Crops

The environmental impacts of sugarcane have been analysed in considerable detail in the case of Brazil. When Brazil began its effort to expand sugarcane for ethanol production in the 1970s, the environmental impacts were quite significant, especially the disposal of large streams of waste effluent from ethanol distilleries. Over the past thirty years, dramatic improvements have been achieved in technical efficiency and in the efficiency of key resource inputs (e.g. water). The case of water use is particularly interesting, since cane requires significant amounts of water during a key period in the growth cycle. Cane is rain-fed in Brazil, and furthermore, the amount of water that is recycled in the cane-ethanol processes is on the order of 90% (Macedo, 2005).

In other parts of the world where water is scarcer, sweet sorghum could provide a useful alternative, with its low water requirements, about 65-70% that of cane. Additionally, it has the ability to remain dormant during periods of drought, resuming growth upon the re-occurrence of favourable conditions (El Bassam, 1998). This means there is a much greater likelihood of small scale farmers with no access to irrigation raising a crop of sweet sorghum in dry conditions than one of sugar cane, or even of maize. This could potentially have strong socioeconomic benefits by increasing the productivity of small scale farmers.

Sweet sorghum has low requirements for nitrogenous fertiliser, about 35-40% of that of sugar cane (Praj, 2005). This has economic benefits for the farmer, as the crop will require less investment in inputs, as well as possible environmental benefits from avoiding impacts of fertiliser run-off. Sweet sorghum has high potassium uptake, however, and is therefore highly depleting

of this mineral (El Bassam, 1998).

1.1.2 Woody Biomass

Woody biomass is a major source of primary energy for the majority of the world's poor, but it could also become a major source of feedstock for production of second-generation (lignocellulosic) ethanol. The environmental impacts of wood fuel use by industries and households are well known, and include:

- health effects of indoor air pollution, which kills more women and children than tuberculosis and malaria (UNDP, 2004)
- contributing to deforestation, a major problem in some southern African countries
- soil degradation and erosion problems

However, the consumption of woody biomass as a fuel need not be inherently unsustainable. Improvements in conversion efficiency and use are needed, especially in more densely populated regions. Woody biomass is also available in large quantities as a residue from wood industries. This has been demonstrated in Sweden and other countries, where sawdust from the wood sawing industry is used extensively for energy. This has the economic and environmental benefits of using what would otherwise be a waste product. The payments from the energy industry are now greatly contributing to the survival of the sawing industry (Kåberger, 2005).

1.1.3 Oil-bearing and Other Biomass Crops

Jatropha trees yield oil that is highly suitable for use in raw form or for refinement into bio-diesel. This tree is reported to have strong environmental benefits when intercropped with other produce. It can be used as a hedge to prevent soil erosion, and can also have regenerative effects on the soil, being a nitrogen fixer (Francis et al, 2005).

Several oil bearing crops, currently used predominantly in food products, are strongly associated with severe environmental impacts. In particular, soya bean plantations are encroaching on rainforests in Brazil, and the palm oil industry is a major cause of deforestation in Malaysia and Indonesia, threatening species such as the sumatran tiger and the orangutan with extinction (Friends of the Earth, 2005). In order to preserve the credibility of bioenergy as an environmentally sustainable source of energy, particularly in the context of a possible future international trade in biofuels, such sustainability concerns will have to be addressed. Some form of social and environmental

certification would seem to be desirable. The precise structure of such a scheme, whether it could be mandatory, or would have to remain voluntary, and how it could be linked to other existing social and environmental certification schemes, needs to be established.

One starchy crop that is quite important in the southern African context is cassava, a staple food crop in many parts of southern Africa; it could serve a dual purpose by providing food and energy. It could also be seen as a food reserve crop in case of food shortages; in Tanzania, farmers devote more than 10% of their land to cassava for this purpose. Cassava is productive on poor soil, resistant to drought and capable of achieving high yields (10 tonnes / hectare). It also has the advantage of being able to remain in the soil for long periods, and can be harvested only when required. This eliminates storage problems, making it an ideal back-up crop, for fuel or food. A major programme has been initiated in Nigeria to make ethanol from cassava.

1.1.4 Industrial Processing Impacts: The Case of Vinasse

There are many further impacts from the industrial side of bioenergy processing. Stillage or vinasse, a by-product of ethanol production, presents a somewhat special case since it is produced in large volumes but is also a potentially valuable input for further bioenergy production as well as for other uses such as fertiliser. Each litre of ethanol produced is accompanied by 10-15 litres of vinasse. This large volume of vinasse and its high BOD and high COD (80,000 to 100,000 mg/l) poses a problem for its disposal.

The hazardous substances present in the vinasse generate a very high BOD (Biological Oxygen Demand), ranging from 30,000 to 40,000 mg/l and a low pH of 4-5, because of the organic acids which are corrosive and require stainless steel or fibre glass to resist it. Vinasse contains unconverted sugars, non-fermented carbohydrates, dead yeast, and a variety of organic compounds all of which contribute to the BOD (Cortez et al, 1998). The organic components in the vinasse can be used for biogas production through anaerobic digestion, a process in which methane is produced when microorganisms breakdown the components under conditions of low oxygen and low temperature.

One possibility of reducing its polluting effect is recycling it in the fermentation process. Vinasse may be partly used to dilute the sugarcane juice or

molasses in the fermentation step. The juice or molasses need to have the Brix adjusted to allow proper yeast growth a process that normally requires water to dilute it. Alfa Laval developed a process called Biostil that uses vinasse to dilute the molasses prior to the fermentation step.

In Brazil, detailed and extensive studies and field testing have shown that vinasse is an excellent fertilizer and improves the physical, chemical and biological properties of the soil, namely, it increases the pH, enhances the nutrient availability, improves the soil structure due to the addition of organic matter, increases the water retention capacity and improves the microorganisms' population.

1.2 Energy Yields

The various biofuel feedstock differ considerably in their energy yields, based on their photosynthetic productivity, adaptability to climatic conditions, and the amount of useful inputs provided. Biodiesel crops are characterised by the amount of oilseed that can be extracted per hectare, while bioethanol crops are described according to total biomass yield. Among the 1st Generation biofuel crops, sugarcane and palm oil are the most productive. However, sweet sorghum and jatropha useful ecological properties since they require less water than sugarcane and palm oil, respectively, and can therefore grow in drier climates. Sweet sorghum grows rather quickly (3-4 months) and therefore the figure in Table 1 is based on tow yields per year. Maize and soybeans are rather poorly performing as biofuel crops and therefore it seems ironic that the U.S. relies on maize and Brazil on soybean (for

biodiesel). Among the main reasons is the long experience that farmers have with these crops and their well-established market distribution and supply networks

1.3 GHG Emissions Overview

Since biomass sequesters carbon, GHG emissions of bioenergy systems are neutral. However, since there are fossil energy and other input requirements for biomass feedstock, there are some energy losses and hence some net GHG emissions result. In some cases, there can also be N₂O and methane emissions associated with biomass for energy systems, both of which are also GHGs. The GHG savings for liquid biofuels tend to be less than that of solid biofuels mainly because of the fossil fuel being replaced, i.e. since coal is the most carbon-laden fossil fuel, any substitution for it has proportionally higher carbon savings. For most liquid biofuels, GHG reduction is directly related to the yield and energy balance of the feedstock. A rough indication of GHG reductions and yields for various liquid biofuels is given in Table 2.

There are other potential GHG impacts associated with growing biomass, which depend on the previous use of lands. Land that stores a significant amount of carbon and is cleared to grow biomass incurs a "carbon debt" that has to be "paid off" before the system becomes a net carbon sink again (Fargione et al, 2008). On the other hand, degraded lands that are used for biofuels will tend to incur a low carbon debt or none at all, depending on the properties of soil, the root systems of the new crops, the impact on nutrients, and other factors.

Table 1 Characteristics of various 1st Generation biofuel crops

Crop	<i>Seed yield (t/ha)</i>	<i>Crop yield (t/ha)</i>	<i>Biofuel yield (litre/ha)</i>	<i>Energy yield (GJ/ha)</i>
<i>Sugarcane (juice)</i>		100	7500	157.5
<i>Palm oil</i>	9800	70	3000	105
<i>Sweet sorghum</i>		60	4200	88.2
<i>Maize</i>		7	2500	52.5
<i>Jatropha</i>	740		700	24.5
<i>Soybean</i>	480		500	17.5

Table 2 Estimated ranges of GHG reductions and yields for various biofuels

Fuel	Process	Feedstock	location	GHG Reduction (relative to petrol or diesel)	Yield (litres per hectare)
Ethanol	Fermentation	Corn	U.S.	15-35%	3000-4000
Ethanol	Fermentation	Sugar beet	Europe	45-65%	4000-5000
Ethanol	Fermentation	sugar cane	Brazil	80-90%	6000-7000
Ethanol	Enzymatic hydrolysis & fermentation	Cellulosic	U.S.	70-90%	4500-5500
Biodiesel	Extraction & esterification	Soya	Brazil	30-50%	500-600
Biodiesel	Extraction & esterification	Rape	Germany	40-60%	1000-1400
Biodiesel	Extraction & esterification	Oil palm	Indonesia	75-85%	4000-6000
Biodiesel	Fischer-Tropsch method (biomass as raw material)	Various	various	50-100%	Varies

Source: adapted from IEA (2004) and Sakar and Kartha (2007)

The wide range in GHG reductions and yields for biomass and biofuels, even when substituting for the same fossil fuel, are due in part to the fact that biomass that is produced in tropical and sub-tropical climates has an average productivity that is on average 5 times higher than that of biomass grown in the temperate regions of Europe and North America (Bassam 1998). Since developing countries are located predominantly in the warmer climates and lower latitudes, they have a tremendous comparative advantage. However, the large amount of financial capital available in Europe and North America facilitates the technology and strong infrastructure that can compensate somewhat for the natural disadvantage.

1.4 Co-product Allocation

Co-products impact the economics of biofuels and the accounting methodology for co-products affects how GHG emissions are apportioned and therefore how they count in carbon finance or other initiatives to reduce GHG emissions. Often co-products are allocated according to energy content, and crop residues are excluded from the accounted co-products.

ISO 14041 recommends the more sophisticated approach of avoiding allocation either by dividing the process into multiple sub-processes, or by expanding the system boundary to include the functions of all co-products (ISO, 1998). Division into sub-processes is usually impossible for biofuel refining, but expansion of the system boundary is possible and has been demonstrated

in the literature (Kim and Dale, 2002; Rosentrater, 2005; Cederberg and Stadig, 2003). In the system expansion approach the GHG emissions associated with the unit system, as well as the GHG emissions associated with other unit systems affected by the various co-products, are accounted together. A set of simultaneous equations is solved to show the degree to which each product contributes to the GHG total. The method accounts for the degree to which various products substitute for each other in markets. Though this method of accounting is relatively new and requires sophisticated analysis, it is recommended by the ISO and deserves encouragement.

When system expansion is not possible, the ISO standard recommends that inputs and outputs to the system be partitioned in a way that “reflects the underlying physical relationships between them.” One way to do this is to measure the energy consumption associated with a unit-process-based substitute for each co-product, and use these energies as the allocation factors (Shapouri et al, 2002). Only as a last resort does the ISO standard recommend to use an allocation method based on economic or physical values, such as energy content.

1.5 Carbon Finance: Clean Development Mechanism

The Clean Development Mechanism of the Kyoto Protocol (CDM) permits non-Annex I parties to generate Certified Emission Reductions (CERs) that can be purchased and used by Annex I parties to meet their Kyoto obligations. Several proposed CDM methodologies deal with biofuels; however proposed methodologies may be revised significantly prior to approval by the Executive Board and therefore do not constitute a significant reference point for the proposed Directive.

Some approved methodologies address related issues, however. Methodology ACM0006, Consolidated Methodology for Electricity Generation from Biomass Residues, considers the GHG value of displacing fossil electricity with biomass electricity, but the GHG balance of crop growth is not accounted. Methodology AM0047 (UNFCCC, 2007) also considers the GHG value of displacing fossil energy, but again excluding life-cycle GHG emissions relating to the bio fuel's source.

In the context of the CDM, biofuels have received special attention on the issue of double-counting. Specifically, concern has been expressed that biofuel producers and consumers could potentially generate CDM credits from the same biofuels. One implication for future, biofuels-based CDM projects is that the produced biofuels will be required to displace fossil fuels (be consumed) in the same non-Annex I country.

Of more interest may be the uncertain effects of legislation such as the EU Directive on the CERs market. On the one hand, the large international market for biofuels supported by the Directive may mature the biofuels industry to the point that many biofuels-based CDM projects will be implemented and biofuels CERs flood the market. On the other hand, European demand for biofuels could divert biofuels away from domestic consumers in the non-Annex I countries, taking biofuels technologies out of the suite of potential CER sources.

2. Socio-economic Impacts

Socio-economic impacts that are of primary interest generally include income generation, job creation, provision of new services, creation of new infrastructure, establishing opportunities for entrepreneurs, and stimulating innovative technical and institutional approaches. At the same time, large scale projects have encountered controversy

involving the acquiring of traditional land and competition with food crops.

The range and extent of socioeconomic impacts of bioenergy use is greatly dependent on the scale and intensity. The Brazilian model exemplifies the large scale intensive approach, using high capacity central processing points fed by intensively farmed surrounding areas. The establishment of large estates can bring significant benefits to employees, such as health care, sanitation and improved infrastructure (Tomlinson, 2005). Indeed, the large-scale crop enterprises are more economically efficient. However, the question remains whether or not they can be designed to improve local livelihoods.

However, in the southern African context, the high proportion of subsistence farming amongst livelihoods in rural areas, and the complexities of land ownership under traditional land law regimes, has made such large scale acquiring of land somewhat more controversial. It has been suggested that a smaller scale approach may be more appropriate, possibly involving the contracting of small scale farmers to work as 'out growers', dedicating a proportion of their land to growing a crop for guaranteed purchase by a processing company. Such an approach has the advantage of providing additional seasonal income for poor rural farmers, without dismantling the structure of their existing livelihoods, which may be vital to their survival. However, the lower intensity of land use entails a larger area of agricultural production for each processing plant, resulting in feedstock transport costs becoming a serious obstacle to commercial viability.

A decentralised approach could also help to reduce feedstock transport costs by reducing the weight of the cargo—in other words—by decentralising more of the production process through the setting up of small scale distilleries. This would create another important benefit for the rural poor—access to clean, domestic fuel—with resultant benefits to health from reduction of indoor air pollution. The economic viability of such small scale distilleries has not been proved, however, and concerns have been expressed about the dangers of alcohol abuse. It is nevertheless an area worthy of some further investigation.

Seasonal employment can pose social problems in industries such as sugarcane in southern Africa. The sudden influx of migrant seasonal workers into regions to which they have no attachment has been reported to have negative effects on community cohesion, causing ethnic tension and disinte-

gration of traditional structures of authority. Migrant workers sometimes establish unauthorised settlements that they are unwilling to leave at the end of the season, ultimately increasing overall unemployment levels and pressure on land for subsistence farming. Due to the sometimes drunken and promiscuous behaviour of migrant workers, it has also been observed that HIV infection rates are high around sugar cane plantations (Cornland et al, 2003; FAO, 1995).

A major area of concern for critics of biofuels is the possibility that bioenergy crops could replace land for food crops. Another advantage of sweet sorghum is that as well as producing sugary stems suitable for ethanol production, many varieties also produce edible grains, which can be ground to make 'mealie meal', a staple food in many parts of southern Africa. This has the attraction of providing potentially a double benefit- subsistence food and an income, allowing the farmer the chance to rise out of poverty, without losing self sufficiency.

3. Land Use Changes

Land use change has been a significant source of global GHG emissions through time, between 1989 and 1998 land use change accounted for 1.6 ± 0.8 Gt C yr⁻¹ (IPCC LULUCF, 2000). GHG emissions from land use change can significantly change carbon stored as a result of the harvest or removal of vegetation, as well as accelerated decomposition rates of soil carbon (IPCC, 2000a). Conversion of forest and grasslands to cropland for biofuels production can result in significant GHG emissions and reduce the relative carbon savings of biofuels over fossil fuel sources. Growing recognition of the contribution emissions from land use change can have on the GHG impact of biofuels has increased attention and caution regarding accuracy of LCA calculations (Fargione et al. 2008).

Biofuel feedstock production can contribute GHG emissions from direct land use change, emissions from conversion of land from a prior use (e.g. forest) to biofuel feedstock production, as well as indirect land use change, emissions from conversion of other lands as a result of biofuels production due to increased agricultural pressure or demand for biomass material. Direct land use change GHG emissions can be incorporated, but indirect land use change GHG emissions are much more difficult.

3.1 Carbon Stocks

Carbon stock and productivity values can vary significantly by ecological zone based on climate, soil, terrain, and management conditions (IPCC Guidelines, 2006). Clearly defined land use classifications and incorporating climate region specific carbon stock values based on the IPCC Guidelines and productivity values based on FAO agro-ecological zones (AEZ) will reduce uncertainty and improve transparency of calculations.

The IPCC Guidelines for National GHG Inventories provides guidance on classification of land-use categories so they are applied as appropriately and consistently as possible in inventory calculations. Legislation should be aimed at harmonising GHG emissions calculations with the IPCC Guidelines to the greatest degree possible. In doing so, opportunities to coordinate with National GHG Inventory efforts and data resources increase, as well as improving consistent and transparent GHG accounting.

The IPCC Guidelines provide detailed guidance on calculating annual emissions from carbon stock changes as a result of land use change. Using a three tiered approach, the IPCC Guidelines allow for improved accuracy of calculations at higher tiers if data and resources are available. The proposed Directive would be well advised to harmonize emissions calculations of changes in carbon stock as a result of land use change with the IPCC Guidelines. This could be achieved by either requiring users to use the IPCC Guidelines when calculating emissions from carbon stock changes caused by land use change. Otherwise a table or web based tool using carbon stock values for land use types eligible for biofuels production under the proposed Directive could be developed to facilitate users.

Using the FAO agro-ecological zones methodology for calculating the productivity values of biofuels crop production could improve the accuracy of emissions calculations. The FAO agro-ecological zones methodology calculates potential crop yields by matching crop environmental requirements and land resources (IIASA, 2000). To facilitate users a simplified table of biofuel crop production by climate zone or web-based tool with further stratified crop production values could be generated based on the FAO agro-ecological zones methodology.

3.2 Direct Land Use Changes

There has been increasing concern that carbon losses from intensification of agriculture and clearing of natural lands leads to large emissions that are not fully accounted for in analysis of the lifecycle assessment of biofuels production (Fargione et al. 2008, Searchinger et al. 2008). GHG emissions from direct land use change can be addressed as annualised emissions from carbon stock changes caused by land use change and emissions from the extraction or cultivation of raw materials.

3.3 Indirect Land Use Changes

Indirect land use change occurs when pressure on agriculture due to the displacement of previous activity or use of the biomass induces land-use changes on other lands (Gnansounou et al. 2008). The GHG emissions that result from indirect land use change are known as leakage, defined by the IPCC as changes in emissions and removals of GHG outside the accounting system that result from activities that cause changes within the boundary of the accounting system (IPCC, 2000). Article 15 of the proposed Directive prohibits conversion of natural ecosystems for biofuels production. However no similar restrictions limit conversion of natural ecosystems to agricultural production that result from indirect land use change from increased biofuels production.

Several recent studies have highlighted that GHG emissions in biofuels production from indirect land use change are more significant than emissions from direct land use change. Recent estimates from Searchinger et al. (2008) based on scenarios to estimate the effect of increasing corn ethanol production in the US, conclude that indirect land use emissions double the emissions of corn ethanol relative to gasoline. Farrell and O'Hare (2008) concluded that shifting corn-soybean production to only corn for ethanol may induce soybean expansion into forest, which would result in GHG emissions 6 times higher than gasoline. The magnitude of indirect land use changes is not expected to be linear, but several factors have been identified which determine the change in cropland including: production of co-products, crop prices, and crop yield (Searchinger et al. 2008).

Several challenges exist to accurately quantifying emissions resulting from indirect land use at a global scale. No current global models of indirect land use change exist. A global trade and economic model with country by country and crop by

crop data would be needed. Searchinger et al. (2008) use the FAPRI international model for their analysis, however since this is a partial equilibrium model interaction with other economic sectors is not accounted for. Analysis by the US EPA using the FASOMGHG model provides assessments of leakage as a result of agriculture and forestry sector activities in the US, though the applicability globally may be limited (US EPA, 2005). Revisions to the GTAP and CLUE models have been proposed and may better account for displacements resulting from indirect land use change (Gnansounou et al. 2008).

Methodologies for accounting for indirect land use change are also being developed. CDM methodologies for bioethanol production from sugar cane include consideration of GHG from indirect deforestation by requiring a fixed area radius around a project site to be annually monitored in order to assess the land use change impact of the plantation on the forested area (UNFCCC, 2007). The Dutch government has proposed a general methodology to estimate indirect land use based on determining the relevant markets/areas delivering biofuels to the country, the expansion of each of these markets due to biofuels due to food/feed and in total, how the additional demand is being met, the GHG emissions of expansion of these markets, the impacts of market expansion over biofuels and food/feed, and dividing these effects by the amount of biofuels per market (Cramer Commission, 2007).

Recent analysis by the Oeko-Institute proposed accounting for GHG emissions from indirect land use change by using an "iLUC factor" for calculating the GHG balance of biofuels (Oeko Institute, 2008). The impact of applying an iLUC factor, a bonus or penalty from the GHG emissions resulting from indirect land use change, on the GHG impact of biofuels production are shown in Table 3. GHG emissions estimates presented in Table 3 are stratified by biofuel type, an important consideration since indirect land use change will not be the same for all crops, and based on a range of iLUC factor levels.

Market changes through time can be expected to change the indirect land use change resulting from biofuels production. If an approach such as the "iLUC factor" were applied a mechanism to revise estimates through time would be needed. Germany advocates to introduce a bonus for biofuels from residues/wastes and unused/degraded lands based on the iLUC factor (25% level) (Fritsche, 2008). Alternatively it has been suggested that a dynamic iLUC factor bonus be

introduced – 25% level through 2012, 50% until 2015, and 75% until 2020 (Fritsche, 2008). Alternatively, biofuels prone to induce indirect land use change risks could receive an iLUC factor penalty (Fritsche, 2008).

existing ecological, cultural, agro-industrial and land use systems that are specific to the area under consideration. However, it is possible to devise a 'check list' of sustainability criteria most likely to be relevant to a bioenergy project. The following are among the key criteria are identified by

Table 3 GHG emissions from indirect land use change based on iLUC factor approach (formerly known as “risk adder”) approach.

biofuel route, <i>life-cycle</i>	kg CO _{2eq} /GJ with a risk adder level:			relative to fossil diesel/gasoline		
	max	med	min	max	med	min
Rapeseed to RME, EU	117	89	60	38%	4%	-30%
palmoil to PME, Indonesia, rain forest	180	142	103	112%	67%	21%
palmoil to PME, Brazil, tropical	199	154	110	135%	82%	29%
sugarcane to EtOH, Brazil, tropical	60	48	37	-30%	-43%	-56%
maize to EtOH, USA	89	73	57	5%	-14%	-33%
maize to EtOH, EU	69	60	50	-19%	-30%	-41%
SRC/SG to BtL, EU	52	37	23	-39%	-56%	-73%
SRC/SG to BtL, Brazil, tropical	59	42	25	-30%	-50%	-70%
SRC/SG to BtL, Brazil, steppe	73	52	30	-14%	-39%	-64%

bold red = no GHG reduction!

Source: Fritsche, 2008a

It is important to note that this is only one approach and other methodologies have not yet emerged since the issues addressed are not yet well-researched. Therefore, it would be logical to call for more research on this topic, and to recommend to the EC Research programme to support such research.

4. Sustainability Criteria

There has been considerable effort during the past several years aimed at the development of sustainability criteria for biomass and biofuels, both within regions and in the context of international trade. In Europe, a recent analysis shows that 15-17% of expected primary energy requirements in the EU-25 in 2030 could be met through bio-energy, even with the application of rather stringent sustainability criteria. The expansion would be facilitated by increased availability of significant quantities of waste residues, the increasing productivity of agricultural biomass sources, and the increased amount of land available for dedicated energy plantations (EEA, 2006).

It is worth reiterating that in the context of bio-energy projects, 'there are no "one size fits all" solutions' (ESMAP, 2005). Socio-economic and environmental impacts must be assessed for every new bioenergy project in the context of the pre-

Smeets et al (2005) in their case studies of Ukraine and Brazil.

- Land use patterns: deforestation, competition with food, protection of natural habitats
- Socioeconomic: child labour, minimum wages, employment, health care, education
- Environmental: soil erosion, fresh water use, fertilisers pollution, agricultural chemicals

Smeets et al assess the costs of applying these criteria both in a 'loose' and 'strict' fashion, the latter set sometimes being defined as not merely minimising negative impacts, but making positive improvements, most notably in the provision of health care and education services. It is worthwhile considering whether the concept of sustainability in bioenergy projects or programmes should mandate simply that conditions measured according to these criteria should not be negatively impacted; or whether in fact true sustainability should entail positive improvement of conditions. At the same time, it is important to recognise that bioenergy in some cases will replace fossil fuels, and as such the costs and benefits must be compared to those of the fossil fuels being replaced.

Sustainability criteria for bioenergy will inevitably have to address certain core criteria, which will differ considerably in different regions and for different crops. The core criteria would likely cover the following areas (WWF, 2006):

- land use and land ownership, including food security
- maintenance of biodiversity
- reduction and minimisation of greenhouse gas emission
- soil erosion and degradation
- water use and contamination
- socio-economic impacts

The criteria would also have to be applied at varying levels: local, regional, national, and international (i.e. particularly in relation to trade). Undoubtedly there will be conflicts across the scales and consequently a governance system or perhaps an environmental regime would have to be somewhat flexible but also capable of maintaining fairly high standards. The Roundtable on Sustainable Biofuels (RSB, 2008) has gone through several rounds with various stakeholders in order to develop a set of sustainability criteria, and these are being distributed for comments.

5. Conclusions

All biofuels are not created equal: there are wide variations in the efficiency and environmental impacts of the various biofuel crops. Some first generation crops in tropical and sub-tropical climates are highly productive and efficient—namely sugarcane and palm oil. Temperate crops are much less efficient and the amount of land and resources required can be excessive. Considerable care is also needed in assessing the impacts on land use and the possible emissions from land clearing or alterations, as there is uncertainty as to the benefits of bioenergy when virgin land is used. The use of degraded land could offer benefits, as well as the application of second generation biofuels, which in some cases can lead to 100% reduction in GHG emissions.

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7. Discussion

Mr. Amitab Rajouria

Regarding the guideline and mandatory framework in the regional terms and not on a country wide basis because of small countries like Sri Lanka and Nepal, if we have own guidelines, the manufacturers would not care. But if we have regional directives, they are bound to follow that, like the EC. So if somebody wants to any car or equipment, they have to follow those. So far, such standards are developed by the EC, not the car manufacturers or equipment manufacturers. So if we are able to having worked towards developing them for SAARC, it would be a real strength as we have a huge population in the region.

Dr. Muhammad Pervaz

I would like to know the process of making these standards. When EU makes standards or any other policy, you consult the member states or you consult the member state institutions?

Mr. Xavier Johnson

It works like this. You have 3 branches, commission which is the executive branch, you have the parliament which is the legislative branch and you have the council which represents each of the 27 member states. The Commission makes the proposals and then the parliament and council both debate it. The council is more limited in presenting a unified response because it has 27 member countries, but the parliament is better able to make a response. So what they did in this case is the environment committee and industries committee worked together to come up with these guidelines. But most interested aspect about this is that, unlike the Americans, who still are pushing the maize to Ethanol, they actually are tough on their own producers because meeting the criteria of 45% GHG reductions is very difficult for the 1st generation temperate Biofuels like rapeseed, wheat, maize or even sugar beet, where as for tropical Biofuels, such is easier. So it is an interesting case where they were tough on their won industry so these changes with the directives were not popular within the European Biofuels industries. Actually, because they are basically telling them that you have to move very quickly to 2nd generation or you will not survive.

Dr. Muhammed Pervaz

Coming to the SAARC, We don't have a SAARC

parliament, its only heads of states meet regularly and there are other levels, ministerial, then senior officials and then working groups and technical committees. What do you think that, as you are having a strong system, you are having the guidelines and national governments have their own strict laws that are to be followed? What would you suggest for SAARC?

Mr. Xavier Johnson

I think it is an interesting opportunity for SAARC and ASEAN and other regional organisations, because now that this is coming out, you can then formulate by consulting your member states in a forum like this. You can consult on how to meet these criteria basically. You can develop a sort of road map for how we can first of all checking what feedstock, what crops and what regions where most likely to meet the criteria. So that is your first step I think. Then you need to say okay, we have a rough idea what crops that can meet this and where, and now we need to know how we can institutionalise this in order to show the life cycle and then some type of an implementation plan, may be to assist the member states in doing this. So I think it is an interesting opportunity because simply by being more aware of how to or what crops meet the criteria and what regions, then how to monitor and show compliance. You can already be a little ahead of the market, because it will be a few years before the directives really get into place. In 2014, they are going to make a review of the directives. So that means, there is 6 years to prepare because if they go ahead and stick with the 10% target, then there would be quite substantial market by 2020.

Mr. P M Kancharla

I have gone through all the regulatory mechanisms and changes on mandatory requirements. But I think that could be more of a regulatory mechanism, in the sense guidelines, for Asia is to evolve itself. Since Europe has adhered to WTO and removed subsidies of sugarcane, we foresee a major market for sugarcane and Biofuels.

Mr. Xavier Johnson

Basically for regional guidelines, I think it would be good to start that now and by the time of this reviews, you have a system in place

Mr. P M Kancharla

I think EPLF's RSB almost have the entire guidelines stipulated and formulated by the EU. I think it could give us good benchmark and a roadmap where we could formulate and regionalise in a regional context, on soil, water, agronomy and even air.

Mr. Xavier Johnson

I wanted to say, take the RSB guidelines and the requirements in the directives together, because some member states wanted to have social criteria in here as well. They ended up noticing that there not being social criteria. In a way, it is quite strange. For Biofuels eventually, probably would get shot down at the WTO. But in that respect, RSB is interesting because it tells something about people and also about social criteria, not just environment.

C. Technology

Biodiesel; Oil Expelling and Processing

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Abstract

Biodiesel is a domestic, renewable fuel for diesel engines derived from natural oils and fats (soybean, canola, palm, sunflower, jatropha, lard, etc.) which meets a fuel specification such as ASTM D 6751.

Oils and fats normally occur in vegetable and animal tissues mainly as a mixture of tri-acyl-glycerides (TAG). Oils from seed kernel are usually obtained by exerting mechanical pressure or by solvent extraction. The expelling process involves several unit operations including seed cleaning, shell decortication, drying, expelling, gravity setting and filtration. Animal fats are often extracted by boiling fat-containing tissue in water. Use of straight oil (SVO) in existing engines pose a risk of engine damage, therefore it is advisable to convert SVO into biodiesel.

Laboratory scale Oil expelling and biodiesel processing was conducted aiming at erecting a community biodiesel processing facility at Rasnayakapura, Sri Lanka. Rubber (*Hevea brasiliensis*), jatropha (*Jatropha Curcus*), neem (*Azadirachta Indica*), castor (*Ricinus communis*), domba (*Calophylluminophyllum*), and coconut (*Cocos nucifera*) oils were extracted mechanically as it was found convenient compared to chemical method. The highest oil yield of 60 % (W/W) was obtained with domba seed while the lowest 32 % (W/W) with neem.

Extracted and filtered oils were converted into biodiesel by three methods: i) base catalyzed transesterification (one-step method), ii) purification followed by transesterification and iii) esterification followed by transesterification (two-step method). Oils with high free fatty acid contents (all except coconut oil showed FFA>2%) were difficult to transesterify by simple one-step method as the formation of soap at the product interface made the biodiesel separation extremely difficult. Oil purification by NaOH promoted-soap formation (method ii), considerably reduced the usable oil content. Although two-step method utilized heavy chemical dosage, a high biodiesel yield (>85%) were received with all tested oils.

Raw biodiesel was washed with slightly acidic aqueous solution to remove excess reactants and impurities as proposed by the University of Idaho bubble wash technique. Blends of refined coconut and neem oil biodiesel were tested in an internal combustion engine and reported that they perform are better than mineral diesel.

Keywords: oil extraction, transesterification, biodiesel.

Notation

B100	100% biodiesel
B20	mixture of 20% biodiesel with diesel
CO	carbon monoxide
DPCE	Department of Chemical and process Engineering, University of Peradeniya
NERDC	National Engineering Research and Development Centre, Ekala, Ja-Ela
O ₃	ozone
PAH	polyaromatic hydrocarbons
PM10	particulates
THC	total hydrocarbons

1.0 Introduction

Crude oil is used mostly, for producing "primary energy" sources. Eighty four percent (by volume) of the hydrocarbons present in petroleum is converted into energy-rich fuels (petroleum-based

fuels), including LPG, gasoline, diesel, jet fuel, fuel oils, and other heating fuels. Average price of crude oil and crude derivative oils are increasing rapidly over the past few years due to reasons of macro political situations, limitations, and increasing demand. Worldwide oil production in the year

2030 has been predicted to be the same as it was in 1980 while the world's population will be both much larger (approximately twice) and much more industrialized (oil-dependent) than it was in 1980 (1). Consequently, worldwide demand for oil will outpace worldwide production of oil by a significant margin. As a result, the price will skyrocket, oil dependant economies will crumble, and resource wars will explode.

Combustion converts chemical energy stored in fossil fuels into useful forms of thermal energy. However, burning of fuels not only produce energy but waste products such as CO₂, CO, H₂O vapour, SO_x, NO_x, particulates and volatile organic compounds which were found affecting the environment in harmful ways. A research that examined the health effects of the use of fossil fuels reported that reducing air pollution in just four of the world's largest cities; New York, Mexico City, Sao Paulo; and Santiago could prevent 64,000 premature deaths and 37 million lost workdays over the next two decades (2). Burning fossil fuels produces around 21.3 billion tonnes of carbon dioxide per year, but it is estimated that natural processes can absorb only about half of that amount, so there is a net increase of 10.65 billion tonnes of atmospheric carbon dioxide per year. Carbon dioxide is one of the major greenhouse gases that contribute to global warming, causing the average surface temperature of the earth to rise. Climate scientists agree that global warming cause major adverse effects, including sea level rise and reduced biodiversity.

Biofuels provide a short and medium term alternative to global energy related problems. They offer number of economical (energy independence, carbon credit benefits, foreign exchange), environmental (carbon neutral, biodegradable, lower toxic emissions), and social (jobs, entrepreneurship, rural development) advantages. Biodiesel is the alternative to crude oil based diesel fuel which can be made from vegetable oil and animal fats.

2. Biodiesel

Biodiesel is the name of a clean burning alternative fuel, produced from renewable resources of vegetable oils and animal fats. Biodiesel is defined to be the alkyl monoesters of the respective oil that is made by chemically reacting the oil or fat with a primary alcohol under controlled condition. These fuels contain no petroleum (fossil), but can be blended at any level with petroleum diesel to create a biodiesel blend. Biodiesel blends can be used in compression-ignition

(diesel) engines with little or no modifications.

Biodiesel can be mixed with petroleum diesel in any percentage. Blends are represented by a number following a B. For example, B20 is 20 percent biodiesel with 80 percent petroleum. In United States biodiesel is produced in accordance with strict industry specifications. Most major engine companies have formally stated that the use of blends up to 20% will not void their parts and workmanship warranties. Several statements from the engine companies are available on the NBB website (3). Higher percentage biodiesel blends (above B20) can cause a variety of engine performance problems, including filter plugging, injector coking, piston ring sticking and breaking, elastomer seal swelling and hardening/cracking and severe engine lubricant degradation.

2.1 Benefits of Biodiesel

2.1.1 Environmental Benefits

Biodiesel has many environmental benefits. It is biodegradable and non-toxic fuel with essentially free of sulphur and aromatics components. It has been reported that 100% biodiesel (B100) will reduce the emissions of THC, CO, PM10, sulphates, PAH and O₃ by more than 90%, 50%, 30%, 95%, 80%, and 40%, respectively, compared to the crude oil base diesel fuel. Even a 20% blend (B20) exhibited a reduction of above parameters approximately by 30%, 20%, 23%, 20%, 15%, 50% and 8% (4).

Since biodiesel is produced from plant oils, it has been promoted as a means for reducing emissions of carbon dioxide that would otherwise be produced from the combustion of petroleum-based fuels. Carbon dioxide is considered to be the main component for the global warming.

Biodiesel is the only alternative fuel to have fully completed the health effects testing requirements of the 1990 Clean Air Act Amendments (5). Biodiesel that meets ASTM D6751 is legally registered with the Environmental Protection Agency (EPA US) as a legal motor fuel for sale and distribution.

2.1.2 Economical Benefits

Since biodiesel can be made within the country from renewable and non-edible oil resources such as rubber, jatropha, castor bean, and neem, its use may decrease the country's dependence on foreign oil and contributes to the country's economy.

From an economic point of view the possibility of receiving financial resources through the commercialization of carbon credits (as it was established by the Clean Development Mechanism - CDM), should also be considered.

2.1.3 Societal Benefits

The social impact of the biodiesel contains the creation of new jobs and the improvement of the present income situation of local farmers and entrepreneurs. A case study aiming at producing biodiesel with capacity of 60,000 tons per year, reported that it may require 120 persons as employees, in addition to 30 farmers for the cultivation of oilseed plants (6).

2.2 Drawbacks

2.2.1 Air Pollution by NOx Emission

Emissions of NOx appear to increase when biodiesel is used. The fact that NOx emissions increase with increasing biodiesel concentration could be a detriment in areas that are out of attainment for ozone. Thus it is appropriate to consider the limited conditions under which NOx might actually has a minimum effect on environment with increasing biodiesel concentration. It was suggested to use maximum 20% biodiesel blends (B20) to reduce NOx generation (7)

2.2.2 Fuel Quality

Fuel quality is extremely important; low quality fuel may create serious engine malfunctions. Therefore biodiesel quality has to be match with an international standard such as ASTM specification ASTM D-6751. Few selected international biodiesel standards are given in the Appendix A. Blends up to B20 can be used in existing equipment without any modification.

2.2.3 Solvency

High solvency of biodiesel reported causing dissolution of rubber parts of vehicles including paint, rubber hoses, and gaskets (8). Fibre-reinforced nylon, copper, or inert materials like viton fabricated components should use when high biodiesel blends (>B20) are applied.

2.2.4 Deforestation

Irrespective of all benefits there is a serious a counter argument that the demand for land to grow fuel crops would lead to the probable destruction of forests. The Rights and Resources

Initiative (RRI) says only half of the extra land needed by 2030 is available for all kind of human needs without invading into tropical forested areas (9). It further argued that the deforestation would lead to more human conflicts, carbon emissions, climate change and less prosperity for everyone. However, scientists believe that agricultural technologies including genetic engineering will boost crop yields so that the problem can be solved to a certain extent.

2.2.5 Food Crisis

Another common objection to biomass energy production is that it could divert agricultural production away from food crops (10). This will lead to food shortage and increase in food prices resulting under-nourishment among poor nations. Therefore it is essential to limit biofuel resources to non-edible (2nd generation biodiesel) sources and large plantations limit only in unfertile lands where food crops are hardly grown.

3. Oil Bearing Raw Materials

Transesterification of vegetable oil was conducted as early as 1853 by scientists, many years before the first diesel engine became functional. Rudolf Diesel's prime model ran first time in Germany on August 10, 1893 by peanut oil, a biofuel, though not biodiesel. On August 31, 1937, G. Chavanne of the University of Brussels (Belgium) was granted a patent for a "Procedure for the transformation of vegetable oils for their uses as fuels" which described the alcoholysis (transesterification) of vegetable oils using methanol and ethanol. Research into the use of transesterified sunflower oil, and refining it to diesel fuel standards, was initiated in South Africa in 1979. By 1983, the process for producing fuel-quality, engine-tested biodiesel was completed and published internationally (11). Oil from rapeseed (canola), an oilseed originally bred for food purposes, was the first commercial raw material source for biodiesel in Europe (12).

The first generation source material for biodiesel was derived from widely available edible vegetable oils, depending on the region: rapeseed in northern Europe, soybean in the US, and palm oil in tropical regions. Coconut and sunflower oil are also commonly used. However, due reasons such as food shortage and high oil prices, the attention is diverted into the 2nd generation (from non-edible sources) and 3rd generation (algal based) feed stocks. *Jatropha*, castor, and recycled restaurant greases are among the most studied oils and fats as the non-edible sources.

Common oil bearing seeds and oil yields are listed in Table 1.

Table 1 Yields of oil bearing plants

Crop	litres oil/ha	Crop	litres oil/ha
Corn (Maize)	172	Peanuts	1059
Cashew nut	176	Rape-seed	1190
Cotton	325	Olives	1212
Soybean	446	Castor beans	1413
Coffee	459	Jatropha	1892
Linseed (flax)	478	Brazil nuts	2392
Pumpkin seed	534	Avo-cado	2638
Safflower	779	Coconut	2689
Rice	828	Oil palm	5950
Tung oil tree	940	Algae	46800-140000
Sunflow-ers	952		
Cocoa (Cacao)	1026		

3.1 Raw Material Collection

Seeds for oil can be found either from natural forests or specifically grown plantations. The former source is suitable only for few litres of biodiesel production per week to fulfil a community needs such as water pumping or electrification; however for a medium to large scale operation, a plantation is a must. Collection of oil seed is usually a manual operation. In a day, a person could collect up to about 80 kilograms of seeds, which can produce 20 to 23 litres of oil (depending on the seed). Therefore, for 1 tons per day plant, it needs approximately 150 people to collect the seed requirement. Collecting and organizing such a large manpower is a challenge in the industry.

Collected seed should be dried and stored to prevent seed quality deterioration. Though this could be a logistical problem for large biodiesel processing facilities, is an essential operation. Sun drying is the easiest way of seed drying. Seeds were spread and dried for some time directly un-

der sunlight or in solar dryers. The moisture content needs to be reduced to about 6-7% depending on the seed, climate and the season.

4. Oil Expelling

4.1 Preparation

Preparation of the raw material often includes removing husks or seed coats from the seeds and separating the seeds from the chaff. Decorticators are used for stripping bark or rind from nuts, plant stalks and grains.

Dehullers are used for the separation of foreign materials from seed kernel (in which oil is available). Figure 1 shows dehulling of rubber seed by NERDC designed seed huller. Light foreign material and dust is removed by blowing while heavy ones using a flat screen. The mesh of the screen depends on the size of seeds and impurities. Seed kernel remain on the screen is used for the oil extraction.



Figure 1 Dhulling of Rubber Seed
(a) Huller, (b) Rubber seed kernel

4.2 Extraction

Mechanical methods such as hydraulic pressing (Figure 2a) and continuous screw pressing (Figure 2b) dominate the oil extraction (expelling) industry. In conventional expelling, where maximum oil yield is the criterion of emphasis, it is not uncommon to make several passes through the expeller. While this increases oil recovery, it also results in excessive heating of the cake, accompanied by over-heating, darkening, and deterioration of oil.

In the native state, oil is deposited within the bean tissue cells in bodies known as spherosomes. In conventional pressing operations, the beans are cracked and subjected to dry heating (ex. solar drying or steam cooking) over a prolonged period of time so that the moisture is reduced to somewhere between 2-5%. Low moisture is generally desired in expelling operations. The heated material is held at high temperature for moisture equilibration before being fed into an expeller.



(a)



(b)

Figure 2 Mechanical Oil Expellers
(a)Hydraulic Press (b) Continuous screw press

The expeller performs two functions. First, it further disrupts the tissues and releases hot oil within the matrix. Second, it forces the oil out of the matrix under pressure (13). Figure 3 shows extraction of jatropha oil. The oil such extracted are used for biodiesel processing, while the spent cake is used predominantly for livestock feed (if edible) or as a soil conditioner (in cases such as jatropha).



(a)



(b)



(c)

Figure 3 (a) Extraction of Jatropha oil
(b) Oil Outlet, (c) Oil Cake

Solvent extraction has replaced mechanical methods of oil extraction in the developed world. Oils from seeds (or the cake remaining from expelling) can be extracted with solvents and the oil is recovered after distilling off the solvent under vacuum. Chemical extraction is efficient; the cheapest way on a large scale operation, but an expensive way on small scale processes. Figure 4 shows photographs of laboratory and industrial scale extractor units. Table 2 gives the oil yields received for 5 oil varieties tested at NERDC laboratory.

With some 18% fat in the soy bean, only 10-14% oil can be expelled mechanically. All 18% can be extracted only through a hexane process (14). Solvents such as normal hexane, carbon tetrachloride, acetone and supercritical fluids are used but

most of them are highly flammable and moderately toxic. Hexane is a petrochemical derived from Benzene, which was outlawed as a malignant chemical causing cancer while hexane is also targeted for discontinuation in extraction of oil in human food applications.



(a) (b)

Figure 4 Chemical oil extractors; (a) Sohlet Apparatus, (b) Solid-liquid Extractor

Table 2 Mechanically and Chemically

Seed	Average Oil Extraction Yields, Wt. %	
	Mechanically	Chemically
Rubber	32	44
Neem	22	32
Domba	52	60
Jatropha	39	49
Castor been	23	33

4.3 Clarification

Clarification removes contaminants, such as fine pulp, water, and resins. Raw oil can be clarified by allowing it to stand undisturbed for a few days and then removing the upper layer or by filtration through a fine filter medium under exerted pressure (Figure 5).



(a) (b)

Figure 5 Oil filters; (a) Hydrostatic Filter (low rate), (b) Centrifugal Filter (high rate)

Product yields received in oil extraction tests conducted at NERDC are given in Table 3. The total expelling time was about 4 hours while filtering was continued for 12 hours.

Table 3 Summary of oil extraction test

	Rub-ber	Domb a	Neem	Jatropha
Seed with cover, kg	100	100	100	100
Seed Cover, kg	44	42	44	44
Kernel, kg	56	58	56	56
Filerd Oil, L	20	32	18	19

Most of the edible oils currently used are stable. These do not decompose much on storage, hence are better for biodiesel processing. Non-edible oils are not that stable, and need a lot of pre-treatment adding to the cost of manufacture of biodiesel. Figure 6 shows the change in FFA% of neem oil after extraction (a result from an experiment conducted at DCPE). To prevent the oil get rancid, it can be heated to drive off traces of water and destroy any bacteria.

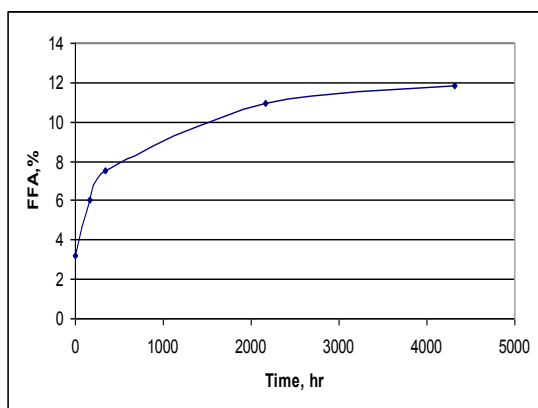
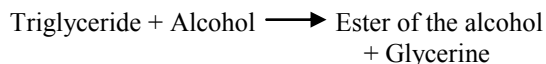


Figure 6 %FFA Vs. Time after extraction of Neem oil

5. Processing

Biodiesel is defined to be the alkyl monoesters of vegetable oils or animal fats that are made by chemically reacting oil or fat with a primary alcohol under controlled condition. Triglycerides in vegetable oils are therefore converted into respective mono-alkyl esters by the process known as transesterification. Main products of this reaction are monoesters; (the diesel fuel equivalent) and glycerine (a high value by-product).



Because of its low cost, methanol is the most common alcohol used. Figure 7 presents the transesterification reaction of an oil with methanol. R1, R2 and R3 are long alkyl chains containing carbon and hydrogen atoms.

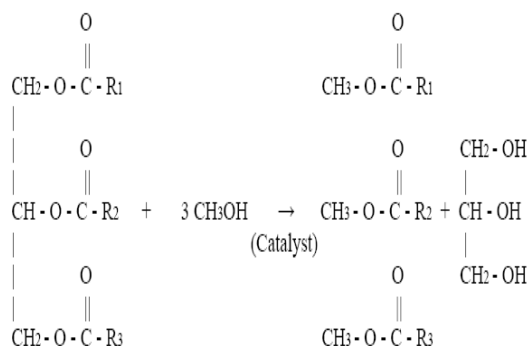


Figure 7 Transesterification of triglycerides with methanol (R1, R2 and R3 are alkyl chains)

Presence of free fatty acids (FFA) in oil interferes with the transesterification reaction. However, if the FFA content is less the effect is insignificant. Therefore based on the FFA content of raw oil, a suitable transesterification process has to be chosen.

5.1 Transesterification of Oils with Low FFA

When the oil has less than 2.0% FFA, the transesterification can be performed by a single step (one-step method). This is the simplest method which needs only sodium methoxide for the conversion. If sodium methoxide (as it is) is not available, a calculated quantity of sodium hydroxide is mixed with methanol to make a suitable solution. Empirically 3.5 g NaOH per 1L of oil and six parts alcohol to one part triglyceride (approximately 200 ml/l of oil) is needed to drive the reaction to completion. This solution of sodium hydroxide in the alcohol is then added to the heated oil (typically 50-60 °C) and stir for a pre-determined time period (typically 0.5 to 1.5 hours) to allow the transesterification to proceed.

The reaction yields two phases. The lower layer is composed primarily of glycerine and other waste products (Figure 8). The top layer; a mixture of biodiesel and excess alcohol, is decanted. The excess alcohol can be distilled off, or can be extracted to water by bubble washing.



Figure 8 Products from 1-step transesterification of coconut oil

5.2 Transesterification of Oils with High FFA

High free fatty acid oils (FFA > 2%) may create 4 major problems if they are fed to a base catalyzed system:

- More catalyst will need to be used leading to higher cost ;
- Soap (fatty acid salt) will be formed (see Figure 9), making glycerine and other waste material separation more difficult;

- iii) More water will be formed which will retard the main reaction ; and
- vi) Since the FFA's are not converted into fuel, it will reduce the yield.

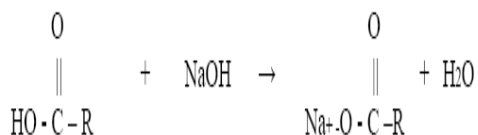


Figure 9 FFA in High FFA oil (> 2%) will react with the catalyst and form soaps

There are several methods to transesterify high FFA containing oils

- i) Method I: mix the high FFA oil with low FFA oil and proceed with one-step method;
- ii) Method II: Add base catalyst to change FFA to soap, remove soap, and then proceed with one-step method;
- iii) Method III: Add an acid catalyst and methanol and heat to convert FFA into respective monoglyceride and then proceed with one-step method.

Method I is the simplest of all. However, it needs oil containing very low FFA% which may be expensive to produce or purchase.

Adding an aqueous solution of a base catalyst and to oil (Method II) is another simple method, but it has some disadvantages. The percentage of feed-stock that will be lost due to soap formation is high (all FFA will be converted into soap). The resulting water and soap would be difficult to gravity separate but can be filtered off by exerting an external pressure. Figure 10 shows a photograph of refined and unrefined Jatropha oil samples.



Figure 10 Refined (left) and unrefined (right) oil samples

Reaction of oils with very high FFA (>20%) sometimes ended up by forming a bulky solid phase with very little amount of usable oil (Figure 11).



Figure 11 Solidified oil due to high FFA content

Method III is known as the 2-step method. First step is the esterification of FFA (to reduce FFA content below 2%) and the 2nd step is the transesterification of triglycerides. The esterification is often conducted by a primary alcohol in the presence of an acid catalyst and the subsequent transesterification by a method similar to the one-step method. Sulfuric acid and methanol are the commonly used chemicals for the 1st step. Methanol and sulfuric acid requirements needed for the esterification can be estimated from the generalized relationships given below :

$$\text{Methanol} = 2.25 \times W_{\text{TAG}} \text{ grams} \quad (1)$$

$$\text{Sulphuric acid} = 0.05 \times W_{\text{TAG}} \text{ grams} \quad (2)$$

Where W_{TAG} is the weight of un-reacted triglycerides in grams in the sample. High FFA oil is first heated to a temperature between 50 and 60°C and the methanol-acid solution is added. The mixture is agitated for about 2 hours and let the mixture to settle for 12 hours.

The esterification reaction is shown below. This reaction produces monoesters of the respective triglycerides and water as a by-product.

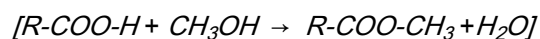


Figure 12 shows the change of FFA% as the reaction progress for rubber seed oil. Biodiesel is also

formed by a parallel transesterification reaction but the reaction rate is extremely slow. Therefore when the FFA content is reduced to 2%, the process is terminated and low FFA oil is drained.

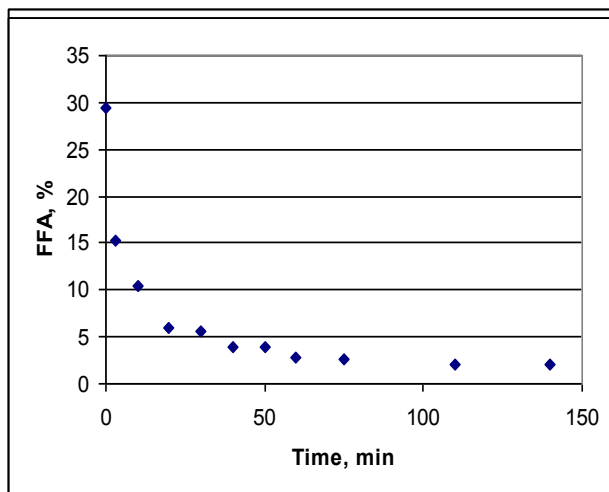


Figure 12 Reduction of FFA% in rubber seed oil during esterification

The excess methanol, catalyst (acid), and water is separated to top and monoesters with unreacted tryglycerides settled to bottom as shown in Figure 13.

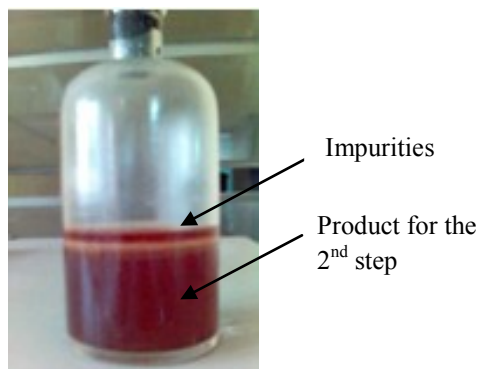


Figure 13 Product Separation after esterification reaction

If the FFA content of the bottom fraction after settling is less than 2%, it can be continued with transesterification. Otherwise the above process (the 1st step) is repeated until the required reduction is achieved. Methanol and sodium hydroxide requirements for the transesterification reactions can be estimated as follows (15):

$$\text{Methanol} = 0.217 \times W_{TAG} \quad (3)$$

$$\text{NaOH} = (0.16 + \% \text{FFA} \times 0.14) W_{TAG} / 100 \quad (4)$$

The oil is heated to about 60 °C and NaOH/methanol solution (estimated from equations 3.3 and 3.4 and dissolved completely so that no solids are remained) is added. The mixture is continued to stir at the same temperature until all triglycerides are converted to monoesters (for 30-60 minutes). Then the mixture is kept still to gravity separate the products (Figure 14).

The 2-step method is the most commonly used method for the biodiesel processing from high FFA oils. The disadvantages are lengthy operational period (about 2 days per batch) and the high the cost of reactants especially methanol. In general, about 2 L of methanol is required to treat 1L of FFA in oil. For example, for 40 L of oil with 10% FFA, needs 7 L of methanol for the first stage of treatment and 8 L for the second stage. Although, a methanol recovery system could return 3 L from the first stage and 1½ L from the second, it requires additional time and energy.

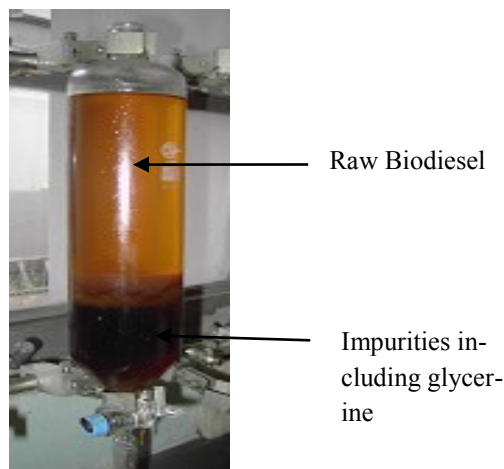


Figure 14 Raw biodiesel and impurities

Two qualitative tests could be performed to see if the reaction has successfully completed. A test that could approximate the completion of the reaction is known as methanol test in which 3 ml of the raw biodiesel is vigorously shake with 27 ml of methanol. Formation of a single phase indicates the reaction is completed. Wash test (vigorously stirred 50:50biodiesel/distilled water mixture should settle no more than a "paper-thin" white layer between the oil and water after separation) indicates the oil is free from soap (16).

6. Purification of Biodiesel

Transesterification reaction produces biodiesel and glycerin. The bottom layer (mainly glycerin) is separated and methanol is recovered by distillation. There may be unwanted and undesirable constituents such as excess methanol, alkali soaps, waxes and acids presence in the top biodiesel fraction. Therefore, it requires removing these constituents to save possible damage to the IC engine in subsequent fuel usage.

A bubble washing technique (wash with water bubbles) was developed at the University of Idaho which is reported as the most economical way of raw-biodiesel washing. In the method, air is gently bubbled through the biodiesel water mixture (1:3 volume ratio) using an aquarium pump. Wash water is gravity separated and the process is repeated three times. Washed biodiesel is dried and tested before apply in diesel engines. Properties of biodiesel made from neem oil at DCPE is given in Table 4. Figure 15 shows biodiesel samples prepared at DCPE from different oil precursors.

Table 4 Properties of Neem methyl esters (neem biodiesel)

Property	Standard Value ASTM D-6751	Raw Oil	Biodiesel
FFA %	<0.8	31.59	0.2
Density g/cm ³	0.88-0.94	0.93	0.906
Moisture Wt%	<0.05	0.08	0.03
Viscosity At 40°C	1.9-6	66.2	5.82
Cal. Value MJ/L	33-40	35.4	33.5
Flash Point °C	130	*N/M	132

*N/M—Not Measured



Figure 15 Biodiesel samples prepared at DCPE (from left to right: jatropha, castor, rubber, neem, domba and coconut)

7. Engine Tests

Although, there is a difference in calorific value between diesel (mineral) and biodiesel, tests conducted with coconut oil biodiesel (B100) at DME, showed only an insignificant reduction in the break specific fuel consumption (see Figure 16). Results indicated that the said offset would also be disappeared when the load increases beyond 2.5 kW.

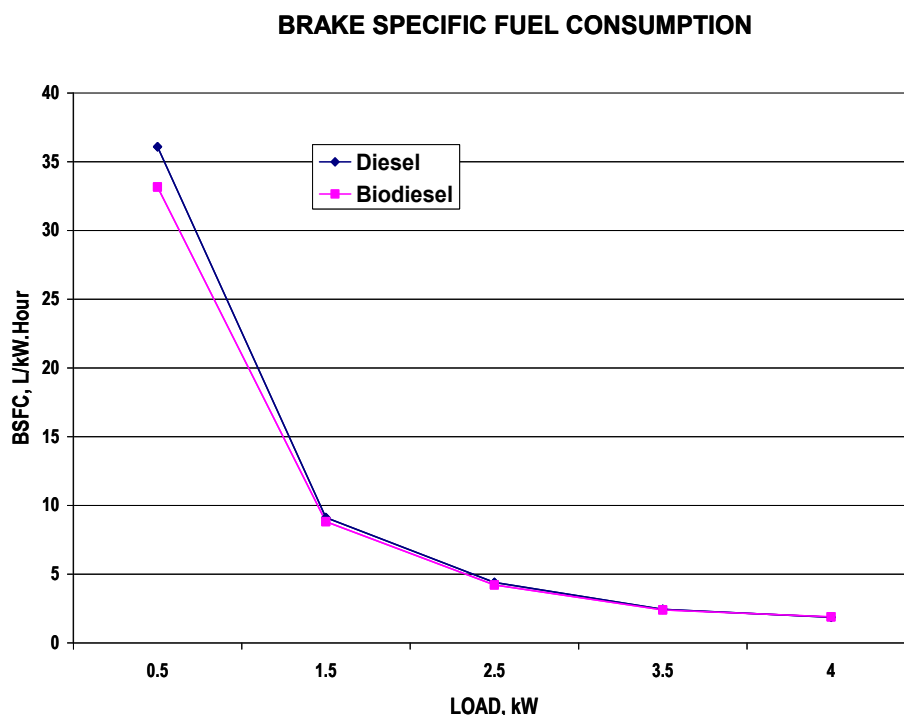


Figure 16 Comparison of engine performance between diesel and coconut oil based B100

8. Conclusions

This report describes seed oil extraction and processing into biodiesel; a fuel that can replace the crude oil based diesel for existing internal combustion engines. Vegetable oils and animal fat is used as the precursor for the process.

Oil extraction from seeds involves several pre-treatment steps; decortication, hulling and drying. Oil extraction by chemical methods is very efficient but expensive for small to medium scale operations. Mechanical oil expelling by hydraulic or continuous screw pressing is widely used in developing countries due to low capital investment and less complicity in operation. The extracted oil is vulnerable to degradation if foreign material is present. Therefore, the oil needs to process further by filtration and drying with an agent like sodium sulphate.

The oil or fat converted into biodiesel using an appropriate method upon the quality of the oil. One-step straight forward method is adopted with oil having low FFA (<2%). Most commonly used method for high FFA oils (>2%) is known as 2-step method. The reaction converts triglycerides in the oil into respective monoester which has physical and combustion properties similar to diesel fuel. Transesterification also yields glycerine; a valuable by-product in a crude form.

Refined biodiesel should confirm the quality specified by an international standard such as ASTM-D6751 or EN14214. Such biodiesel can be blended up to 20% with crude based diesel and use in existing engines with out any modification. This will not void the engine guarantee according to most engine manufacturers.

In a project aimed at erecting a community based biodiesel processing facility, preliminary studies on extraction and processing of five different locally available oils were studied at NERDC and DCPE laboratories. Engine tests with two of the biodiesel varieties (neem and coconut based) were also performed.

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9.0 Appendix A—Biodiesel Quality Standards

-	Europe	Austria	Czech Republic	France	Germany	Italy	Sweden	USA
Standard / Specification	EN 14214	ON C1191	CSN 65 6507	Journal Official	DIN V 51606	UNI 10635	SS 155436	ASTM D-6751
Date as on	2003	July 1997	Sep 1998	Sep 1997	Sep 1997	April 1997	Nov 1996	Jan 2002
Application*	FAME	FAME	RME	VOME	FAME	VOME	VOME	FAMAE
Density, 15°C g/cm	0.86-0.90	0.85- .89	0.87-0.89	0.87- .90	0.875- 0.90	0.86-.90	0.87- .90	-
Viscosity, 40°C mm ² /s	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	1.9-6.0
Distillation 95% °C.				<360		<360		90% @ 360° C
Flashpoint °C	>120	>100	>110	>100	>110	>100	>100	>130 (150 av.)
cold filter plugging point, °C	*country specific	0/-15	-5	-	0/-10/-20	-	-5	-
Pour point °C, <-15	-	-	-	<-10	-	<0/		
Sulfur, % mass	<10 mg/kg	<0.02	<0.02	-	<0.01	<0.01	<0.001	<0.05
CCR 100%, mass	-	<0.05	<0.05	-	<0.05	-	-	-
10% dist. Resid % mass.	<0.3	-	-	<0.3	-	<0.5	-	-
Sulfated ash% mass	<0.02	<0.02	<0.02	-	<0.03	-	-	<0.02
(Oxid) Ash % mass	-	-	-	-	-	<0.01	<0.01	-
Water mg/kg	<500	-	<500	<200	<300	<700	<300	<0.05% vol. (water & sediment)
Total contam. mg/kg	<24	-	<24	-	<20	-	<20	-
Cu-Corros. 3h/50°C	1	-	1	-	1	-	-	<No.3
Oxidation stability hrs; 110°C	6 hours min	-	-	-	-	-	-	-
Cetane No.	>51	>49	>48	>49	>49	-	>48	>47
Neutral. No. (Acid value) mgKOH/g	<0.5	<0.8	<0.5	<0.5	<0.5	<0.5	<0.6	<0.8
Methanol % mass	<0.20	<0.20	-	<0.1	<0.3	<0.2	<0.2	-
Ester content % mass	>96.5	-	-	>96.5	-	>98	>98	-
Monoglyceride % mass.	<0.8	-	-	<0.8	<0.8	<0.8	<0.8	-
Diglyceride % mass	<0.2	-	-	<0.2	<0.4	<0.2	<0.1	-
Triglyceride % mass	<0.2	-	-	<0.2	<0.4	<0.1	<0.1	-
Free glycerol % mass	<0.02	<0.02	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02
Total glycerol % mass	<0.25	<0.24	<0.24	<0.25	<0.25	-	-	<0.24
Iodine No.	<120	<120	-	<115	<115	-	<125	-
Linolenic acid ME % mass	<12	-	-	-	-	-	-	-
C18:3 and high. un-sat.acids								
% mass	-	<15	-	-	-	-	-	-
C(x:4) & greater unsaturated esters % mass	<1	-	-	-	-	-	-	-
Phosphor mg/kg	<10	<20	<20	<10	<10	<10	<10	<0.001% mass
Ramsbottom carbon residue, % mass	-	-	-	-	-	-	-	0.10
Carbon residue	-	-	-	-	-	-	-	<0.050% by mass
Gp I metals (Na,K) mg/kg	<5	-	-	-	-	-	-	-
Gp II metals (Ca,Mg) mg/kg	<5	-	-	-	-	-	-	-
Alkalinity mg/kg	-	-	<10	<5	<5	-	<10	-

11. Discussion

Mr. B Gunaratne

The calculation on Biodiesel production, it was mentioned the cost of required methanol for 1 litre of Biodiesel as LKR. 100. The requirement of Methanol is 200 ml per 1 litre of Biodiesel. Majority of the Methanol can be recovered after processing Biodiesel. So when we go for commercial production, we have to think about Methanol recovery. At the time, the cost of Methanol is much lesser in the market if we purchase in bulk.

Dr. C S Kalpage

That is when you go for the 1 step method. When the oil quality is good, you need only 200 ml of Methanol to produce 1 litres of Biodiesel. When you go for the 2 step method, which is used when the oil quality is not that good, then you need about 450 ml of Methanol. The calculations I have given are based on the laboratory experiments carried out and therefore, at commercial scale would be unrealistic. Methanol was purchased at LKR 200 / litre and the excess Methanol was used to make the reaction to move forward. We can recover majority of them, but at a cost.

Mr. M U Ranasinghe

The methods used in the USA for which you gave the cost data may be something different. We have to do the calculations for the methods we use. I was you had used a tractor to remove the kernel and you have to use diesel to run the tractor. You have used water to wash Biodiesel and to remove water, you may have to put more energy than what you gain. There are low cost methods used in countries like Malaysia and other countries. Why can't we directly do what they are doing at the moment?

Dr. C S Kalpage

I tell again that the figures given by me are based on experiments at laboratory and published literature. At the moment, this is not sustainable. With the help of the government, if we continue, one day there will be a break-even point and after that we would gain. But, if we don't start right now, then, it will be too late and we may have to import Biodiesel from other neighbouring countries. The 3 methods I discussed about were found from the published literature and therefore, they are published methods. Countries like Malaysia may have their own indigenous methods. For commercial interests or otherwise, such methods are not revealed. We have to R & D and reduce our costs.

.Dr. Muhammed Pervaz

You have given an idea about the cycle of Biodiesel. In South Asia, diesel or any other hydrocarbon fuel is a source of revenues to the governments. They are taxed, in a way; these are indirect ways of taxing. There can be subsidies given for kerosene or diesel in some cases. In addition to this cost, we have oil marketing companies' margins, oil transportation costs etc. When we are considering Biodiesel, these will be added factors.

Prof. S A Kulasooriya

Cost of material for the production of 1 litres of Biodiesel was presented. But along the process, there are by-products which can bring in some revenue. They must be considered in the costs and deduct those, the revenues from the sale of Glycerine and residue cake for fertilizer. Any manufacturing company would get income from selling the by-products. So you have to see the overall picture of commercial venture as different from what is shown, which is only the cost of material

Dr. C S Kalpage

Glycerine is sold at 4.25 per litre, which is an advantage of the process where you can get an income from selling by-products

Unidentified voice

In your experiments, you have used NaOH. Have you used KOH instead of NaOH?

Dr. C S Kalpage

I have not used KOH, but the University of Ruhuna has. I think NaOH is used by most Biodiesel manufacturers. A Free Fatty Acid molecule will attach with a Na or a K and make soap. If we can separate the soap, we can sell them and get an income. Price of K based soap is higher than the price of Na based soap.

Mr. S H Malik

Adding to the cost factor, in any commercial venture would not only be the material cost, but also personnel, administration and cost of financing. These can be very significant

Mr. P R Devkota

I wonder how Biodiesel can compete with petrodiesel, is it economically justifiable or not?

Dr. C S Kalpage

We got to start with the government's help with incentives. During the first oil crisis of 1970s, Brazil started their Bioethanol programme with the government's help and succeeded for a certain period. Then in 1980s and 1990s, they failed, but

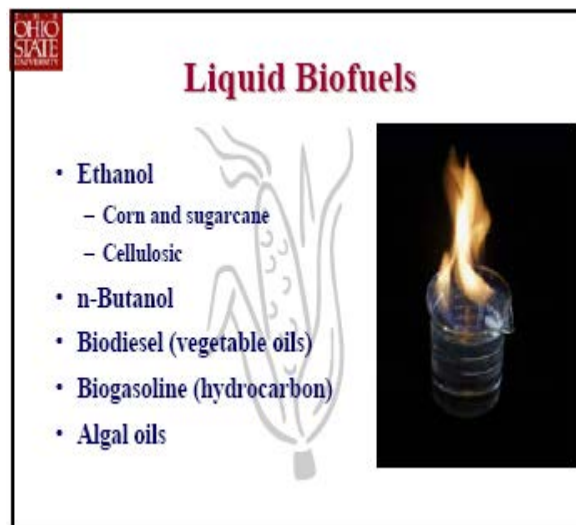
now they have developed their technologies and competing with fossil fuel. Their cost of Bioethanol is less than the cost of petrol. Now the Brazilians buy flexi fuel vehicles and they can use either Bioethanol or petrol. I heard most of them use Bioethanol. One day there will be a time where Biodiesel has a place in the world

Future of Biofuel Technologies

Prof. Shang- Tian Yang, Ph.D
The Ohio State University, Columbus, Ohio 43210 USA

Abstract

This presentation will report recent progresses in metabolic and process engineering for economical production of biofuels from renewable biomass. Efficient microbial conversion of sugars and lignocellulosic biomass to fuels and chemicals is the core operation in biorefinery. The product yield depends on metabolic efficiency in cells as well as process conditions. Metabolic engineering is a powerful tool that can be used to improve fuel production in fermentation. One classical example is to clone heterologous genes into yeast to endow yeast the ability to ferment pentose sugars (mainly xylose) to ethanol. However, pre-treatment of biomass to break down the recalcitrant structure of the lignocellulosic feedstock in order to expose cellulosic fibres for enzymatic saccharification also produces organic inhibitors that have severe inhibiting effects on ethanol fermentation. We have developed several novel processes for production of biobutanol as a better biofuel than ethanol. Butanol is an important industrial solvent and potentially a better fuel than ethanol. Because of the high toxicity of butanol, its production via conventional ABE fermentation is limited. However, *Clostridium acetobutylicum* cells immobilized in a fibrous bed bioreactor (FBB) can be adapted to tolerate higher butanol concentrations. The FBB is an effective reactor device that can not only maintain high cell densities but also help cells to be more tolerant to solvent toxicity thus yields a higher product concentration. Using novel two-step processes can increase butanol yield by 50% to 100%. The advantage of using butyrate as a cosubstrate to sugar for biobutanol production will be discussed. A hybrid process consisting of butyric acid fermentation and catalytic hydrogenation of butyric acid to butanol has a potential to reduce biobutanol cost to a competitive level with bio-ethanol. The future for cellulosic ethanol and butanol is bright as they are expected to replace at least 30% to 40% of liquid fuels or gasoline by 2030 when the technique for cellulose hydrolysis is mature and low-cost energy crops become largely available.





Liquid Biofuels

Properties of some biofuels and gasoline and diesel

Name	Energy Content		Water solubility	Vapor pressure (mmHg)	Octane rating	Flash Point (°C)
	(KJ/g)	(MJ/L)				
Ethanol	23.4-26.8	18.4-21.2	100%	46 (20°C)	116	14
Butanol	36	29.2	8%	4.8 (20°C)	87	35
Gasoline	48	32-34.8	nil	-	87-93	<-40
Diesel	48.1	40.3	nil	0.35 (20°C)	N/A	>62
Biodiesel	37.8	33.3-35.7	nil	-	N/A	>130



Bioethanol

- Commercialized; can be blended with existing fuels; is viable for crop-based, but not for cellulosic ethanol, which doesn't compete with food crops
- Has lower energy content; cannot be distributed through existing infrastructure
- Major players: many, including ADM, Cargill, Adventine Renewable Energy, New Energy Corp, VeraSun Energy, MGP Ingredients, Abengoa Bioenergy, Iogen (Canada),



Biobutanol

- Has higher energy density than ethanol - closer to that of current gasoline; Lower vapor pressure - can be added to existing gasoline, fewer VOCs released to atmosphere; Can be used within existing pipeline infrastructure; Less susceptible to moisture
- Toxicity is harmful to microbes; Lower yields with current technology; Difficult and more expensive to produce by fermentation
- Majority is being researched on a lab/bench scale; Commercialization expected in next 2-5 years for the chemical market, longer time frame for biofuel market
- Major players: BP-DuPont, Shell, Chevron, Green Biologics (UK), Gevo, Tetra Vitae, Butalco, Metabolic Explorer, ButylFuel, Cobalt, EnerGenetics, IE Group, Integrated Genomics, Cathay Biotech (China), China New Energy (China), RITE (Japan)



Biodiesel

- High energy content, but use is limited due to engine knocking, fouling and other problems
- Produced mainly from vegetable (soybeans) and restaurant waste oils; relatively expensive
- Potentially can be produced from oil crops (rape seed, jatropha, etc.) and non-crop plants (palm oil, etc.);
- Major players: many, including ADM, Cargill, Virent Energy Systems,



BioGasoline (hydrocarbon)

- Can be tuned as gasoline; insoluble in water; easy to separate from fermentation broth
- Productivity and yield are low - less than 1 g/L
- Early stage research and development in engineering microbes to produce fatty acids and esters as biofuels; Lab/bench scale; not ready for commercial production yet
- Virent Energy is developing a catalytic conversion process to convert sugars directly to various hydrocarbons; the process is energy intensive and yields are low; high separation cost for fractionation of mixed products
- Major players: Virent Energy, LS9, Amyris, Codexis, BGT



Algal oils

- Using microalgae to produce oils that can be converted to biodiesel
- Use CO₂ and light as carbon and energy sources for growing algae, which can produce up to 50%-75% of oils in the cell biomass dry weight
- Difficult to scale up the light-dependent cultivation process; slow cell growth; low cell density (<1 g/L) and low oil concentration - high production cost
- Not ready for commercial application - need major technology breakthroughs
- Major players: Sapphire Energy and many other new start-ups



Liquid Biofuels

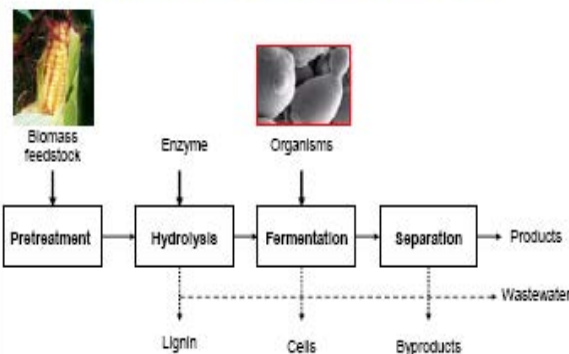
Energy content, price and market size for various biofuels

Name	Energy Content (KJ/g)	Energy Content (MJ/L)	Price (US \$/gal)	US Market - 2007 (billion gal)
Ethanol	23.4-26.8	18.4-21.2	2.4	7.0
Butanol	36	29.2	6.5	1.45*
Gasoline	48	32-34.8	3.6	150
Diesel	48.1	40.3	4.2	65
Biodiesel	37.8	33.3-35.7	5.3	0.4

*Worldwide market mainly for chemical or solvent use



General bioprocess flowsheet

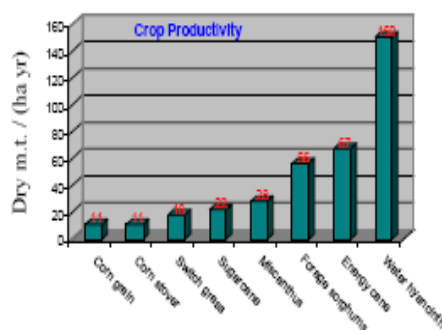


Economic Production of Biofuels

- Low-cost feedstock
- Efficient fermentation process
 - Productivity
 - Final product concentration and purity
 - Product yield
 - Process stability and scalability
- ❖ Microbial cell factory
- ❖ Bioreactor
- ❖ Product recovery and purification



Biomass Feedstock



Lignocellulosic crops have much higher productivities than corn and sugarcane.



Biomass Feedstock

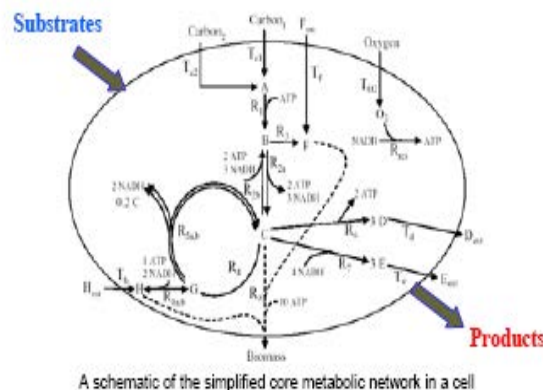
Production of ethanol from various feedstock

Feedstock	Sugar (wt%)	Gal/ton	Gal/acre/year
Corn	70% starch	105-120	640
Sugar cane	55% sucrose	19	548-970
Sugar beet	68% sucrose	24	680
Cassava	20% starch (wet basis)	46	360
Cane bagasse	40% cellulose, 24% hemicellulose	35	-
Wheat straw	38% cellulose, 21% hemicellulose	67	-
Switch grass	45% cellulose, 31% hemicellulose	95	1150
Wood chip	44% cellulose, 20% hemicellulose	80-90	-

1. Sanchez O, Cardona C. Trends in biotechnological production of fuel ethanol from different feedstocks, *Bioresour Technol*, 99(13): 5270-5295, 2008.
2. Hattenhaus J. Achieving sustainable production of agricultural biomass for bioenergy feedstock, *Industrial Biotechnology*, 2: 217-275, 2006.



Metabolic Engineering





Ethanol fermentation

- Yeast: use glucose with high ethanol yield and titer; but cannot use xylose
- Bacteria and filamentous fungi: utilize both xylose and glucose, but low ethanol yield and titer
- **Challenge 1:** Engineering yeast strains to utilize both xylose and glucose with high ethanol yield and titer
- Cellulase producing bacterial strains: no/low ethanol production
- **Challenge 2:** Engineering bacterial strains to produce both cellulase and ethanol

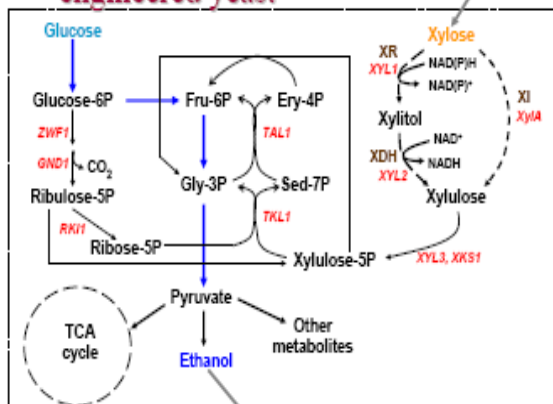


ME for ethanol production

- Metabolic engineering of *S. cerevisiae*, *Z. mobilis*, and *E. coli* for improved ethanol fermentation has been extensively studied.
- Most efforts have been focused on the creation of efficient xylose-fermenting mutant strains.
- Metabolically engineered *S. cerevisiae* and *Z. mobilis* strains can ferment both xylose and glucose, but produce ethanol only at a lower concentration level and is sensitive to inhibitors present in hemicellulose hydrolysates.
- Metabolically engineered *E. coli* with *pdh* and *adhB* genes can produce ~40 g/L ethanol in 48 hours from hemicellulose hydrolysate supplemented with corn steep liquor, but is limited by the neutral pH required for bacterial fermentation, its lower ethanol tolerance, and issues related to the disposal of spent media.
- Engineered *Klebsiella oxytoca* mutant can ferment cellobiose and cellotriose, and can be used to produce ethanol from cellulose, but ethanol titer is low.



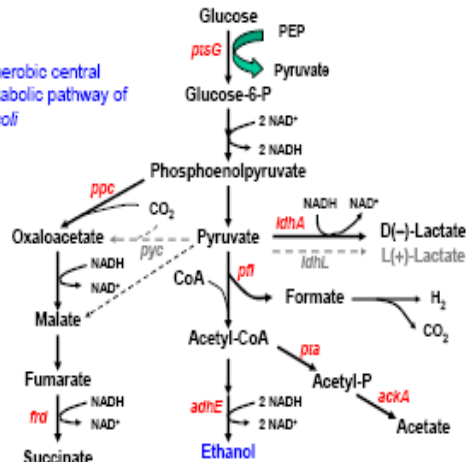
Ethanol production from xylose by engineered yeast



Metabolic pathways in *S. cerevisiae* engineered for xylose fermentation



Anaerobic central metabolic pathway of *E. coli*



BIOFUELS



	Energy Content (Btu's per Gallon)	Motor Octane Number	Vapor Pressure (psi@100F)
Methanol CH ₃ OH	83K	91	4.6
Ethanol C ₂ H ₅ OH	84K	89 - 103	2
Butanol C ₄ H ₉ OH	110K	80 - 81	0.33
Gasoline	115K	85	4.5

- Butanol is a better biofuel candidate with higher energy content, less evaporative and more environmentally friendly.

Biobutanol

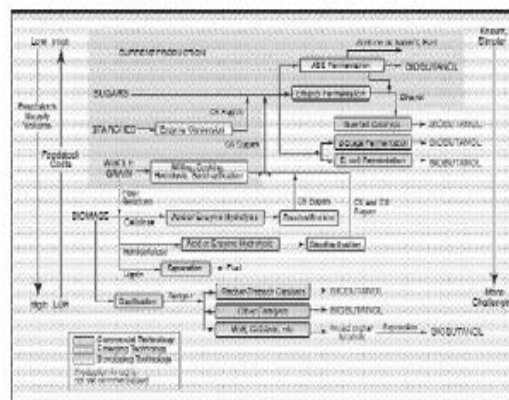


Figure 1. Biobutanol can be made by a variety of fermentation and biochemical processes.

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ME for Biofuels

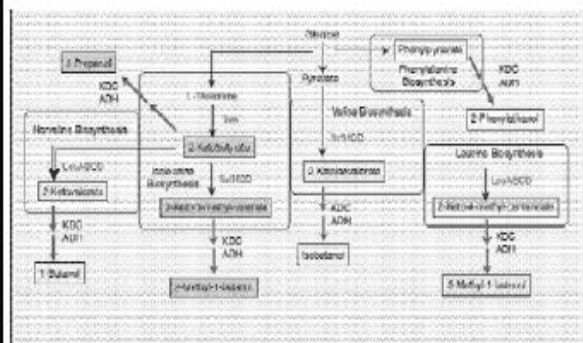
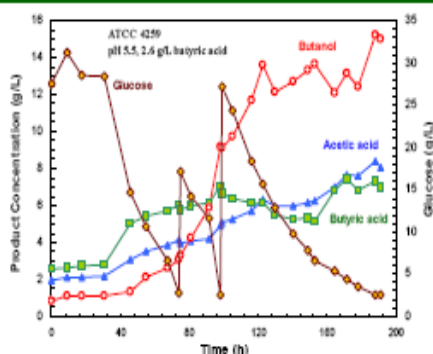


Figure 1. Various 2-keto acid precursors lead to corresponding alcohols through 2-ketoacid decarboxylase and alcohol dehydrogenase. The bolded portion of the diagram depicts the synthetic pathways for the non-driven before alcohol production is engineered. *E. coli* that carries out the 2-keto acid decarboxylation and reduction pathway. Blue enzyme names represent amino acid biosynthesis pathways. The double lines represent a side pathway leading to pyruvate and 1,4-bisphosphoglycerate. Source: [7].

Butanol $CH_3-CH_2-CH_2-CH_2OH$

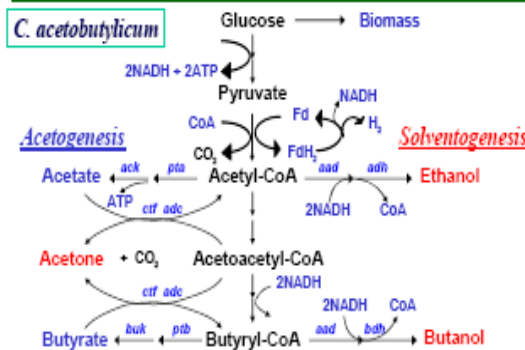
- Important industrial solvent and potentially better fuel extender than ethanol
- Can be used as a transportation fuel without any modification of existing pipelines and car engines
- Currently produced from petroleum-based feedstock
- Conventional acetone-butanol-ethanol (ABE) fermentation is limited by product inhibition (butanol yield < 20%, concentration < 15 g/L, productivity < 0.5 g/L/h)
- CBE bioreactor (U.S. Patent 5,563,069) and related bioprocessing technologies can produce butanol from corn and other biomass with 25% more energy per bushel of corn

ABE Fermentation



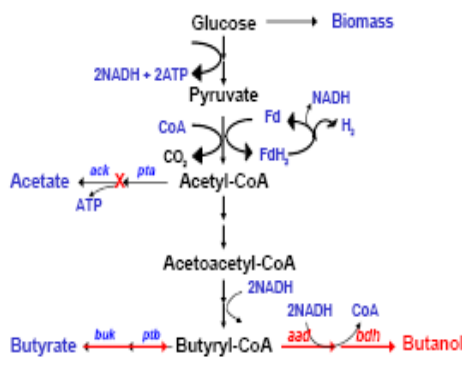
Low productivity; Low yields; Low final product concentrations
Need to improve the fermentation in order to be economical

ABE Fermentation Pathway



aad: alcohol/aldehyde dehydrogenase; ack: acetate kinase; aad: acetoacetate decarboxylase; adh: alcohol dehydrogenase; buk: butanol dehydrogenase; buk: butyrate kinase; crt: CoA transferase; pta: phosphotransacetylase; pta: phosphotransbutyrylase

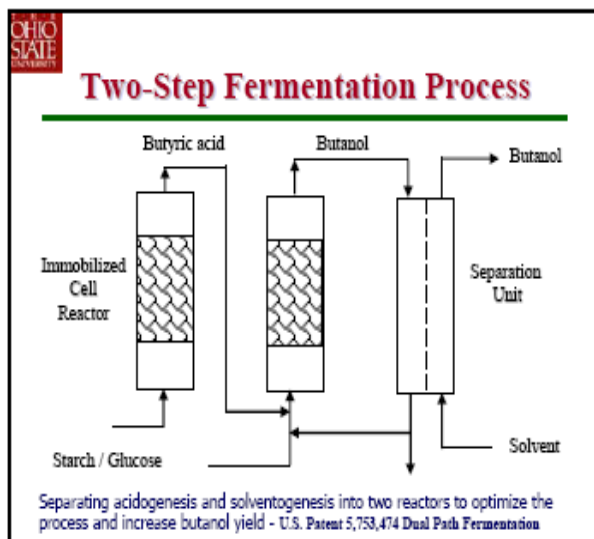
Novel Butanol Fermentation Pathway



ack: acetate kinase; pta: phosphotransacetylase;
aad: alcohol/aldehyde dehydrogenase; adh: butanol dehydrogenase;
buk: butyrate kinase; pta: phosphotransbutyrylase

Objectives / Approaches

- Develop an economical butanol production process by separating acidogenesis and solventogenesis into two fermentation steps:
 $glucose/xylose \rightarrow butyric\ acid \rightarrow butanol$
- Expectations: overall butanol yield ~ 40% (w/w)
- productivity ~ 5 g/L/h or higher
- Increase final product concentration: >20 g/L
- Stable continuous operation: at least one month or longer



Butanol Production from Biomass

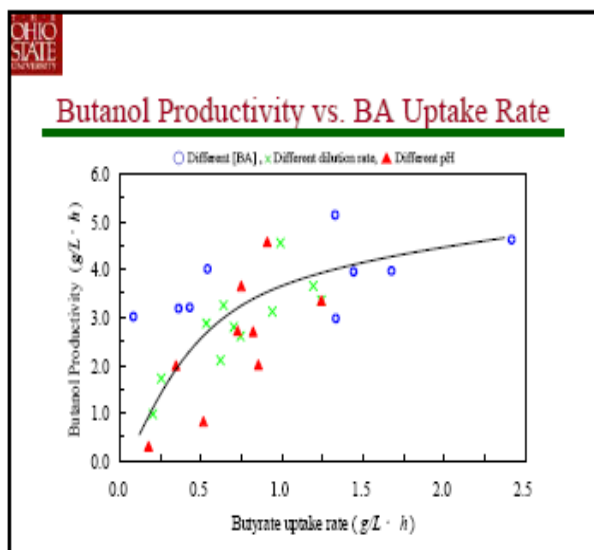
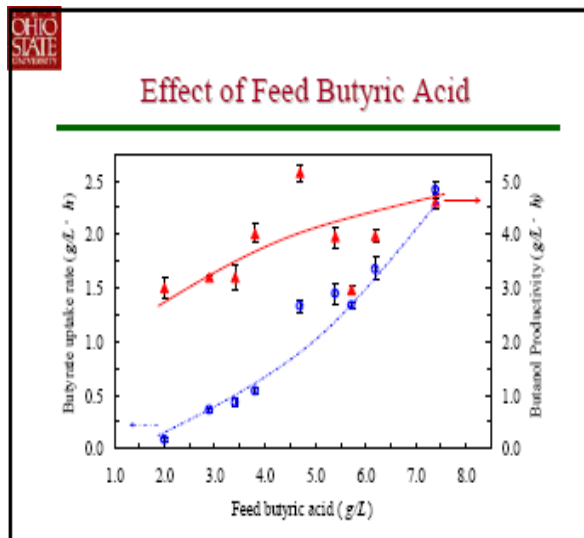
- Acid / enzymatic hydrolysis to glucose and xylose
- Butyric acid production from glucose and xylose using anaerobic fermentation (*Clostridium tyrobutyricum*)
- Butanol production from butyrate in ABE fermentation (*Clostridium acetobutylicum*)
- Separation of butanol from fermentation broth by extraction or adsorption

Immobilized Cell Fermentation Fibrous-Bed Bioreactor

(U.S. Patent 5,563,069)

C. acetobutylicum *C. tyrobutyricum*

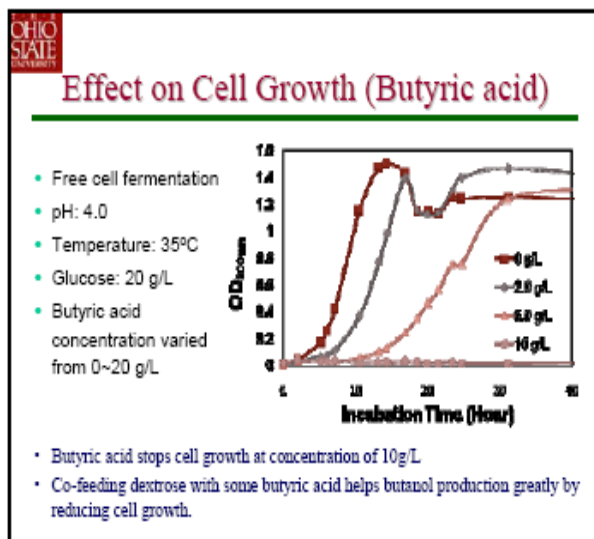
High cell density: 35 - 100 g/L





Summary of All Fermentation Conditions

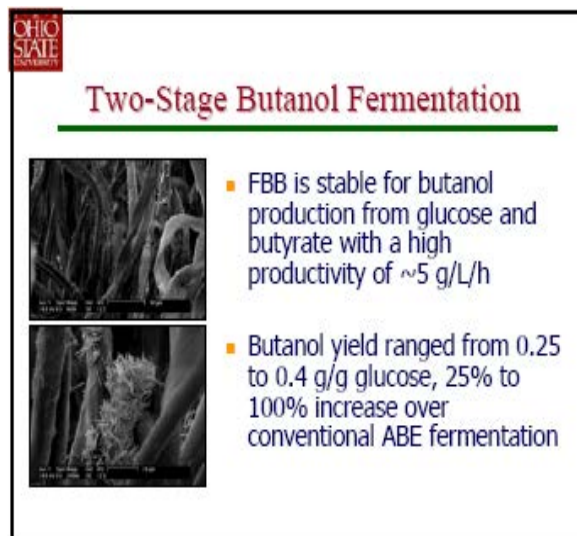
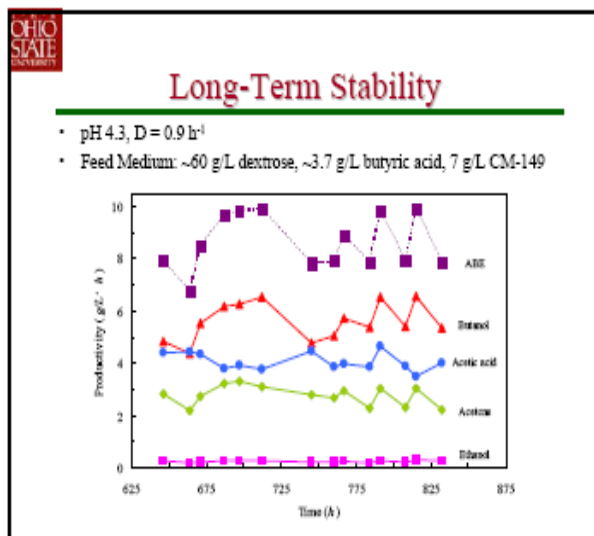
pH	D (h^{-1})	Feed (g/L)		Y (g/g)	P (g/L · h)	Uptake (g/L · h)	
		Dextrose	BA			Dextrose	BA
4.3	0.9	34	3.6	0.42	4.6	9.1	0.99
	0.8	30	2.4	0.37	2.9	6.4	0.53
	0.6	34	3.9	0.29	3.3	9.7	1.2
4.5	0.6	65	3.9	0.31	3.7	10	0.75
5.1		67		0.26	4.6	16	0.91
4.3	0.6	61	3.8	0.34	4	11	0.54
		39	4.7	0.28	5.1	16	1.3
		57	7.4	0.27	4.6	12	2.4
4.3	0.9	61	3.6	0.28	5.6	18	1.1



Comparison of ABE Fermentation Studies

Reactor type	Feed [BA] (g/L)	BA uptake rate (g/L·h)	Butanol productivity (g/L·h)	Reference
Batch	4.9	0.20*	0.38	Datta and Zeikus, 1985
Continuous	0.2	0.10	0.33	Afschar et al., 1986
Continuous	3.5	0.27	0.20	Rao and Murtharasan, 1988
Batch	9.5	0.33	0.53	Soni and Jain, 1997a
Continuous	7.4	2.4	4.6	This study

* Numbers are estimated from figures or tables if not reported in the literature.



Comparison of ABE Fermentation Studies

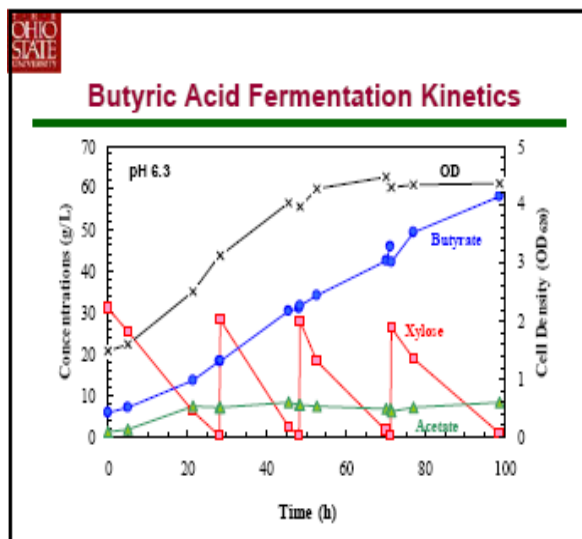
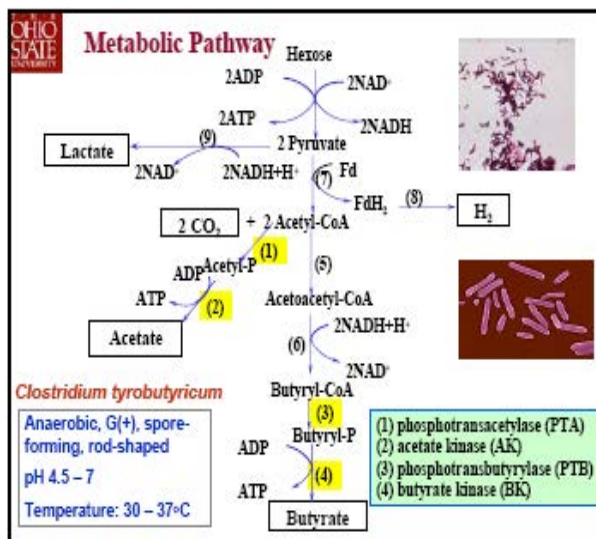
Fermentation system	Yield (g/g)	Productivity (g/L·h)	Total solvents (g/L)	Dilution rate (h ⁻¹)	Reference
Conventional system	0.28-0.33 (= 0.25)*	< 0.3	< 20 (= 13)	0.1-0.6	Qureshi and Blaschek, 2001
Immobilized-cell system					
Trickle bed (sponge)	0.34 (0.19)	4.2 (2.4)	16 (8.8)	0.27	Parik et al., 1989
Brick	0.38	16	7.9	2.0	Qureshi et al., 2000
FBB	0.43 (0.28)	8.6 (5.6)	10 (6.5)	0.9	This work

* Numbers shown in parentheses are for butanol only.

Butyric Acid Fermentation

Approaches:

- Use low-cost agricultural residues as feedstock
- Metabolic engineering to change the fermentation pathway to improve butyric acid production and yield
- Cell immobilization in a fibrous-bed bioreactor (FBB) to increase cell density, tolerance to product inhibition, and reactor productivity



Comparison between free-cell and immobilized-cell (FBB) fermentations

Substrate	Free-cell fermentation		Immobilized-cell fermentation	
	Glucose	Xylose	Glucose	Xylose
Specific growth rate (h ⁻¹)	0.063 ± 0.004	0.055 ± 0.004	0.094 ± 0.008	0.057 ± 0.002
Butyric acid				
Final concentration (g/L)	16.3	19.2	43.4	37.3
Yield (g/g)	0.34 ± 0.01	0.17 ± 0.47	0.42 ± 0.02	0.28 ± 0.54
Productivity (g/L.h)	0.19 ± 0.08	0.14 ± 0.27	6.77 ± 0.23	1.45 ± 3.3
Acetic acid				
Final concentration (g/L)	3.6	0.7	8.4	4.9
Yield (g/g)	~0.06	~0.02	~0.095	0.06 ± 0.11

*Productivity for Immobilized-cell fermentation was based on the fibrous bed bioreactor volume of 400 mL, instead of the total liquid medium volume of 2 L in the reactor system.

Metabolic Engineering

Objective:

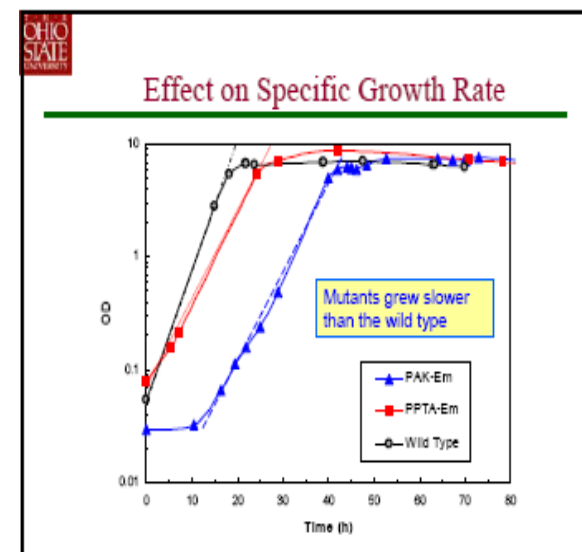
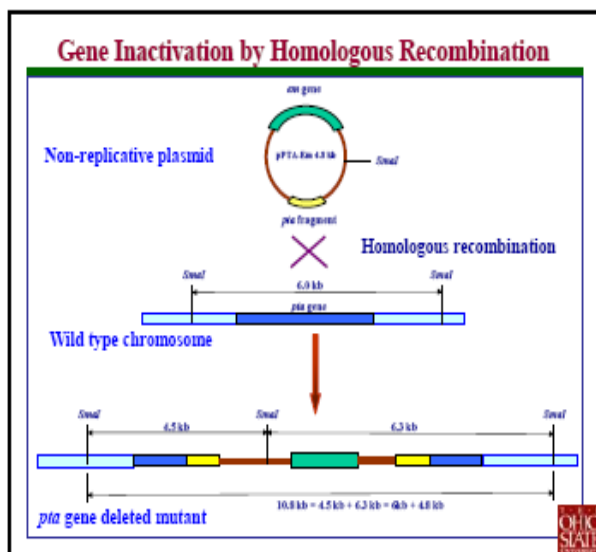
- To develop mutants of *Clostridium tyrobutyricum* with knocked-out acetate formation pathway

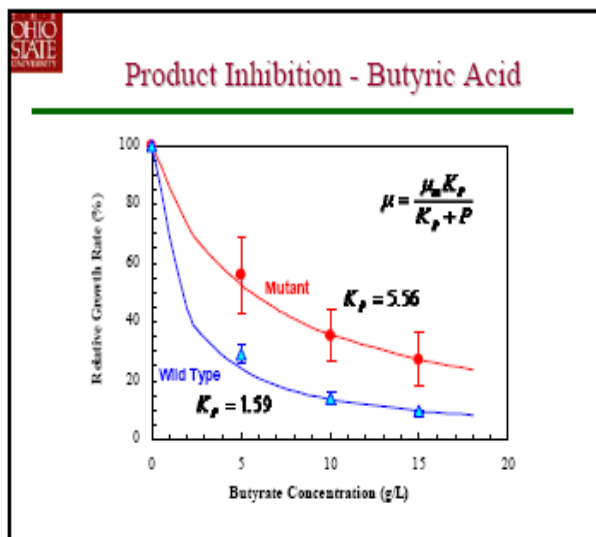
Method:

- Homologous recombination with a non-replicative integrational plasmid containing partial DNA sequence of phosphotransacetylase (*pta*) or acetate kinase (*ack*) gene

Expected Results:

- Knocking out AK or PTA enzyme expression should eliminate or greatly reduce acetate formation and increase butyrate production in the fermentation

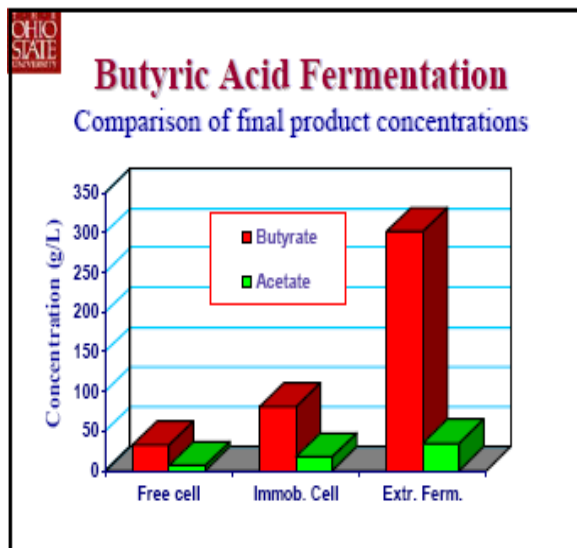
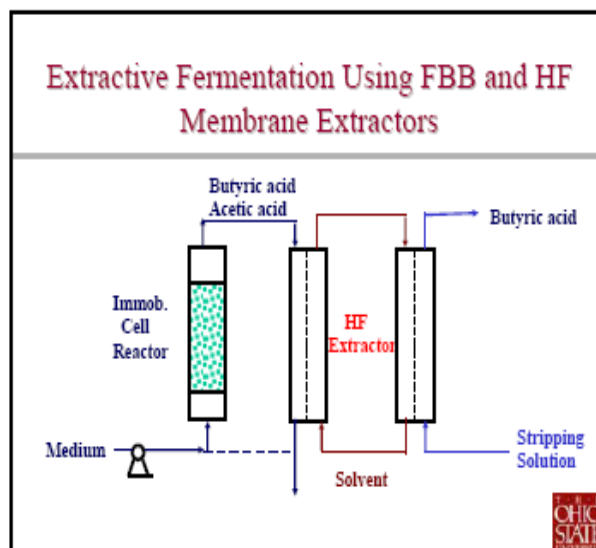
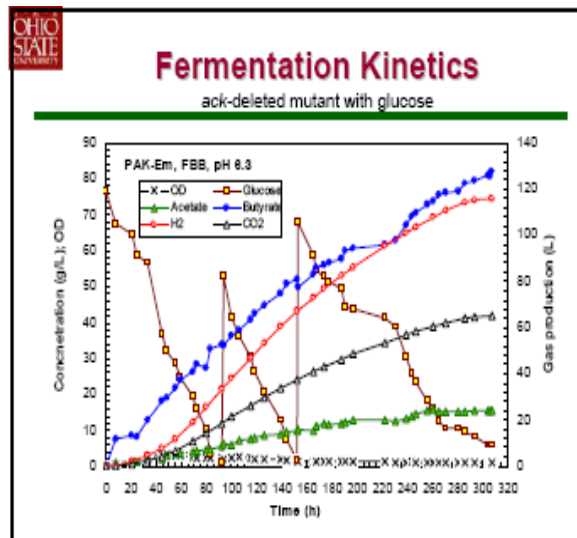




Comparison between wild-type and mutants PPTA-Em and PAK-Em

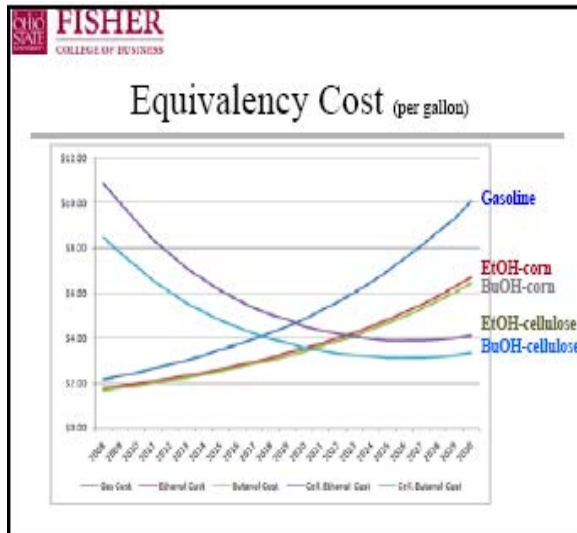
	Wild Type	PPTA-Em	PAK-Em
Cell Growth			
Specific growth rate, μ (h^{-1})	0.28 ± 0.03	0.19 ± 0.02	0.19 ± 0.02
Cell biomass yield (g/g)	0.13	0.15	0.11
Acid Production			
Final butyric acid conc. (g/L)	28.6	42.1	43.0
Butyric acid yield (g/g)	0.34 ± 0.01	0.40 ± 0.02	0.47 ± 0.03
Final Acetic acid conc. (g/L)	9.7	12.2	11.9
Acetic acid yield (g/g)	0.12 ± 0.01	0.13 ± 0.01	0.12 ± 0.01
Butyrate/Acetate ratio (g/g)	2.96	3.19	3.74
Gas Production			
H_2 yield (g/g)	0.013	0.012	0.029
CO_2 yield (g/g)	0.305	0.251	0.446
H_2/CO_2 ratio (mol/mol)	1.06	1.06	1.43

- ### Metabolic Engineering (Summary):
- Ack* and *pta* were partially inactivated in the mutants; AK and PTA were not completely knocked out.
 - Butyrate yield increased by 38%, and final butyrate concentration increased by 50%
 - Cell growth rate reduced by 32%, but cell became less sensitive to butyric acid inhibition
 - Hydrogen production increased by 94% in PAK-Em mutant



Summary

- Butyric acid yields increased when cell growth was reduced due to partial knock-out of *ack* or *pta* gene, and when cells were immobilized in the FBB
- The mutants with partial *ack* knock-out gave the highest butyrate production of >80 g/L.
- After adaptation of the *ack*(-) mutants in FBB, the adapted mutants had both high growth rates and high acid product yields.
- Butyric acid can be used to enhance butanol production by *C. acetobutylicum*. The two-step fermentation process has a high butanol yield (0.3-0.4 g/g glucose) and productivity (5 g/L/h).



Discussion

Mr. Buddika Gunaratne

You said that there is a problem of replacing diesel by Biodiesel due to engine knocking and some other problems. I don't agree with it as Biodiesel is very easy to blend with diesel. It is very much easier than blending ethanol with gasoline. Experiments on Butanol also can be done in countries like ours at lower costs. We can't expect the high cost methodologies in doing experiments in our country. Is it suitable for countries like ours?

Prof. Shang Tian Yang

I agree that Biodiesel easily blends, depending on the level of technology. The vegetable oil and their composition can change from season to season and also depends on the chemical reaction, the process you used. Therefore, the quality of Biodiesel can vary a lot. So producer need to be very careful in making. If you can do away with these problems, Biodiesel has the advantage of high energy content for transportation. Depending on the feedstock and their evaluation, people have to work on their variation.

Mr. Buddika Gunaratne

When conducting experiments on Butanol, which seems to be the future of Biofuels, are the technologies expensive for us or can it be done?

Prof. Shang Tian Yang

In general, Biodiesel is more expensive than Butanol, because vegetable oil or other oils are generally more expensive. To give you some idea about the level of technical difficulties for difference between Ethanol and Butanol, everyone can

prove on your own basement or in your house by producing some Ethanol. But the technology of fermentation for Butanol has to be worked on strict anaerobic conditions. Bacteria in general grow lower than yeast. Sp technology level, especially in micro biology is needed and the required skill level is one level higher than in the yeast fermentation. Certainly it is not easy for a high school student to do the experiments on Butanol production compared to yeast fermentation. Skill level is different.

Dr. Muhammad Pervaz

What is the approximate cost of equipment for research? You said you started with US\$ 150,000. What kind of cooperation and guidelines you can provide to the research scientists and engineers of our region?

Prof. Shang Tian Yang

In terms of R & D efforts, there are several aspects people are working on and certainly people of the SAARC also can work on these which include isolation, adaptation & local microbe of high Butanol tolerant and high producing strength. At higher technical level, you can do the genetic engineering to change pathways either to incorporate different substrates, different genes to make them better producers. On the process aspects, this would include fermentation, conventional or otherwise, separation, extraction, absorption, gas stripping, distillation and membrane technology to improve the mass transfer to be economical and efficient.

Mr. Anwar Sadat

You mentioned about many Biomass feedstock that can be used for Butanol production. In our

country, water hyacinth is available. I would like to know the production of Butanol from various feedstocks. Can you discuss about the production rate from water hyacinth?

Prof. Shang Tian Yang

There is no work done with that, so people don't know it yet. But you can do some rough calculations based on the Carbon & Hydrogen content, roughly the conversion in the hydrolysis and fermentation. You can estimate how much Ethanol you can produce based on that particular type of Biomass.

Mr. N de S Cooke

In one of the slides you showed a person making a trip of 6,000 miles. How do we take the excess fuel that is required?

Prof. Shang Tian Yang

He had another pick up truck not shown in the picture, driving together with him carrying Butanol. It is because you cannot refuel Butanol on the way as it is not available. He had necessary logistics

Dr. Sanja Gunawardena

You showed the table comprising the Energy content, Octane value and vapour pressure of various alcohols. According to that vapour pressure of Butanol is 0.33. Isn't it a problem in starting the engines with a low vapour pressure?

Prof. Shang Tian Yang

In general it is not. The vapour pressure is lower only if you are in the cold regions. Below 0°C, even the gasoline engines sometimes are hard to start with the engine of old cars. Modern new cars with modern engines are always easy to start even at very cold temperatures. Something I did not tell about Butanol is that one of my colleagues uses Butanol with a slight modification. He adds a small canister of fuel to get initial ignition during the cold start. In general, it is not necessary especially in Sri Lanka or SAARC region as you have relatively a warm weather, and it is not a problem in general.

Technological Aspects of Bioethanol Production

*Prof. Ajith de Alwis
University of Moratuwa, Sri Lanka*

Abstract

Globally biofuels are gaining significant attention and bioethanol is one biofuel which has shown significant interest and volume growth. The paper presents the value chain of bioethanol production with emphasis on the technological aspects. All types of possible raw material options (edible, non-edible to cellulosic) are included which result in several technical pathways. The key process of realizing anhydrous alcohol is presented in some depth with techno economics. Newer and important developments taking place are also included such as the developments in second generation biofuels. Possible innovations in various technical steps and within industrial environments are also discussed.

Keywords: Bioethanol, Feedstock, Anhydrous alcohol, second generation biofuels, techno economics.

1. Introduction

Henry Ford designed a car that ran solely on Ethanol. Even his model T could run on either ethanol or Gasoline. This was in 1880's. Today with oil process showing dizzying trends of price fluctuations the interest on ethanol again has grown with global production dominated by two countries Brazil and USA. Both these countries had strong committed programs in coming up to this position. Many lessons could be learned from these two programs for developing economies and from Brazil in particular. US DOE's program – National Bioethanol Program - offer much more strategic guidance on developing a program. US DOE's program had the following elements:

- Developing new, more versatile, micro-organisms capable of squeezing more ethanol from biomass
- Gained a greater understanding of how the individual technology components work together in an integrated process
- Supporting the private sector's initiatives to commercialize bioethanol technology

The government's both in Brazil and USA supported quite strongly to develop the situation to its current position. President Bush signed the Energy Policy Act of 2005 into law is the most recent. The comprehensive energy legislation includes a nationwide Renewable Fuels Standard (RFS) that will double the use of ethanol and biodiesel by 2012. Under the Renewable Fuels Standard, a small percentage of US's fuel supply will be provided by renewable, domestic fuels includ-

ing ethanol and biodiesel, providing a positive roadmap for reduced consumer fuel prices, increased energy security, and growth in rural America. These are the basics that national policy planners should understand as technology and its development is strongly supported by policy.

2. Bioethanol Production and Feedstock

In 2006 Bioethanol production globally amounted to 12.1 billion gallons. Bioethanol currently accounts for more than 94% of global biofuel production, with the majority coming from sugar cane. The possible raw material base for ethanol production is quite wide ranging from sucrose-containing feedstock, starchy materials to ligno-cellulosic biomass. Anything that contains sugar, starch, or cellulose can be fermented and distilled into ethanol. It can be made from cassava, sweet sorghum, corn, potatoes, wood, waste papers, wheat, brewery waste, molasses and many other agricultural products and food wastes. Gasohol is E10, Now one has E85, E95, E93. Ethanol is often blended in gasoline as an oxygenate to meet clean fuel requirements a possible entry mechanism for ethanol in the conventional fuel market. Technology to produce ethanol is well established with only the second generation processes awaiting entry to the market place. Feedstock costs typically account for greater than one-third of the production costs, maximizing bioethanol yield is important. Table 1 provides a summary of some of the current data on production costs and bioethanol yields from different energy crops.

Table 1 Bioethanol yield and production cost

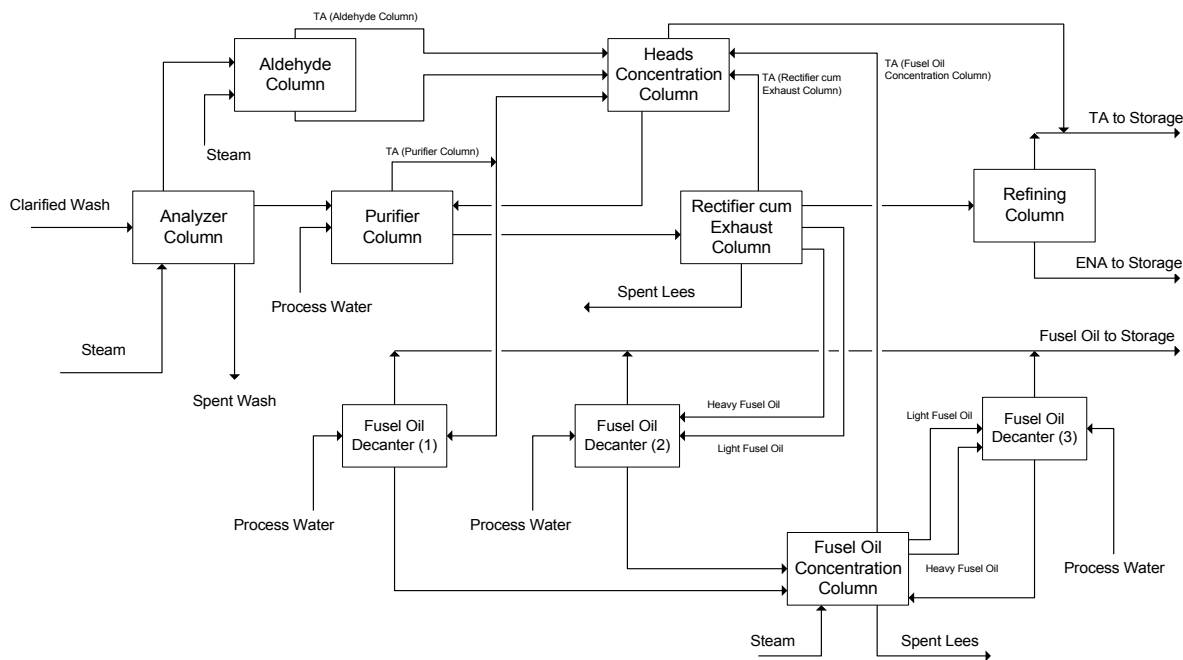
Type	Yield (t/ha/ year)	Conversion rate to sugar or starch	Conversion rate to bio- ethanol	Bioethanol yield (kg/ha/ year)	Cost (\$/m ³)
Sugarcane	70	12.5	70	4900	~ 160
Cassava	40	25	150	6000	700
Sweet sorghum	35	14	80	2800	200-300
Corn	5	69	410	2050	250-420
Wheat	4	66	390	1560	380-480

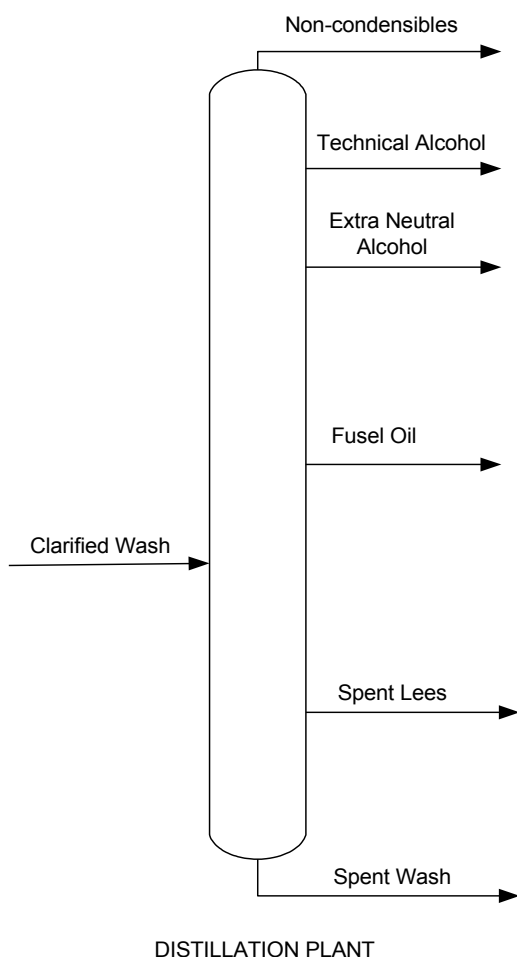
The transportation systems now do have built in flexibility to accommodate variations in fuel quality. Flex fuel vehicles (FFV's) can operate on any combination of EtOH and gasoline by automatically sensing the percentage of alcohol in the fuel tank adjusting the engine's parameters accordingly. In developing economies the wider age range of vehicle presence need to be factored into the planning process.

3. Ethanol Production

Ethanol production from sugars is quite well known with many practitioners of the art and science some quite legal and commercial and many with different backyard practices. Illicit alcohol production is a major industry and a source of livelihood

Figure 1 indicates the overall picture with the substrate and process options with biofuel production.

**Figure 1 Distillation Process at PSDL**



When raw materials such as corn are used a preliminary process step of hydrolysis is necessary. This is a chemical reaction to get the sugar released from the complex structure that is naturally present. The acid based hydrolysis has been now replaced with cellulose enzymatic process. There are still examples of concentrated acid and dilute acid processes in use (with sulphuric acid) and some even under development (Table 2). The enzymes are capable of targeting the relevant structures more effectively, leading to very high yields of fermentation sugars. The hydrolysis of starch by amylases which is the enzyme of choice, is known as liquefaction. The factors important in the process optimization are substrate type and composition, enzyme activity, operational conditions (T, pH and other process parameters). There had been significant improvements in the enzyme efficiencies over a period of 30 years during which this industry sector has grown. A higher process temperature is important (413-453K) in obtaining a higher yield and adds to the cost of operations.

Figure 2 Distillation Column

Table 2 Acid based hydrolysis methods

Hydrolysis Method	Advantages	Disadvantages
Concentrated-acid process	Operated at low temperature High sugar yield	High acid consumption Equipment corrosion High energy consumption for acid recovery Longer reaction time(e.g. 2-6hr)
Dilute-acid process	Low acid consumption Short residence time	Operated at high temperature Low sugar yield Equipment corrosion Formation of undesirable by-products

The common step after realising sugars is the fermentation process. This is achieved through the use of yeasts and bacteria. The process of culturing yeast under conditions to produce alcohol is called fermentation. Ethanol's toxicity to yeast limits the ethanol concentration obtainable (the issue of cell metabolism of the employed yeast becoming inhibited and subsequently destroyed). The most ethanol-tolerant strains of yeast can survive up to approximately 15% ethanol by volume. The fermentation process must exclude oxygen. If oxygen is present, yeast undergo aerobic respiration which produces carbon dioxide and water rather than ethanol. Research areas are expanding the range and efficiency of the organisms used in the process. The use of all

available sugars will enhance yield and process efficiency. In this type of process about 25% of the sugars available, are not available due to them being tied up in hemicellulose.

Distillation techniques are used in increasing the concentration of the product from fermentation step (Figure 3). Water content is usually higher than 80% in the initial stage. Large quantities of energy are required to concentrate up to the azeotrope (95.6% wt basis). The process flow sheets when fuel ethanol is desired are simpler than that is used for potable ethanol production

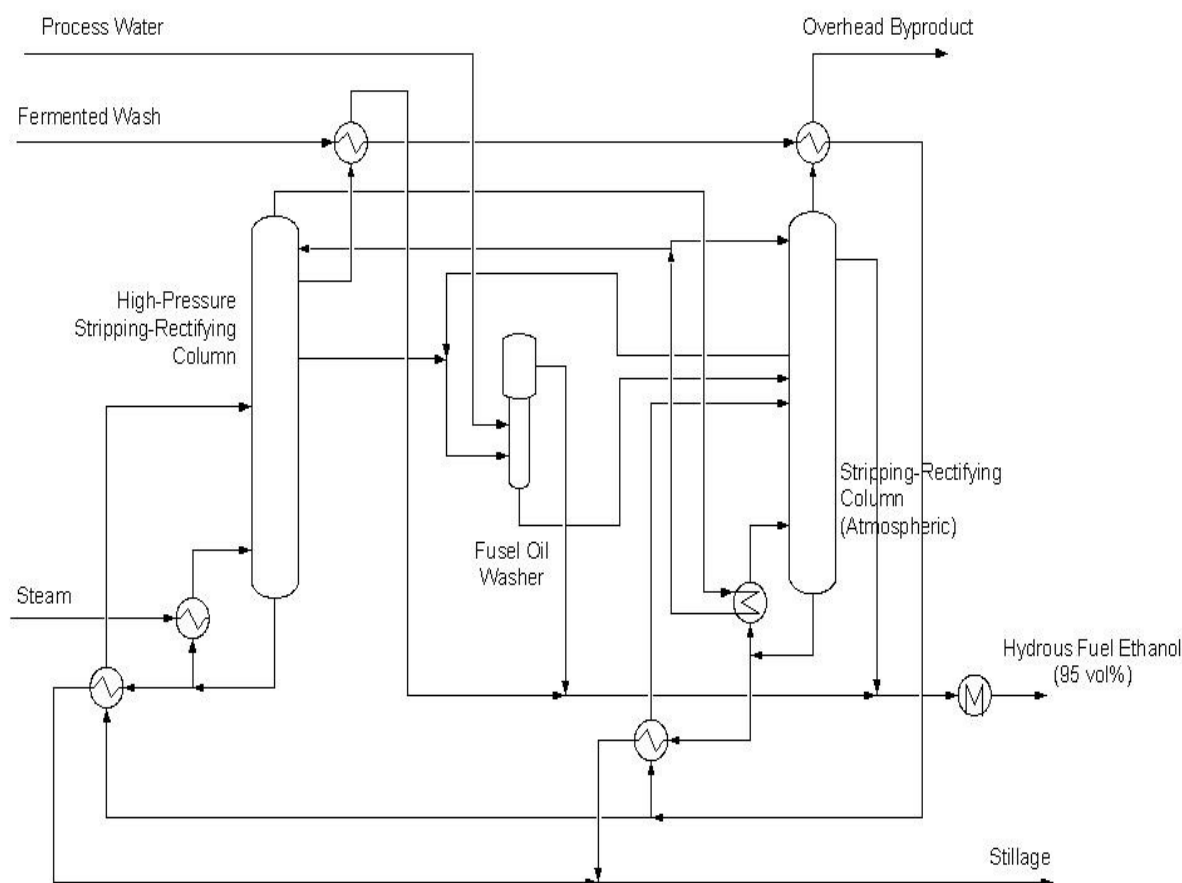


Figure 3 Simplified scheme available for fuel Ethanol production

3. Thermochemical Bioethanol Production Processes

Two processes could be identified which can be characterized in this manner. One is a hybrid system which has a biochemical component. In this gasified biomass produces synthesis gas which is bubbled through specially designed fermenters. GMO's are used in the fermentation process. In the second process the generated synthesis gas is passed through a reactor containing catalyst, which causes the gas to be converted into bioethanol. Bioethanol yields up to 50% had been reported. This type of process may favour the use of lignin fraction of biomass for ethanol production.

3.1 Anhydrous Alcohol

With ethanol it is usual to produce anhydrous ethanol and then blend with gasoline (petrol) to produce a blend for use in vehicles. The reason behind this is the instabilities associated with gasoline-ethanol-water mixtures if hydrous ethanol is directly blended with gasoline. This fact need to be considered with the phase diagram of the system. In the Philippine program of Proal-cool it was observed that vehicles faced sudden loss of power when direct blends (hydrous alcohol with gasoline) were used as fuel.

Anhydrous ethanol is costly to produce for two reasons: ethanol production and anhydrous ethanol separation. Ethanol production can be accomplished by biomass fermentation to produce a mixture of ethanol and water. However, higher productivity of ethanol cannot be achieved by the process since at much higher concentration of ethanol. Commercially, anhydrous ethanol can be produced by simple distillation to distill 12 wt% ethanol to 94.6 wt% ethanol. In this case, ethanol forms an azeotropic mixture of 94.6 wt% ethanol and 5.4 wt% water. To obtain anhydrous ethanol, the last 5.4 wt% of water in the azeotropic mixture has to be removed by azeotropic distillation using benzene or cyclohexane as an entrainer. Benzene, ethanol, and water form a ternary azeotrope with a boiling point of 64.9 °C. Since this azeotrope is more volatile than the ethanol-water azeotrope, it can be fractionally distilled out of the ethanol-water mixture, extracting essentially all of the water in the process. Azeotropic distillation is a very energy intensive technique. With a high demand of ethanol for fuel uses – gasohol, enhancing ethanol production with reduction cost of anhydrous ethanol separation is in high demand.

3.2 Molecular Sieve Separation

A *molecular sieve* is a material containing tiny pores of a precise and uniform size that is used as an adsorbent for gases and liquids. Molecular Sieve often consist of aluminium silicate minerals, clays, porous glasses, micro porous charcoals, zeolites, active carbons, or synthetic compounds that have open structures through which small molecules, such as nitrogen and water can diffuse. Molecules small enough to pass through the pores are adsorbed while larger molecules are not. It is different from a common filter in that it operates on a molecular level. For instance, a water molecule may be small enough to pass through while larger molecules are not. Because of this, they often function as a desiccant. A molecular sieve can adsorb water up to 22% of its own weight. Molecular sieves are often utilized in the petroleum industry, especially for the purification of gas streams and in the chemistry laboratory for separating compounds and drying reaction starting materials.

A molecular sieve can be used to selectively adsorb the water from the 95.6% ethanol solution. Synthetic zeolite in pellet form can be used, as well as a variety of plant-derived absorbents, including straw, and sawdust. The zeolite bed can be regenerated essentially an unlimited number of times. The life of molecular sieve may be around five to seven years. However, the operating cost is considerably less than azeotropic distillation.

Methods for regeneration of molecular sieves include by pressure change as in oxygen concentrators or by heating and purging with a carrier gas as when used in ethanol dehydration.

3.3 Membrane Methods

The use of a membrane can break the water-ethanol azeotrope because separation is not based on vapor-liquid equilibria. Membranes are often used in a hybrid membrane distillation process. This process uses a pre-concentration distillation column as first separating step. The further separation is then accomplished with a membrane operated either in vapor permeation (vapour membrane feed) or pervaporation mode (liquid membrane feed).

3.4 Drying using Absorbents

Use of adsorbents for removal of water is also a possibility. After distillation ethanol can be further purified by "drying" it using a hygroscopic material such as rock salt or cotton.. When lime is

mixed with the water in ethanol, calcium hydroxide forms. The calcium hydroxide can then be separated from the ethanol. Similarly, a hygroscopic material will dissolve some of the water content of the ethanol as it passes through, leaving a purer alcohol.

4. Second Generation Biofuels

Recent attention on biofuels has raised its negative impacts in the current ways of production. The food and fuel debate has bared much detail in this regard. As seen in Table 3 the amount of food grain used for alcohol production in USA has increased quite significantly.

The second generation pathways offer better prospects and will resolve these competing scenarios. Advanced bioethanol technology will allow bioethanol production from the cellulose and hemicellulose, which will add significantly enhanced resource base. The bioconversion of these substrates is difficult to accomplish than the conversion of starch.

Table 3 Ethanol from food grains in USA

Year	Ethanol Produced	Grain Used
1997	1.3 billion gallons	500 million bushels
1998	1.4 billion gallons	538 million bushels
1999	1.47 billion gallons	565 million bushels
2000	1.63 billion gallons	627 million bushels
2001	1.77 billion gallons	681 million bushels
2002	2.13 billion gallons	819 million bushels
2003	2.81 billion gallons	1.077 billion bushels
2004	3.4 billion gallons	1.22 billion bushels

Refer Figure 4 and 5 for understanding the options available.

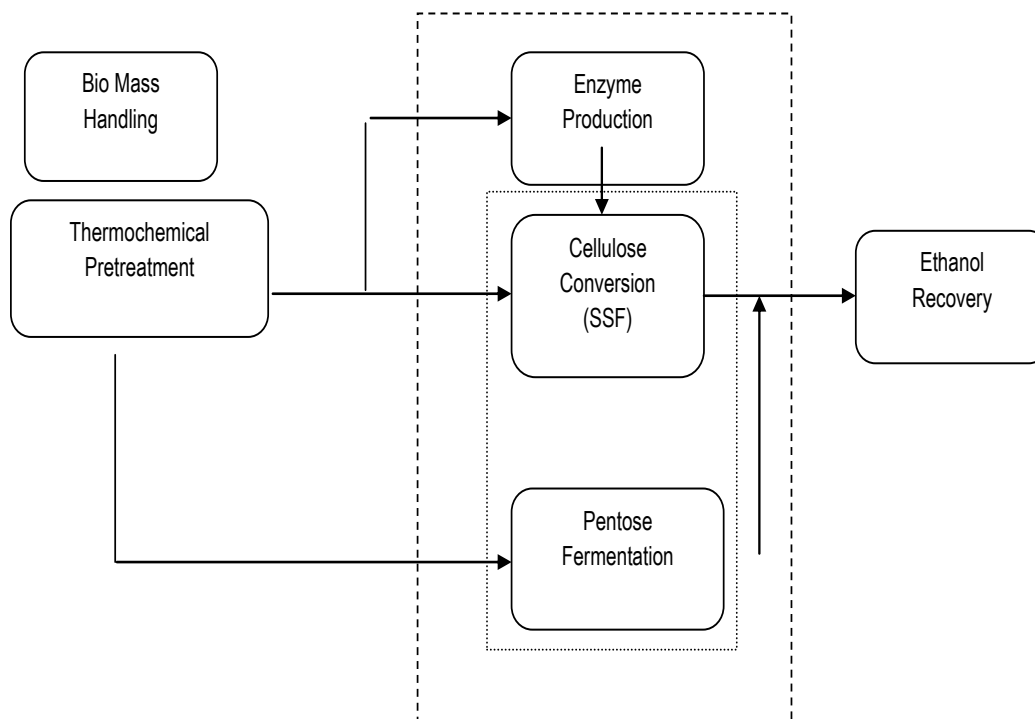


Figure 4 Processing options for Bioethanol production

The process development had been facilitated by the discoveries by microbiologists and advances in biotechnology. Some of the examples are the development of *E. coli* capable of ethanol production, *Zymomonas* recognition as a naturally efficient ethanol-producing bacterium with the added capability for utilizing multiple sugars and the *Saccharomyces* with the added ability for utilizing multiple sugars. Figure 2 presents a simplified picture of the pathway.

Pre-treatment is an essential step which promotes the physical disruption of the lignocellulosic matrix. This will facilitate acid or enzyme catalysed hydrolysis. Many pre-treatment steps are under review. Mechanical pre-treatment, steam explosion (auto hydrolysis), ammonia fibre explosion, alkali or acid pre-treatment, ozone pre-treatment, and biological pre-treatment are examples. Within individual processes many variations can occur (eg steam explosion, aqueous separation and hot-water systems in auto hydrolysis).

Two studies published in the journal *Science* recently have reinforced the urgency of moving quickly to a second generation of biofuels. The two studies, one produced by a team of researchers at the University of Minnesota, and the other led by researchers from Princeton University, found that biofuels can actually produce more carbon dioxide emissions than they save—if they force natural habitats to be converted to cropland, releasing the carbon contained in trees and grasses and in the soil they grow on.

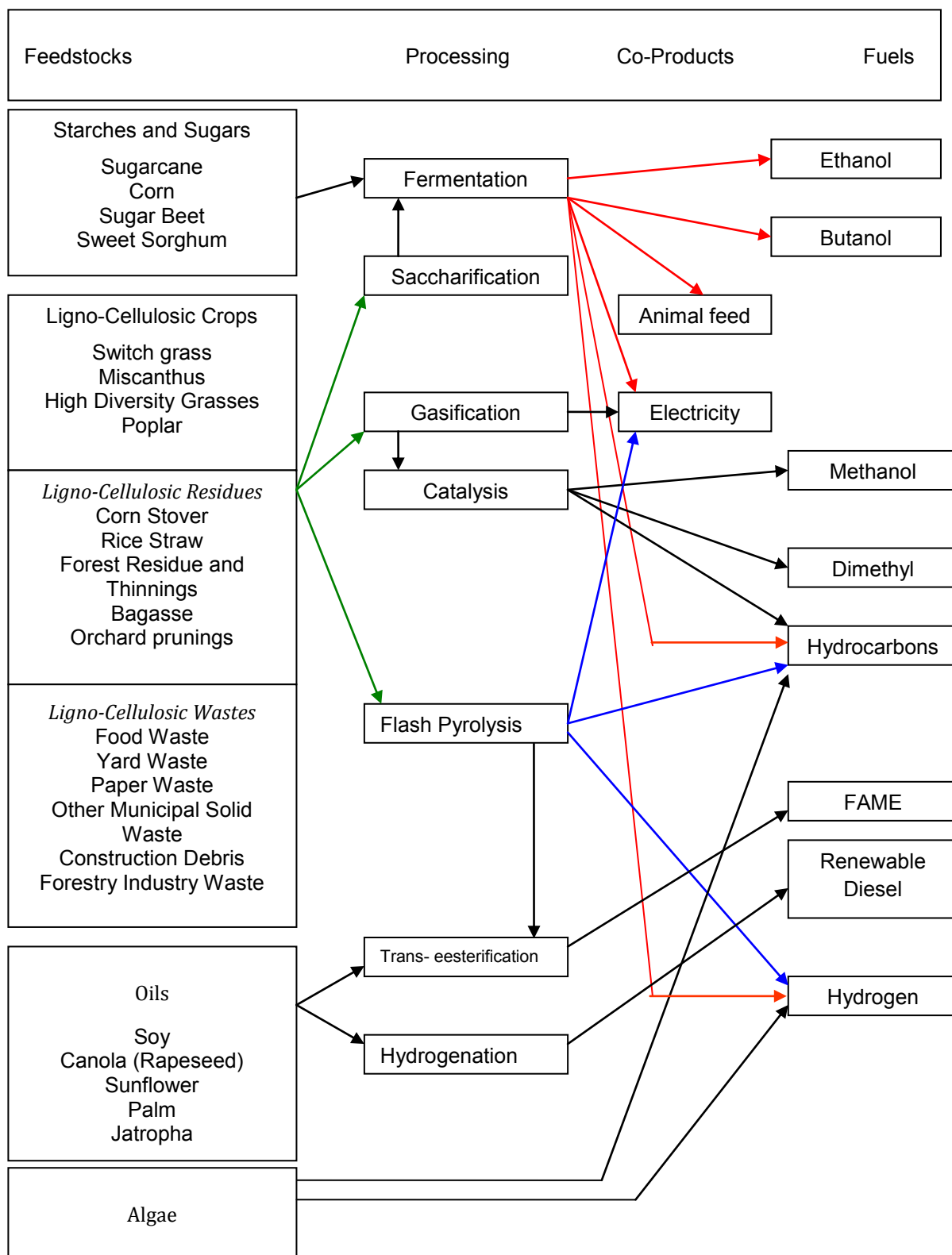


Figure 5 Selected biofuel production pathways with currently dominant pathways highlighted

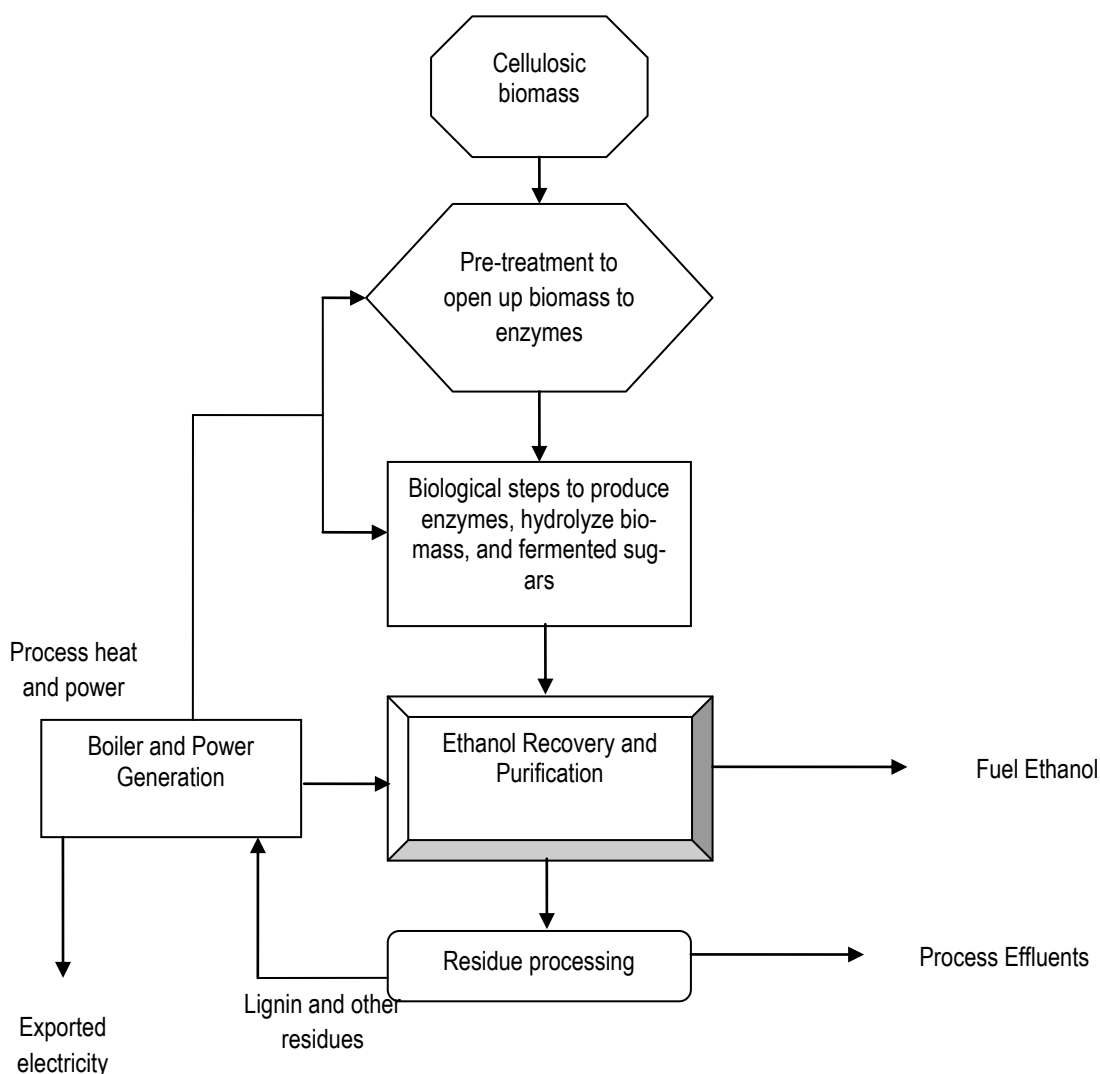


Figure 6 Overall process flow diagram illustrating the important operations in the biological conversion of cellulosic ethanol

5. Conclusions

It appears that there is a greater urgency in resolving food-fuel-environmental issues soon and speedier development of technologies may be the answer. Achieving these really called for creative project management. Technology is available as well as developing and it is within the purview of the planner on the direction to take.

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7. Discussion

Mr. Xavier Johnson

On multiple feedstock, in theory of course it is very valuable and allows generate economic flexibility and so forth, but the experience in Brazil and few other countries has suggested that they have really become experts with one plantation feedstock. It is also extremely valuable because they can optimise everything based on that. Because some crops, especially sugarcane, already have such a rich agricultural diversity, so many varieties have been developed. So you already have a lot of diversity. In fact, on the agricultural side, can you comment whether you really think that multiple feedstock are really feasible given the past experience.

The second issue is more common. I do not know whether the people are aware of it, but there is this Dutch Company that promotes blending hydrous Ethanol with Petrol and they have a patent for it. What do you think about feasibility of that, cost savings that would come with that avoiding dehydration all together?

Prof. Ajith de Alwis

That is the company HE. That is the patent they have come out with and they are demonstrating that. We have a common misconception of going all the way to anhydrous. It is not happening. They are demonstrating phase separation even in meta stable region in which you can operate. What we say is that it is quite useful information one can try. We are looking at the option in a small way. We still feel that in ternary diagram in the context of gasoline that you are putting in also has to be understood. But if you know your Gasoline, get the boundary, and then you can draw in a line and say in this range you can operate. Normally it is like 1-3%, looks still tricky. Even they would go to recommend 12-15% and on the top range. Blend more hydrous, then the situation is terrible. In Sri Lanka we are still looking at 3 maximum on the available Ethanol and that seems to not to give us much options other than for going for anhydrous because the ternary diagram still indicates tricky behaviour in that point. That is the Dutch one.

Obviously, if the hydrous can be mixed, there is one single process, step out. It looks definitely cost effective. From a technical sense, you should not do technology for the sake of technology, because their concept was that you need anhydrous and otherwise we will have a problem. That is the kind of Philippine experience. That is what we see at the lab with separation. So it really

needs to be looked into. But you see that this patent has come slightly over 5 years ago, but not making much waves on the international or rather in the literature. So you are not capturing that event in a major way in the commercial Ethanol sector. Another thing perhaps to look is how much of blending & national blending regulations. You don't have 25%. Most countries are having less than 10%. Less than 10% is a shakier region. Perhaps that is the reason, but that need to be looked into and we are looking into it now.

And on the second one on multiple feedstocks, I don't think we will ever be able to repeat the Brazil. We don't think we should because we can learn the important steps. But there is a major sugarcane producer. When you are a smaller country and you are looking at processes where economies of scale are to an extent important, you don't have much of a choice other than planning for slightly wider variety in feedstock. Where Brazil had like Sao polo or non-Amazon areas, they had land areas and said 'look, we are dedicating these to sugarcane' and we get it. The conflict with Soya and Amazon is a different path. Perhaps they are benefited by having a landmass. We can learn from it, but, in a large scale. Let us say even for Biodiesel, Jatropha, Neem and waste vegetable oils, we can have different ways of thinking, high Free Fatty Acid or low Free Fatty Acid feedstock. So we don't attach a name, but we attach a composition. And, then blend and put in at the pre-treatment stage or pre-preparation stage which is happening in the food industry.

In margarine production, you do multiple feedstocks depending on the cost in the world market. One day you use palm oil and on another day use different oil depending on the varying prices of oil in the world market. You have a formula to change the margarine, but the taste is the same margarine. I think from Sri Lanka's side, being a smaller country, perhaps we have to keep a multiple feedstock, but learn always because Brazil is a unique one. We should learn a lot. USA has given us more learning points where we should drive the way & our work on technology development.

Dr. Muhammad Pervaz

Are there any applications of nanotechnology in this area?

Prof. Ajith de Alwis

Obviously, nano can come in. What I would like to say is that nano is size and bio is life. In that sense, it is 10 to the power minus 9 (10^{-9}) and 100 times is the nano range where as biologists have worked on in nano for lives and molecules and all

that stuff. Only thing is that now we have realised that a segment has a new potential ways of applications or learning and making use of that knowledge. So that will play a role. We have an example of cellulose and one can immediately pin point on dehydration. So I suppose that the time is growing showing that it becomes more important. Nano bio is a good area to work on.

D. Bioethanol

Bioethanol as a Major Source of Energy

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Bioethanol has taken precedence as the prime biofuel after a lot of controversy that erupted on international food shortages and spiralling food prices. In spite of all the controversy, there has been an understanding that we need to continually look at alternate sources of fuels and feedstock's which are non food and this has seen visible interest for sugarcane based Bioethanol to wheat, maize and other food crops. Also Biodiesel too has feedstock problems as palm oil, rapeseed, soya are also edible. The non food Crops like *Jatropha*, *Karanja* have not seen visible success and are also viewed as invasive species by certain nations. In this paper, bioethanol as a major source of energy (fuel oxygenate) and also other advantages that accrue with Ethanol distillation are discussed.

The two major fuels as sources of fuel energy are diesel and petrol. Bioethanol when blended with Petrol acts as oxygenate to burn hydrocarbons completely reducing emissions, particulates and noxious gases. Feedstock availability and scale is critical for successful blending. Sugarcane has proven to be the most successful feedstock. With little controversy of food diversion to fuel and sugarcane distillation moving towards its second generation, technological advancements, carbon, energy and water foot print models are being worked out.

Most of SAARC/ ASEAN nations have successfully cultivated sugarcane for centuries and have known all aspects and implications of this crop on soil, water, air and animal husbandry. Recent new developments in agronomy, harvesting, crushing whole cane, improved distillation practices using better enzymes & catalysts have been improving the capacities of ethanol production. Apart from price of ethanol, factors of carbon footprint of hydrocarbons, logistic implications of transporting hydrocarbons and its distillation, particulate emissions from using hydrocarbons (either leaded or using MTBE oxygenate) which has shown impacts on water bodies in leakages need to be seriously looked into.

With international trade and shipping becoming dearer each day, self dependence for energy needs is a must. Energy needs of each nation keeps enhancing and to cater to them each nation should have its own energy/ biofuel policy in place. Other forms of energy in this sector is power from cogen, i.e. burning biomass along with coal in a

boiler to cater to industry's usage and sale of excess to grid. The energy / emission savings in cogen also generate CDM, but this is applicable for higher boiler capacities and there is no fixed methodology at UNFCCC and is evolving all the time.

The Biofuels industry in the APEC region consists of two distinct sectors, ethanol and biodiesel. Fuel ethanol production within the region in 2007 was estimated at approximately 27,600 million litres, mainly produced in the United States; China; Canada; Australia; and Thailand. Biodiesel production in 2007 was approximately 4,400 million litres with the majority of the production coming from the United States; Indonesia; Malaysia; China; Australia; and Canada. Biofuels in the APEC region are produced from a variety of first-generation feedstock using well-established conversion technologies. For ethanol production, these include: starches from grains (cereals, feed, and grains), tubers (cassava and sweet potatoes), sugars from crops (sugar beets, sugarcane, and sweet sorghum), and food-processing by-products (molasses, cheese whey, and beverage waste). First-generation biodiesel feedstock used in the APEC economies includes vegetable oil (mainly soybean, rapeseed, and palm oil), used cooking oil, and animal fat (tallow and cat fish oil). Second-generation feedstock for ethanol production includes lignocellulosic material, such as crop and forest residues.

Economies with large-scale agriculture and forestry operations such as Canada; the United States; and China have set up demonstration projects using lignocellulosic biomass for ethanol production. An advanced biodiesel feedstock includes microalgae, and few companies in the United States and New Zealand have started pilot projects to grow algae.

Use and promotion of biofuels in different countries are discussed below.

Vietnam

Biofuels production in Vietnam is in its very early stage of development. Although Vietnam has been producing ethyl alcohol for many years (76 million litres in 2005), it has been consumed primarily by the alcoholic beverage and pharmaceutical industries. In November 2007, the government

approved the production and use of Biofuels as it seeks to diversify its energy portfolio. Its target is 500 million litres of fuel ethanol and 50 million litres of biodiesel by 2020. The government plans to create favourable conditions for the development of Biofuels and promote investments, including tax incentives and low-interest loans. The priority for Biofuels R & D in Vietnam on crop productivity and development of advanced conversion technologies is increasing.

Vietnam is rich in biomass resources and it has great potential for Biofuels production. The existing ethyl alcohol industry is already using cane molasses and starches as feedstock. Estimates show that if Vietnam uses all cane molasses and 10% of cassava and corn production, it could produce about 320 million litres of fuel ethanol. Sugarcane production has been consistent during the past six years, about 15 million tons annually; while cassava production has grown rapidly from 2 million tons in 2000 to about 8 million in 2006. Vietnam is also rich in cellulosic biomass, such as agricultural residues (rice husk, straw, baggage, and cane leaf) at 45.6 million tons, and woody residues at 1.6 million tons (Tran Dinh Man 2007). Dedicated energy crops, particularly elephant grass, are also seen as an opportunity. Pilot elephant grass plantations have been set up in Dongthap province (67 ha), BacKan (100 ha), and TuyenQuang (200 ha). Vietnam has also expressed interest in production of ethanol from seaweed.

Two fuel ethanol plants are expected to in Vietnam during 2008-2009: Thier Bien Hoa Sugar Company and Singapore's Fair Energy Asia Ltd. have signed a memorandum of understanding for the construction of an ethanol plant capable of producing 63 million litres a year. The plant will be built in an industrial zone in Ninh Dien village, Chau Thanh district, in the southwestern province of Tay Ninh, and it will use sugarcane molasses (Biopact 2007). Petrosetco, a subsidiary of state-run oil monopoly Petrovietnam, has teamed up with Japan's Itochu Corporation to build a bio-refinery in Ho Chi Minh City's Hiep Phuoc Industrial Park. The facility will use cassava as a feedstock, and it is expected to produce 100 million litres of ethanol annually. The company plans to build three additional ethanol plants using cassava, sugarcane, and rice as feedstock.

Potential biodiesel feedstock in Viet Nam includes animal fat (catfish oil), used cooking oil, rubber seed, and Jatropha oil. After two years of experimentation, the Vietnamese catfish processor and exporter Agifish announced in 2006 that

it had successfully produced biodiesel using catfish oil. The company is building a 10,000 tons/year biodiesel facility in the southern Mekong delta province of An Giang. The company notes that a kilogram of catfish fat could produce 1 liter of biodiesel. Vietnam produced about 60,000 tons of "Basa" fish oil in 2005. The production in the past was primarily for exports to the United States and Europe (Mail & Guardian 2006).

Technology for producing biodiesel from used cooking oil has been successfully developed by HCM City's Research Centre for Petrochemical and Refinery Technology. About 73,800 tons of used cooking oil was produced in 2005, which would translate to approximately 33,000 tons of biodiesel. A trial project producing 2 tons/day biodiesel is underway by Saigon Petro (Tran Dinh Man 2007).

Biodiesel production from rubber seed oil and other oil-bearing crops (*Jatropha*) is being researched by the Institute of Applied Materials & Science and Institute of Tropical Biology in Ho Chi Minh City (HCMC). The Department of Agriculture & Rural Development has a *Jatropha* trial plantation of 5,000 ha. Eco-Carbene has identified four regions in Vietnam for *Jatropha* development, and will enter into partnership with local farmers and communities for a minimum of 30,000 ha. Within the framework of the R&D program carried out by Eco-Carbene, a series of agronomic tests for yield comparison are being implemented to select the most productive *Jatropha* species for cultivation in Vietnam. Biodiesel production is expected to start in 2010 and Eco-Carbene's objective is to reach 60,000 tons of biodiesel production per year at full capacity (Eco-Carbon 2008).

Thailand

Thailand has set up serious efforts to reduce oil imports and carbon emissions by replacing at least 20% of its vehicle fuel consumption with renewable energy sources such as ethanol and biodiesel within the next five years. Biofuels are also seen by the government as an opportunity for rural development and trade. Ethanol production in Thailand was 192.8 million litres in 2007. There are nine operating plants with a total capacity of 435 million litres per year, and nine plants are under construction (440 ML per year). Biodiesel production in Thailand was 58 million litres in 2007. Currently, there are nine biodiesel plants with a total production capacity of 655 million litres annually.

Nearly 90% of ethanol produced in Thailand is from cane molasses. The remaining 10% is from cassava. The proportion is expected to shift over time in favour of cassava. Molasses supplies are expected to increase to 3 million tons, half of which will be used in food industries (mostly for liquor production), and the balance will be for exports and fuel ethanol production (USDA 2007). Cassava production was 22.5 million tons in 2006, and it is expected to grow as the planned cassava-based ethanol production plants start operating.

The main raw material for biodiesel in Thailand is palm oil. The economy ranks third in the world after Indonesia and Malaysia. Total crude palm oil output is 1.3 million tons a year, with about 800,000 tons going to the food sector. Of the 500,000 tons used in non-food businesses, 420,000 tons are now needed to make B2 (2% biodiesel with 98% petroleum diesel). At least 600,000 tons would be required to make B5 (5% biodiesel with 95% petroleum diesel). The government plans to expand palm oil cultivation area by 2.5 million Rai (1 hectare = 6.25 Rai) during the next five years. Few biodiesel plants are using cooking oil as feedstock. *Jatropha* is seen as an alternative feedstock for biodiesel production in Thailand, and one plant intends to use this feedstock. Producing Ethanol from Cassava and cane molasses stand at \$ 0.54 and \$ 0.46 per litre respectively while producing Biodiesel from palm oil and used cooking oil stand at \$ 0.86 and \$ 0.68 per litre respectively (DEDE 2007; 34.5 Baht~1 US \$)

Thailand currently sells gasohol (E10), which accounts for about 20% of total petroleum sales, through its service stations. The state-owned companies PTT and Bangchak started supplying E20 in January 2008. Bangchak plans to introduce E85 at its stations in the near future. B2 is available nationwide; PTT and Bangchak started selling B5 in 2007. There were 3,822 gasohol service stations in Thailand as of December 2007. Currently, 40 stations in Greater Bangkok sell E20 (February 2008). B2 is available at all stations throughout Thailand; 976 stations offer B5 in Greater Bangkok. E20 compatible vehicles are available in Thailand from Ford, Toyota, Honda, and Nissan. Most ethanol producers plan to supply ethanol domestically (particularly those who do not have sugar mill businesses), due to concerns regarding sourcing of raw materials (USDA 2007). However, fuel ethanol export is expected to grow as the production increases in Thailand. About 14.4 million litres of fuel ethanol was exported in 2007 to Singapore, the Philippines, Chi-

nese Taipei, Australia, and Europe.

Policymakers in Thailand have taken measures to increase investments in the production and use of ethanol, including a Board of Investment (BOI) privilege for a fuel ethanol plant, a waiver on the excise tax for the ethanol blended in gasohol, a low rate of oil fund levy, and expansion of cassava production. Also, the government set gasohol prices around 2.0 - 2.50 baht/litres cheaper than regular and premium gasoline. The government requires all its fleets to be fueled with gasohol.

Thailand's Cabinet approved an excise tax reduction for cars using gasoline containing at least 20% of fuel ethanol, proposed by the Excise Department and effective January 1, 2008. The excise tax cut is expected to lower the price of cars by at least THB10,000 (\$1=THB0.03204). A car with a cylinder capacity of no more than 2,000 cm³ and an engine performance of no more than 220 hp will be taxed at 25%, down from a previous 30%. Cars with a cylinder capacity of no more than 2,500 cm³ and no more than 220 hp will be charged at 30%, down from 35%. Finally, cars with a cylinder capacity between 2,500 and 3,000 cm³ and no more than 220 hp will be taxed at 35%, down from a previous 40%. The rates apply to passenger cars and vans with fewer than 10 seats. The Excise Department estimates that about 30,000 new vehicles powered by E20 or higher will be in the market in 2008 (DEDE 2008).

The Thai government announced the Strategic Plan on Biodiesel Promotion and Development in January 2005. The plan targets replacing 10% of diesel consumption in 2012 by increasing palm oil cultivation, and promoting community-based and commercial biodiesel production. The Thai government introduced a B2 mandate in February 2008, which would require the production of approximately 420,000 tons of biodiesel per year. The government is making available 3 billion Baht in soft loans to farmers growing palm crops. It also supports R&D of other crops such as *Jatropha*. A B5 mandate is planned to be introduced in 2011, and B10 in 2012.

The Philippines

Philippines embraced the development of Biofuels a few years ago with hopes of achieving future energy security, augmenting farmers' income, and generating rural employment. The member economy also hopes to position itself as a leading Biofuels producer in the region. The main challenge facing the industry is the availability of feedstock

and the processing facilities to meet the demand of the government's National Biofuels Program. Biofuels production in the Philippines is currently limited to just biodiesel. The member economy had seven biodiesel production plants as of August 2007, with a total output of 257 million litres a year. This production capacity exceeds the requirement of the mandatory volumes set by the Biofuels Act, thus the biodiesel producers see it as an excellent export opportunity. Production of fuel ethanol will commence in late 2008, in time for its mandated use in 2009. Several ethanol plants are under construction, but their scheduled completion, inclusive of their corresponding feedstock supply-base, is uncertain (USDA 2007).

Primary feedstock for biodiesel production in the Philippines is coconut oil. The Philippines is one of the largest producers of coconut oil in the world - approximately 1,400 million litres per year. Nearly 20% (400 million litres) of this production is used for domestic consumption, and the balance of 80% is exported. Mindanao accounts for almost 60% of the economy's total coconut oil production (Embassy of the Republic of the Philippines 2007). Potential biodiesel feedstock in the Philippines is Jatropha and palm oil. The government has announced its plan to launch massive propagation and cultivation of Jatropha seeds covering around 2 million hectares (ha) of unproductive and idle public and private lands nationwide. This effort will produce about 5,600 million litres of Biofuel in the next 10 to 12 years (Bulatlat 2007). There are few pilot plantations growing oil palm.

In the Philippines, sugarcane is considered a primary source for ethanol production. The government sees it as the most reliable feedstock due to its well-established farming technologies and the highest yield per hectare compared to other feedstock (corn, cassava, and sweet sorghum). Sugarcane production in the Philippines is expected to increase to meet the requirements of the Biofuels Act. At present, the sugar industry can only supply 79% of the needs of the 5% ethanol blend, which is between 200 and 400 million litres per year. The Philippines, therefore, needs to expand its current 167,300 sugarcane farms covering a total area of 344,700 hectares to meet the ethanol demand. The Sugar Regulatory Administration (SRA) already identified 237,748 hectares of new sugar fields, mostly in Mindanao, that can be tapped to produce fuel ethanol (Bulatlat 2007). Additional ethanol feedstocks considered by the government are sweet sorghum and cassava.

B1 (1% biodiesel and 99% petroleum diesel) and E10 (10% ethanol and 90% gasoline) are available nationwide. B1 is available through all service stations in the Philippines, and it has been

successfully used by thousands of vehicles in the Philippines since 2002. E10 is currently offered by all Sea oil stations nationwide. It is expected that in 2008 more gas stations will be offering E10 (Biofuels Philippines 2007). In 2007, Ford Philippines opened a plant that manufactures flexible fuel engines in Santa Rosa, Laguna. These engines are designed to run on a mix of up to 20% ethanol. Production output of the Ford facility reportedly is estimated at 105,000 FFV engines in the next five years, with some units intended for export to South Africa and other Association of Southeast Asian Nations (ASEAN) countries. The Ford plant's opening is expected to enhance and accelerate the adoption of Biofuels in the economy (USDA 2007).

Chemrez Inc. has exported 500,000 litres of coconut-based biodiesel to Germany and to Asian markets including China, Chinese Taipei, South Korea, and Malaysia. If the mandated biodiesel blend increases to 2% in the next two years, as specified in the Biofuels Act, biodiesel companies in the Philippines may concentrate on supplying the domestic market and export only excess volumes. The Philippine Biofuels Act, implemented in January 2007, establishes some requirements for ethanol and biodiesel. Within two years from the effectivity of this Act, at least five percent (5%) Bioethanol shall comprise the annual total volume of gasoline fuel actually sold and distributed by each and every oil company in the member economy, subject to the requirement that all Bioethanol blended gasoline shall contain a minimum of five percent (5%) Bioethanol fuel by volume. Within four years from the effectivity of this Act, the National Biofuels Board (NBB) created under this Act will be empowered to determine the feasibility and thereafter recommend to the Department of Energy (DOE) to mandate a minimum of ten percent (10%) blend of Bioethanol by volume into all gasoline fuel distributed and sold by each and every oil company in the member economy. In the event of supply shortage of locally-produced Bioethanol during the four-year period, oil companies shall be allowed to import Bioethanol but only to the extent of the shortage as may be determined by the NBB.

Within three months from the effectivity of this Act, a minimum of one percent (1%) biodiesel by volume shall be blended into all diesel engine fuels sold in the member economy; provided that the biodiesel blend conforms to the Philippine National Standards (PNS) for biodiesel. Within two years from the effectivity of this Act, the NBB created under this Act is empowered to determine the feasibility and thereafter recommend to DOE to mandate a minimum of two percent (2%) blend of biodiesel by volume which may be

increased taking into account considerations including but not limited to domestic supply and availability of locally-sourced biodiesel component (Republic Act No. 9367). Among the incentives designed to encourage the production and use of Biofuels are an exemption of the ethanol/biodiesel portions of fuel blends and an exemption from value-added taxes for raw materials (coconut, sugarcane, *Jatropha*, cassava, etc.). There are also favorable loan policies available from banks for Biofuel investors and producers.

Malaysia

Biofuels in Malaysia has been identified as a new source of growth for the plantation commodities industry. The concentration is on biodiesel from palm oil, because of the large domestic production of this feedstock. An opportunity for cellulosic ethanol production exists from the oil palm biomass (part of it left unutilized), but this technology is yet to be commercialized. Meanwhile, the economy is focused on creating a successful industry with what exists, which is palm biodiesel. The main concern for expanding biodiesel production in Malaysia is land availability and associated sustainability and biodiversity issues.

Biodiesel production in Malaysia was 120,000 tons in 2006. There were five operating plants as of December 2006 with a total capacity of 258,000 tons per year. The government has approved licenses for the establishment of 84 biodiesel plants with a potential annual capacity of 9.26 million tons. However, the pace of commercialization is expected to slow down, due to the rapid increase in the cost of palm oil. The primary feedstock for biodiesel production in the member economy is palm oil. Until recently, Malaysia was the world's largest palm oil producer; however, Indonesia surpassed Malaysia in 2007. Together, these economies produce about 90% of the world's palm oil. In Malaysia, nearly 11% of the total land area (about 62% of the economy's agricultural land) is devoted to oil palm. The production more than doubled during the past 10-11 years, from 7.81 million tons in 1995 to 16.5 million tons in 2006. Malaysian government policy currently allows only 6.0 million tons of palm oil to be converted into biodiesel.

A study by Tatsuji Koizumi and Keiji Ohga indicates that the cost of producing biodiesel from crude palm oil (CPO) was roughly U.S. \$0.54 per litre in 2006. The raw material is about 80% of the total cost. Due to the increased price of palm oil in 2007, the production cost of biodiesel from palm oil in Malaysia today (in 2008) is probably

double that in 2006.

Malaysia introduced a type of biodiesel known as Envo Diesel, which is a mixture of 95% petroleum diesel and 5% processed palm oil (RBD palm olein). Envo Diesel is different from the biodiesel blend B5 used in Europe (it uses straight palm oil, not a methyl ester), and it is intended for local use. For export markets — and local use, only if necessary — the industry produces biodiesel (methyl ester) from palm oil and methanol. A small number of government-owned vehicles currently use biodiesel, comprising mainly palm oil, but commercial sales have yet to start. According to the Malaysian Timber Industry Board (MTIB), from August 2006 until February 2007, 52,654 tons of biodiesel had been exported to the United States, European Union, and Japan. Malaysia may export biodiesel to European markets at the range of 300-350 thousand tons by 2010.

The National Biofuel Policy was implemented in March 2006 to encourage the production of Biofuels, particularly biodiesel from palm oil, for local use and for export. The ministry formulated the Malaysian Biofuel Industry Act, which will introduce a B-5 mandate, equivalent to a biodiesel demand of 500,000 tons, from 2008. However, the implementation of the act has been delayed due to soaring palm oil prices. The government will wait until prices for RBD (refined, bleached, and deodorized) palm oil fall to MYR2,000 (\$1=MYR3.49511) per tone, or below, before it decides on the exact date of the introduction of the biodiesel mandate.

Korea

This country is interested in adding Biofuels to its energy matrix, driven primarily by the desire to reduce air pollution and oil dependency. Biodiesel is the primary choice given the fact that Korea consumes large amounts of diesel (twice the amount of gasoline) and it has the option of producing feedstock domestically. Biodiesel production in Korea was 50 million litres in 2006. There are 15 operating biodiesel plants with a total capacity of 625 million litres/year. There is no fuel ethanol production in Korea. Only a small amount of ethanol is produced by Changhae Ethanol Co. Ltd as a test.

Nearly 70%-80% of biodiesel in Korea is produced from imported soybean oil and 20%-30% from used cooking oil. Several biodiesel plants have the capability of using palm oil (USDA 2007). Due to rising soybean and palm oil prices, biodiesel producers are considering alternative

feedstock such as Jatropha oil, produced in the Southeast Asia region, the Philippines and Thailand for example. Options for producing biodiesel feedstock domestically are currently explored in Korea. It is estimated that 300,000–500,000 ha of coastal land could be available for winter canola with potential output of 450,000–750,000 tons of canola oil per year. Three demonstration sites in the Southern part of Korea have been selected for cultivation (KIER 2007). Producing Biodiesel from used cooking oil, rapeseed and soybean would cost 0.90, 0.53 (with a subsidy) & 1.06 \$ per litre (KEEI, November 2007)

B5 (5% biodiesel and 95% petroleum diesel) and B20 (20% biodiesel and 80% petroleum diesel) are available nationwide. Vehicles Korea has supplied B5 through all of its gas stations since July 2006. There are about 200 stations offering B20 operating for fleets only. Korea also is testing E3 (3% ethanol and 97% gasoline) and E5 (5% ethanol and 95% gasoline) stations. Korea imports soybean oil mainly from Argentina (86%) and the United States (14%). The domestic soybean oil industry estimated that of the 260,000 tons of soy oil imported in 2006, less than 25% was used for biodiesel production. Korea may import 1 million tons of soybeans by September 2008, the U.S. Department of Agriculture forecasted recently.

The government of Korea supports the development of Biofuels and it aims to develop energy policy that considers both economic growth and environmental protection. The Ministry of the Environment (MOE) began testing biodiesel and biodiesel fuel blends in early 2002. As a result of these emission tests, MOE recommended biodiesel as a renewable fuel to the Ministry of Commerce, Industry and Energy (MOCIE). MOCIE is responsible for setting standards for petroleum and petroleum substitutes, and MOE is responsible for regulating air pollution. In late 2002, 73 gas stations in the Seoul metropolitan area and Chonbuk Province were designated as demonstration stations and began carrying B20. By January 2006, the number of stations testing B20 reached 200. In 2003, Korea began preparing official biodiesel standards, and the biodiesel demonstration was extended to June 2006. The final standards, drafted in September 2004 by MOCIE, were adopted in January 2006 and are very similar to EN14214, the European biodiesel standards (USDA 2007). Korea plans to mandate nationwide B3 by 2012 and will extend the current tax incentives on production of biodiesel to 2010.

Japan

Japanese fuel ethanol production is in an experimental stage, and the current production level is 30,000 litres (April 2006). Sugarcane molasses in Okinawa, wheat and corn unsuitable for food in Hokkaido, sorghum in Yamagata, and wood residues in Okayama and Osaka are the raw materials used for ethanol production. To further promote domestic ethanol production, the government hopes to use abandoned arable land (Koizumi and Ohga 2007). It also will rely on technological breakthroughs in lignocellulosic ethanol in the near future, which would allow the use of waste material. Biodiesel doesn't receive as much attention as ethanol in Japan. Current annual production from used cooking oil is estimated at nearly 3 million litres. In 2006, Nippon Oil Corporation and Toyota Motor Corporation announced development of a palm oil-based biodiesel that performs comparably to petroleum diesel. They claim to have removed the oxygen from the palm oil, which would normally cause the fuel to degrade. Nippon Oil aims to develop a commercially viable biodiesel by 2010 (USDA 2006). Cost of producing Ethanol from sugarcane molasses and wheat are \$ 0.20 and \$ 0.26 per litre while biodiesel from rapeseed costs \$2.9 per litre (Koizumi and Ohga 2007)

Japan began testing E3 (3% ethanol and 97% gasoline) and ETBE (ethyl tertiary butyl ether) in 2007 and started to offer E3 at two gasoline stations, one in Sakai City and the other in Daito City, in October 2007. E3 is also offered in Osaka but is limited to about 100 cars registered in advance with the local government. Japan is gradually increasing the number of E3-supplying gas stations to sell the product to the general public in 2008. There are about 50 stations in the Tokyo metropolitan area offering ETBE blended gasoline. Their number is expected to reach 100 during 2008, increasing to 1,000 nationwide in 2009 (Asia Times 2007).

Japan imports ethanol (mostly from Brazil and China) to supply its beverage, chemical, and pharmaceutical industries. Brazil has the world's largest ethanol export potential, and it is seen by Japan as its major source of the alternative fuel. Last year, the governments of Japan and Brazil set up a study group on trading in the fuel. It is expected that large amounts of fuel ethanol will be imported from Brazil in the coming years (Ohmy News International 2007). In 2002, the Biomass Nippon Strategy was published, which recognized the need to halt global warming, encourage recycling in Japanese society, and foster alternative

energy industries. As a signer to the Kyoto Protocol, Japan has pledged to reduce CO₂ emissions by 60% from 1990 levels by the year 2010. To reach that goal, the Japanese government plans to replace fossil fuels with 500,000 kilolitres of ethanol for the transportation sector by 2010. In addition, the new National Energy Strategy, compiled in 2007 by the Ministry of Economy, Trade, and Industry (METI), set a goal of reducing the nation's reliance on oil for transport to 80% from the current 100% by 2030.

A preferential tax system for gasoline blended with ethanol is expected to be introduced in 2008. Under the planned tax system, Biofuels mixed with gasoline will be exempted from the gasoline tax — currently 53.8 yen (US\$0.48) per liter — in proportion to the amount of Biofuels included. For example, E3 will be taxed 1.61 yen less per liter than pure gasoline. There is no tax break for gasoline mixed with Biofuels, regardless of the ratios involved. The government is also expected to remove the current 3.1% import tax (Asia Times 2007).

Indonesia

Indonesia sees Biofuels as one of the key instruments to accelerating economic growth, alleviating poverty, and creating employment opportunities while also, under the Kyoto Protocol, mitigating greenhouse gas emissions. The government had set up goals of reaching 2% Biofuels in the energy mix by 2010 (5.29 million kilolitres), growing to 3% by 2015 (9.84 million kilolitres) and 5% by 2025 (22.26 million kilolitres). A major challenge to achieving these goals is financing, and the government has provided a set of incentives to attract domestic and foreign investors. The government prohibits rainforest deforestation for Biofuels purposes.

Ethanol production in Indonesia was about 140 million litres in 2007, and the economy plans to reach 3,770 million litres in 2010. Biodiesel production in 2007 was about 1,550 million litres and it is estimated to reach 5,570 million litres in 2010. The main biodiesel feedstock in Indonesia is crude palm oil (CPO) due to the well-established CPO industry and potential for the increase in production. Indonesia surpassed Malaysia in palm oil production in 2007 and is now the world leader. Together, Malaysia and Indonesia provide 87% of the world's palm oil. Indonesia's CPO output is estimated to be 17.4 million tons in 2007, up from 15.9 million tons in 2006. There are 6 million hectare of oil-palm plantations. The government established laws and regulations

guiding their expansions to prevent deforestation.

Other potential biodiesel feedstock in Indonesia includes coconut oil and Jatropha. In 2006, Indonesia's coconut oil production was about 880,000 tons, with between 450,000 and 550,000 tons used for export purposes. Jatropha is still in the early stage of development and there are concerns that it is not feasible for large-scale production. At least two companies are making serious preparations to use Jatropha as a feedstock. Though using Jatropha would remove the conflict between food and fuel, Jatropha is more labour-intensive and produces less oil than oil palm. At this time, Indonesian government efforts appear to be focused on using Jatropha in villages where electricity is not cost-effective (USDA). Currently, fuel ethanol in Indonesia is produced from sugarcane molasses. Indonesia has about 5.5 million acres dedicated to sugarcane production, and several companies want to expand their plantations. Indonesia is among the top 10 sugarcane producers in the world with about 30 million tons per year. Indonesia is also looking at cassava as feedstock for ethanol. There were 52,195 ha planted with cassava in 2007 and it is expected to increase to 782,000 ha. In Indonesia, 1 ton of molasses yields about 250 litres, and 1 ton of cassava yields about 155 litres of anhydrous ethanol (USDA). Due to abundant biomass resources, such as palm fruit shells, rice husk, sugarcane Bagasse, and other crop and forest residues, Indonesia is interested in cellulosic ethanol production and actively supports R&D in the area. Biodiesel production cost from palm oil and jatropha in Indonesia is \$ 0.41 and \$ 0.48 per litre respectively (APEC Biofuels Task Force, 2007).

B5 (Biosolar) and E5 (Biopertamax) are available through the state-owned oil firm Pertamina. In January 2008, Pertamina reduced the percentage of Biofuels in its Biosolar and Biopertamax products from 5% to 2.5% due to rising palm oil prices and lack of incentives. B5 is offered at 228 gas stations in Jakarta, Surabaya, and Bali. Since December 2006, E5 is offered at 14 stations in Jakarta, 7 in Surabaya, 4 gas in Malang, and 11 in Bali. Bio-premium (E5 using Premium blend) is offered at 1 station in Malang. While Indonesia exports small amounts of biodiesel to China, the European Union (EU), and the United States, CPO remains the main trading commodity. The Indonesian Palm Oil Producers Association estimates that Indonesia's palm oil exports were slowing down in 2007, mainly because of the growth in domestic biodiesel consumption. Exports reached 12.1 million tons in 2006, and it is estimated at 13.1 to 13.2 million tons in 2007. If palm

oil production in Indonesia reaches more than 18 million tons in 2008, exports may be about 14 million tons, but it will also depend on the growth of the biodiesel industry (Pacific Biofuel). The main export market for Indonesian ethanol is Japan. The future of ethanol export is uncertain, considering the growth of domestic fuel ethanol demand.

Some of the current Biofuels policies in Indonesia includes the Presidential Instruction No.1/2006 to 13 central and regional government institutions on supply and utilization of Biofuels as alternative energy (January 2006), Presidential Regulation No.5/2006 on National Energy Policy, calling for 5% Biofuels in the energy mix by 2025 (January 2006) and Presidential Decree No.10/2006, established by the National Team for Biofuels Development to coordinate industry expansion (July 2006). While the Indonesian government had expressed strong interest in Biofuels development, it has been moving slowly and cautiously in implementing supporting policy. The government subsidizes biodiesel, bio-premium, and bio-pertamax at the same level as fossil fuels, leaving Pertamina to cover the difference when biodiesel production costs exceed fossil fuel costs. The government is considering providing various incentives, including value-added tax (VAT) reductions for business players, and excise duty cuts for Biofuels users. In 2007, the government announced an interest rate subsidy of Rp 1 trillion for farmers growing Biofuels crops including *Jatropha*, oil palm, cassava, and sugar cane.

Hongkong

Hong Kong has adopted many programs and measures focused on improving the fuel quality and efficiency, such as liquefied petroleum gas (LPG) taxis and minibus programs, installation of particulate trap and oxidation catalytic converters, and introduction of ultra low-sulfur diesel. To relieve existing pollution, Biofuels and especially biodiesel have also been considered in recent years. Biodiesel feedstock available in Hong Kong is waste cooking oil and animal fats. About 10,000 litres of used cooking oil are produced every day in Hong Kong, which translates roughly into 3.5 million litres of biodiesel per year. There is one existing biodiesel production plant in Hong Kong, with a small output primarily for domestic consumption (annual capacity of 4.3 million litres). ASB Biodiesel, a joint venture company, is building a second plant near the Tseung Kwan industrial area of Hong Kong. The plant will have a capacity of 114 million litres per

year and it will use waste products including used cooking oil, waste animal fat and grease trap waste (restaurant sewage). The biodiesel produced will be for domestic consumption and export to Europe. Hong Kong-based companies have invested in ethanol production projects in other parts of the world, such as Noble Group Ltd. in Brazil and Rapid Grow Investments in Fiji. The government of Hong Kong encourages the use of biodiesel and plans to introduce a duty-free policy on its use. The Environmental Protection Department is developing specifications for biodiesel to ensure fuel quality, boost users' confidence, and help control the impact on environment. The government will further propose a mandatory labeling requirement for biodiesel blends above 5% to ensure their proper use in vehicles and increase awareness of some possible corrosion problems associated with higher blends.

Chinese Taipei

This country is promoting the development and use of Biofuels to reduce carbon dioxide (CO₂) emissions and imports of fossil fuels. The government supports many research projects focused on advanced Biofuels production technologies, such as ethanol from cellulosic biomass and biodiesel from used cooking oil, which don't compete with the food industry. Biodiesel production in Chinese Taipei was 3.8 million litres in 2007, a substantial increase from 2.4 million litres in 2006. Currently, there are five operating plants with a total capacity of 42.1 million litres per year. One plant is under construction with an annual capacity of 100 million litres per year. There is no fuel ethanol production in Chinese Taipei, but state-owned Taiwan Sugar Corporation produces about 20-30 million litres of sugarcane-based ethanol every year, mostly for the beverage industry. Two fuel ethanol plants are planned with an annual capacity of 100 million litres each.

The primary feedstock for biodiesel production in Chinese Taipei is used cooking oil. Additional domestic feedstock includes soybean and sunflower, and the government encourages growing these crops on fallow rice paddy fields. Chinese Taipei is considering ethanol production from sugarcane, sweet sorghum, molasses, and other biomass from agricultural wastes. Production cost of Ethanol from sugarcane is \$ 0.62 per litre while same for Biodiesel from used cooking oil and soybeans are \$ 0.08 and \$ 1.34 per litre respectively (ITRI 2007). Sales of E3 (97% gasoline and 3% ethanol) started in 2006, and biodiesel is offered at different blending levels from B1 to B20 (20% biodiesel). Nearly 300 service stations offer

B1, and E3 is supplied by eight stations. Biodiesel is used by city buses in Kaohsiung City and Chiayi County. The biodiesel produced in Chinese Taipei is for domestic consumption, and no import has been recorded. Biodiesel incentives could force the economy to import more soybeans, if biodiesel demand exceeds the supply of recycled cooking oil, the U.S. Department of Agriculture estimated. Small volumes of ethanol are imported annually from China, Indonesia, and Thailand for use by the food industry. The government plans to introduce an E3 mandate in 2011. It also plans to have B1 available at all gas stations nationwide by 2008 and B2 by 2010. Some policies include exemptions from commodity tax and air pollution control fee, Incentives to encourage motorists to switch to ethanol gasoline and subsidies provided for demonstration programs.

China

The massive economic growth of China in the 1990s resulted in a rapid increase of petroleum consumption and led to serious air pollution problems. To deal with fuel shortage, energy security, and air quality issues, the Chinese government began promoting Biofuels in 2000. However, concerns about feeding the world's most populous nation could limit the growth of China's Biofuels industry. China has long been concerned about its food security; thus, the top priority for land use is growing crops for food.

China is the world's third-largest producer of ethanol, but most of it is consumed by the pharmaceutical and beverage industries. In 2006, there were four operating ethanol biorefinery running at maximum capacity, about 1.02 million tons. Though Beijing has stopped approving new fuel ethanol projects since December 2006, four more plants in the provinces of Guangxi (110,000 tonnes), Hebei (300,000 tons), Liaoning (300,000 tons), and Hubei (200,000 tons) were scheduled to be completed in 2007 (Source: Institute for Energy Economics, Chew Chong Siang). China National Cereals, Oils and Foodstuffs Corporation (COFCO) is investing 50 million Yuan (U.S.\$6.5 million) to build a cellulosic ethanol pilot plant. The plant in Zhaodong, in the north-eastern province of Heilongjiang, will have an annual capacity of 5,000 tons. Another cellulosic ethanol pilot plant with a production capacity of 10,000 tons is being planned in the Yucheng area of Shandong.

Biodiesel is in its early development stage in China. In 2006, biodiesel production was 30,000

tons from a dozen of small-scale production facilities. Principal Biodiesel producers are Fujian Zuoyue New Energy Co.Ltd, Sichuan Gusan Biodiesel Co. Ltd, and Hainan Zhenghe Biodiesel Co.Ltd. Since 2006, biodiesel plants have opened in Shanghai, Fujian, Jiangsu, Anhui, Chongqing, Xinjiang, and Guizhou, among other places. The plants are private, state-owned, and even foreign-owned enterprises. New plants are much larger than the existing ones, some reaching 600,000-750,000 tons/year. Dozens of biodiesel projects are under construction, or in planning stages, with cumulative capacity of more than 3 million tons/year.

Nearly 80% of the fuel ethanol in China is made from corn. Three of the existing facilities (Heilongjiang, Jilin, and Anhui) use the grain as feedstock. The biorefinery in Henan uses wheat. Concerns about food supply and high prices led the industry to look at other, non-grain feedstock, such as cassava, sweet sorghum, and sweet potato, viewed as transitional feedstock in the long term. The crops could be grown on China's 116 million hectares of marginal land unsuitable for producing grains. In the long run, China plans for a transition to ethanol production from cellulosic biomass, particularly crop residue, which is of sufficient supply. Estimates show that the member economy generates approximately 1,500 million tons/year of agricultural and forest residues, which is sufficient to produce 370 million tons of ethanol. Currently, there are several pilot plants producing ethanol from lignocellulosic biomass via biochemical conversion process. Feedstock supply is a key factor in limiting biodiesel development in China. Vegetable oils are the main feedstock for plants elsewhere, but it is not economical for China to import them to make biodiesel because it already imports significant amounts for food consumption. The existing feedstock is used cooking oil, acid oil, and animal fat. A lot of waste oil and grease are produced from the food-processing industry due to cooking habits. It is estimated that about 3 million tons of waste oil and grease are produced in China annually. For a long-term development of biodiesel, China is considering nonedible feedstock, such as Barbados nut (*Jatropha Curcas*), Chinese pistachio (*Pistacia Chinensis*), Chinese tallow tree (*Sapium Sibiricum*), etc. *Jatropha* is abundant in Southwest China (Sichuan, Yunnan, Guizhou, etc.) with the potential for planting in large scale, and providing good economic and social benefits. However, this area also contains ecologically sensitive and biodiverse forest area; thus, careful considerations should be made in policy decisions.

E10 is used in five provinces: Helongjiang, Jilin, Liaoning, Henan, and Anhui; and 27 cities: nine in Hubei, seven in Shandong, six in Hebei, and five in Jiangsu. Gasohol consumption in 2005 accounted for nearly 20% of national gasoline consumption. According to a U.S. Department of Agriculture (USDA) report, biodiesel currently produced in China is of low quality, and it is not suitable for fuel use. It has been used as a solvent or as an additive to coal in thermal power plants or industrial cooking facilities in rural areas. There are 75,000-85,000 refuelling stations in China, with approximately 20,000 offering E10.

Most exports of ethanol from China are undenatured (potable), particularly in Japan, Korea, and Singapore where it is used for alcohol production. In 2006, China hit a record volume of exports, about 500,000 tons. This was mostly due to higher demand in the United States because of phasing out methyl tertiary-butyl ether (MTBE), which increased the price of alcohol. Official statistics on biodiesel trade are not available, but estimates show that total exports were approximately 10,000 tons in 2006 (USDA). Some attempts were made to import palm oil from Indonesia and Malaysia, but they have been suspended due to increasing prices of this feedstock.

In 2001, the State Council launched a Fuel Ethanol Program, which led to the establishment of the four ethanol plants and distribution of E10 in nine provinces. Policies — such as income tax reliefs, VAT refunding and fiscal subsidies — were made available to ethanol producers. In 2006, each ton of ethanol received a 1,373 Yuan subsidy. Beijing has committed 1.1 billion Yuan (U.S.\$143 million) to help develop vehicles that run on Biofuels. In comparison, policy measures for the biodiesel industry are not developed. Technical standards, distribution channels, production techniques, equipment, environmental evaluations, etc. are yet to be finalized. Under the revised National Plan, fuel ethanol production is to increase to 3 million tons/year by 2010 and to 10 million tons/year by 2020. Biodiesel is to grow to 300,000 tons/year in 2010 and 2 million tons/year in 2020. According to the plan, E10 sales are to expand in more provinces in 2010, and E20 and E85 possibly will be introduced, as well as B5 or B10 in 2020. The Chinese government's overall policy for Biofuels is to move this technology forward in a way that it doesn't compete with arable land, grain is not used as feedstock, and it doesn't destroy the environment. No new corn-based ethanol plant is to be approved. It considers giving subsidies and tax breaks to demonstration projects: plants using non-grain feedstock

and plantations growing non-food crops.

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Discussion

Dr. Muhammad Pervaz

It is good that you have given the policies of the ASEAN countries and some other neighbouring countries. ASEAN has prepared some kind of a road map for the future. If a country uses a policy, such can be shared for the other countries' help for bridging their gaps. SAARC Energy Centre conducted a study visit to ASEAN Centre of Energy. We have visited Indonesian and Thailand energy organisations. Their model, specifically with regard to Biofuels is not directly applicable to the SAARC region. Their raw material and technology status are different. During our visit, there was a point that if Indonesia or Malaysia goes for Biodiesel based palm oil; its export price will increase for SAARC and other countries. You have given comparative studies of policies of different countries. Can you conclude in a way which policy is more relevant to SAARC?

Mr. Phani Mohan Kancharla

Let us look this way, Indonesia has very limited sugar cane plantation, but Indonesia had made up a policy to develop fuel Ethanol programme too. They have a comprehensive Ethanol policy. Foreign investments are already coming, 2 Multi National Organisations have entered Indonesia and try to take their fuel Ethanol programme

ahead. If we look at China, they also succeeded their fuel Ethanol programme in spite of its shortages in feedstock. What is required here is determination to position yourself in such a way which caters to your domestic use and look at it in a trade perspective. We have seen in 2005, China imported starch from Thailand and exported all the way to the USA through the Caribbean route. They were smart enough. Policies should be driven understanding the needs of local as well as trade markets. Global Biofuels trade is still at its initial stage, presumably below 1%. Therefore for trading Biomass and Biofuels, the sky is the limit. There are no limitations at all and for the regional context, inter trade between our neighbouring nations could help us achieve our targets.

Once there is trade, possibly, the scale of operations would definitely enhance. We have seen this visibly happening in China, Indonesia and even the smaller nation countries like Hong Kong and Chinese Taipei, who do not have much land and therefore feedstock. Why not we? At-least we should start from some where. We need to mandate a policy and work forward to achieve, drive a road path to reach the policies, we should start some where and for that setting a platform is required.

UN is trying to put up a comprehensive policy to each and every nation giving them directions that could be achievable. It would specify things such as the road maps to achieve, the directions, the ways how to achieve, these are the targets, these are the guidelines to achieve quality and quality parameters and how they should be regulated. They have come out with a draft policy. We too need to address these issues among is and discuss among our policy makers.

Bioethanol Fuel Quality and Downstream Marketing Constraints

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Abstract

Ethanol can be used directly as an alternative transportation fuel or as an octane enhancing component in petrol. Ethanol has to be anhydrous to blend with petrol even though 100% hydrous ethanol can be used in vehicles with modified engines. Ethanol/petrol blends up to 10 volume % ethanol in petrol (E10) can be used in existing petrol vehicles without making any changes to the engine or other vehicle components. However, when pure ethanol or blends having more than 10% ethanol is used as a transportation fuel, significant changes to the engine and vehicle fuel system are required for reliable operation. Flexible fuel vehicles (FFV) are capable of using blends up to 85% ethanol in petrol (E85) or even 100% petrol. When ethanol is added to petrol, it modifies the fuel properties of petrol and affects the nature and quantities of exhaust and evaporative emissions from vehicles. When fuelled with bioethanol E85, vehicles release emissions that are typically 50%-70% cleaner and decrease the fuel economy over using 100% petrol due to difference in the heating value between petrol and ethanol. The existing petrol fuelling systems can be used to store and dispense low ethanol/petrol blends however, for pure ethanol and higher range blends such as E85 only compatible materials have to be used. Because of the hygroscopic nature of ethanol, blending of petrol and bioethanol should be carried out either at regional bulk storage stations prior to distribution to the retail outlets or at the retail outlets using specially designed pumps.

The production of bioethanol is more expensive in many countries than the production of fossil fuels and therefore the growth and the sustainability of bioethanol sector depends on government subsidies in the use of bioethanol. Government support in countries that have emerged as bioethanol producer and user has been strong. Therefore, forward-thinking, supportive government policy and legislations, regulatory and trade framework conditions conducive to the growth of the fuel ethanol industry is important to any country to evolve as a fuel bioethanol consumer.

1. Introduction

Ethanol is an alkyl alcohol, with the chemical formula C_2H_5OH . Compared to petrol, which is a complex mix of hydrocarbons of various molecular weights and chemical structures, ethanol is a simple, discrete chemical compound. The presence of the oxygen atom in ethanol makes it a polar molecule and results in some significantly different properties compared to petrol.

Henry Ford designed the first mass-produced automobile, the famed Model T Ford, to run on pure anhydrous (ethanol) alcohol and also predicted that ethanol would be "the fuel of the future". Ethanol has been used as a motor fuel during the World War I and II when petroleum based fuels were not available. Then the use of ethanol declined mainly due to the high cost of production and not been able to be competitive with the price of petrol. However due to the Arab Oil Embargo in 1973 and in 1980's ethanol came into light as a fuel extender and also as a motor fuel.

Ethanol is produced both as a petrochemical, through the hydration of ethylene (synthetic ethanol), and biologically, by fermenting sugars de-

rived from plant materials with yeast and known as bioethanol. Bioethanol accounts for 95% of the world's ethanol production and this share is expected to increase in the future [1]. Bioethanol is an attractive alternative fuel because it is a renewable bio-based resource.

Today, bioethanol is the world's main biofuel and is now gaining a foothold in many regions across the world. Brazil was the largest producer, consumer and exporter of bioethanol for many years but as a result of the steps taken by the USA to reduce 75% of oil imports from Middle East by the year 2025, USA has exceeded Brazil in the production of bioethanol in 2007. In 2003, global production was double the level of a decade earlier, and from 2000 to 2005, production increased from 4.6 billion to 12.2 billion gallons. Table 1 shows the world production of fuel ethanol in 2007. This shows the world's interest in switching to alternative fuels especially for ethanol to cut down the dependence on fossil fuels and the concerns on the environmental pollution.

Table 1: 2007 World fuel ethanol production [2]

Country	Millions of Gallons
USA	6498.6
Brazil	5019.2
European Union	570.3
China	486.0
Canada	211.3
Thailand	79.2
Columbia	74.9
India	52.8
Central America	39.6
Australia	26.4
Turkey	15.8
Pakistan	9.2
Peru	7.9
Argentina	5.2
Paraguay	4.7
Total	13,101.7

Initially ethanol was used for energy security and fuel diversity reasons to minimize the dependence on petroleum based fuels. Later on its use was supported for its octane quality and for environmental reasons, since it affects some of the vehicle emissions in a positive manner [1, 3].

Ethanol can be blended into petrol and used in unmodified spark ignition vehicles. However, the intrinsic differences in chemical and physical properties between ethanol and the hydrocarbon components of petrol place constraints on the proportion of ethanol that can be successfully blended [4].

Pure ethanol and alcoholic beverages are highly excisable items and can only be produced at licensed distilleries. Generally ethanol that is used for other purposes including as a motor fuel are exempted from these taxes and made available at a lower cost. Therefore, this ethanol is denatured by adding various additives to render it unfit to drink.

2. Fuel Properties of Ethanol

Ethanol boils at 78.5°C, has a specific gravity of 0.7851 at 20°C, and is miscible in water and most organic liquids. Ethanol is miscible in water in all proportions however; separation in to water and ethanol has to be done with difficulty. Ethanol forms a constant-boiling mixture, or azeotrope, with water that contains 95.6% ethanol and 4.4% water and boils at 78.15°C. Since the boiling point of this binary azeotrope is below that of pure ethanol, absolute ethanol cannot be obtained by simple distillation. Therefore ethanol is produced in two forms: hydrous and anhydrous. Hydrous ethanol is the azeotropic mixture of ethanol and water while anhydrous ethanol is produced by further processing the above mixture.

Ethanol contains hydrogen carbon and oxygen in its chemical structure. The presence of oxygen in ethanol makes it a cleaner and more complete combustion fuel. This in turn helps the environment by reducing the mount of CO emitted.

Ethanol's hydroxyl group is able to participate in hydrogen bonding. At the molecular level, liquid ethanol consists of hydrogen-bonded pairs of ethanol molecules; this phenomenon renders ethanol more viscous and less volatile than less polar organic compounds of similar molecular weight. In the vapour phase, there is little hydrogen bonding; ethanol vapour consists of individual ethanol molecules [5].

Ethanol burns in air with a blue flame, forming carbon dioxide and water. It reacts with active metals to form the metal ethoxide and hydrogen (e.g., with sodium it forms sodium ethoxide). It reacts with certain acids to form esters (e.g., with acetic acid it forms ethyl acetate). It can be oxidized to form acetic acid and acetaldehyde.

Ethanol has good properties for use in spark ignition engines. It has a higher octane number, broader flammability limits and higher flame speeds. These properties allow for a higher compression ratio, shorter burn time and leaner burn engine, which lead to theoretical efficiency advantages over petrol in an internal combustion engine [6]. Pure ethanol is a much less volatile liquid than petrol and has a higher heat of vapourization than petrol. Hence cold starts can be a problem in 100% ethanol (E100) applications. However, this issue can be resolved through engine design and fuel formulation. Disadvantages of bioethanol include its lower energy density than petrol (bioethanol has 66% of the energy that petrol has), its corrosiveness, low flame luminosity, cold

starts problems, miscibility with water, and toxicity to ecosystems. Some properties of ethanol fuels and petrol [7] are given in Annexure 1 and a typical Material Safety Data Sheet (MSDS) for fuel ethanol [8] is given in Annexure 2. It has been found that ethanol petrol blends could successively combine the advantages of pure bio-ethanol and decreasing or eliminating the impact of its disadvantages in parallel.

3. Ethanol-Petrol Blend Properties

Ethanol can be used as an automotive fuel by itself and can be blended with petrol in various proportions. Hydrated ethanol is suitable for use as a straight spark ignition fuel in warm climates and anhydrous ethanol is used in blends. Various blends are in use as a motor fuel today; 10% ethanol (known as E10); 85% ethanol (known as E85) which requires particular vehicles known as 'Flexible Fuel Vehicles' (FFV); 20-24% ethanol (known as E22) which requires specific vehicle optimizations (re-calibration and component changes) and 100% ethanol (E100) requires vehicle technology dedicated to the fuel. Blends of E10 and E85 are used in many countries at present while E22 and E100 are used only in Brazil.

Increasing content of ethanol in a blend with petrol progressively alters the properties. Ethanol with high octane rating when mixed with petrol increases the octane value of the ethanol-petrol blend. As the octane number increases, ethanol-petrol blends improve antiknock properties allowing higher compression ratios and improved engine efficiencies [3]. Ethanol in blends acts as oxygenate and it has unique properties that cause petrol to burn more thoroughly, thereby improving combustion and reducing tailpipe carbon monoxide (CO) emissions. Because of the presence of oxygen in ethanol, blends require less air for the complete combustion. The stoichiometric air/fuel ratio (weight basis) for petrol is 14.7 whereas for E10 it is only 14 to 14.1 [3].

The volatility properties determine the evaporative emissions of the petrol, performance during engine start-up and overall driveability. Reid Vapour Pressure (RVP) is the vapour pressure of the fuel sealed in a metal chamber kept at 100°F in a water bath and is a measure of the tendency of a fuel to vapour lock. Ethanol increases the RVP of the blend when mixed with petrol, particularly at low concentrations, causing a marked increase in the vapour pressure of the host petrol. This has implications for vehicle operation and the resultant specification of fuel volatility. Ethanol also reduces the temperature at which the

vapour/liquid ratio of 20 (V/L_{20}) occurs. The temperatures to achieve V/L_{20} for ethanol petrol blend decreases with the increase of ethanol in the blend [9].

The heat of vapourization of ethanol is higher than that of petrol and therefore a blend of ethanol-petrol will also require more heat to vapourize than petrol. Generally a blend of E10 needs 16.5 % more heat to vapourize than does petrol [3]. This property leads to difficulty in starting engines particularly at low temperatures (known as cold start problem).

Due to the difference in polarity between ethanol and petrol, blends of the two can be unstable, particularly if water is present or at low temperatures, resulting in the blend separating into two phases, one rich in ethanol and the other rich in hydrocarbons [5]. Even moderate quantities of water can cause ethanol-petrol blends to separate into two phases, which can reduce engine performance necessitating a water-free blend supply and distribution system.

Further more ethanol is hygroscopic and easily picks up water from ambient air and in the distribution system and therefore water content of the denatured fuel ethanol must be limited when blended with petrol to reduce the risk of phase separation [10]. Phase separation is a phenomenon that occurs because of the solubility behaviour of petrol-alcohol-water tertiary systems. The solubility will vary with the ethanol content (higher ethanol blend has higher water tolerance), the temperature of the blend (at higher temperature has higher water tolerance), and the aromaticity of the base petrol (higher aromatic levels generally result in higher blend water tolerance). Fig 1. shows the liquid- liquid equilibria for the petrol-water-ethanol ternary system. This equilibrium depends on the temperature and the composition of the base petrol. At low temperatures, even small quantities of water present in an ethanol-petrol blend form direct hydrogen bonding between ethanol and water leading to phase separation. This phase separation can cause serious operating problems for normal spark-ignition engines [11]. The upper phase is rich in petrol will have a lower octane number and may knock in the engine, and the lower phase is composed of water, ethanol and the aromatic components of petrol soluble in ethanol. This lower ethanol-water layer if pumped into the engine can cause problems in fuel combustion and also may corrode the fuel tank and the engine.

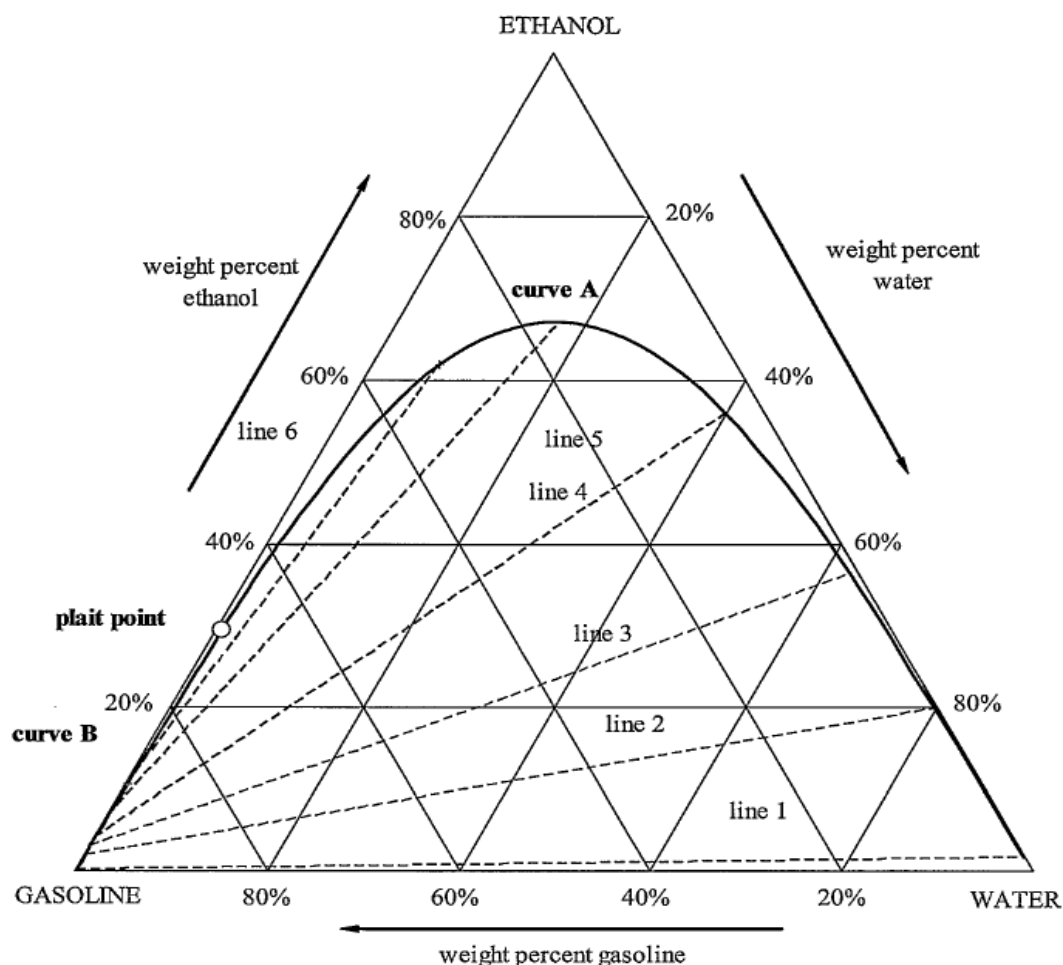


Figure 1 Ternary diagram for petrol-ethanol-water system at 20°C [12]

Researchers have been investigating water tolerances of ethanol petrol mixtures and the conditions under which phase separation can be prevented. Their work has the potential to make a radical change in the use of ethanol for mobility fuel.

Certain materials commonly used with petrol may be incompatible with high level alcohol blends. Some materials may degrade over time in the presence of high-level alcohol blends and contaminate the fuel, which may result in engine damage and poor performance. Soft metals such as zinc, brass, lead, and aluminium are some of the more sensitive metals and ethanol fuel may cause leaching of such soft metals. Non-metallic materials that degrade when in contact with fuel ethanol include natural rubber, polyurethane, cork gasket material, leather, polyvinyl chloride (PVC), polyamides, methyl-methacrylate plastics, and certain thermoplastic and thermoset polymers. Non-metallic materials that have been suc-

cessfully used for transferring and storing fuel ethanol include, thermoplastic piping and thermoset reinforced fiberglass tanks [7, 10, 13].

4. Fuel Specifications

Technical specifications will be required for both the blend and the ethanol used for blending. Anhydrous ethanol produced in the USA and Brazil for blending with petrol is subject to national specifications which focus on water content, corrosive contaminants such as chloride ion and copper, acidity, and specific gravity. These specifications reflect the desired properties of ethanol as a fuel component and the contaminants arising from ethanol manufacture. However, there are no international standards making it difficult for biofuels to reach the global market. Therefore mandating fuel ethanol standard is an important factor in assuring that bioethanol are of the required quality.

The quality requirements for fuel grade ethanol vary depending on the application it is used in. The market for fuel grade ethanol in many countries is currently aimed at use as a blend stock/extender to petrol up to the 10% level. As other applications arise, such as higher blends for flexible fuel vehicles, it may be necessary to review the standard or establish new standards to cover these applications.

Except Brazil, most countries use high purity anhydrous ethanol as a frame of reference when setting a fuel ethanol standard. The primary US fuel ethanol standards are set out in two ASTM standards – ASTM D 4806 for Denatured Fuel Ethanol for blending with petrol for use as automotive spark ignition engine fuel and ASTM D 5798 for Fuel Ethanol suitable for specially designed vehicles as a petrol substitute. ASTM specifications for denatured ethanol and fuel ethanol are given in Annexure 3 & 4 respectively [10]. Proposed Australian fuel ethanol standard takes ASTM 4806 as a base to be adapted where necessary to suit Australian conditions [14]. Poland also use national standards for anhydrous ethanol used in fuel based on the US ASTM 4806.

Brazil follows their national specifications for hydrous and anhydrous ethanol set by the National Petroleum Agency of Brazil and India has Indian standard “IS15464:2004 for Anhydrous Ethanol for Use in Automotive Fuel Specifications” [10]. The European standard for ethanol is currently being prepared and is expected to be adopted in 2008. In Sweden, the fuel producer SEKAB sales specification for anhydrous ethanol 99.5% is serving as the industry standard at the moment.

The use of different standards has led to some discrepancies in certain important parameters. Therefore mandating global fuel standards is an important factor in assuring that fuel ethanol are of the required quality especially in the world trade of bioethanol.

5. Fuel Economy

The heating value of petrol is 31.2 MJ/litre while the heating value of ethanol is 21.2 MJ/litre and ethanol has only 67% of the volumetric energy content of petrol [15]. This difference in heating values between petrol and ethanol results in a theoretical decrease in fuel economy for ethanol-petrol blends when compared to 100% petrol.

Ethanol produces a greater volume of gases per

unit of energy burned than petrol because of its higher hydrogen to carbon ratio. This leads to higher mean cylinder pressures and more work performed during the power stroke. Ethanol also has a much higher heat of vapourization than petrol. As the liquid fuel evaporates in the air stream being charged to the engine, the high heat of vapourization cools the air, allowing more mass to be drawn into the cylinder. This could increase fuel consumption by about 2-3 % and the power produced from a given engine size. Therefore, when a 10 % ethanol blend containing about 97 % of the energy of 100% petrol is burned in a petrol-optimized engine, the combined effect of combustion products and the charge-air cooling will result in an efficiency increase of about 1 to 2 % [3]. This increases the gap between the theoretical and the actual decrease in fuel economy hence the overall practical fuel economy for E10 is expected to be very small compared to petrol. However, as the amount of ethanol is increased in the blend the actual fuel economy will be reduced.

To overcome the fuel deficiency in ethanol, engines are being designed that take advantage of the high-octane benefits of ethanol while increasing fuel efficiency. Internal combustion engines optimized for operation on alcohol fuels are 20 % more energy-efficient than when operated on petrol, and an engine designed specifically to run on ethanol can be 30 % more efficient.

6. Flexible Fuel Vehicles

All vehicles that are manufactured after 1980's can use E10 safely and auto manufacturers recommend the use of E10 in those engines. However, these vehicles are not suitable to run with ethanol containing more than 10 % in petrol. Therefore, flexible fuel vehicles (FFVs) that can run on petrol or E85 fuel (85% ethanol by volume) or any blend of ethanol and petrol from 0% to 85% ethanol have been developed. The main differences between ethanol FFVs and petrol vehicles are the materials used in the fuel management system and modifications to the engine calibration system [10]. Brazilian FFV's are not designed to run on straight petrol but on either E100 (hydrous ethanol) and E22 (22 % ethanol and 78 % petrol) or any mixtures of the two. However a car running on water-free (anhydrous) ethanol will still (even with the better volumetric efficiency) have a higher mileage per litre than one running on hydrous ethanol. If the cost of the hydrous ethanol is sufficiently low it may, however, still provide a lower cost per mile travelled [16].

7. Environmental Benefits

Emissions from engines can be of two types: evaporative and exhaustive emissions. A vehicle may have different exhaust emissions characteristics when operating on ethanol petrol blend instead of petrol primarily because of the shift in the air-fuel ratio, and due to the presence of ethanol in the fuel. The exhaust from ethanol-petrol blends reduces carbon monoxide (CO); hydrocarbons (HCs); particulate matter; and certain known carcinogens, but may increase acetaldehyde and NOx emissions [17]. Ethanol-petrol blends when compared to petrol increase the evaporative emissions because of the high volatility and the depression of the distillation curve the blend [3].

Relative to petrol, ethanol fuels reduce greenhouse gas (GHG) emissions that contribute to climate change. The amount of reduction depends on the type of feedstock and the ethanol production process. Bioethanol is made from plants, which absorb carbon dioxide (CO₂) during their growth. On a full fuel cycle 10% ethanol-petrol blend reduces GHG emissions by up to 4 % if the ethanol is made from grains, and up to 8 % if it is made from cellulosic biomass. Blends with 85 % ethanol can reduce CO₂ emissions by 50-70% when used in FFV's [18].

8. Safety Issues

Like petrol, fuel ethanol is flammable, poisonous, and may contain additives that are harmful, even in casual contact. Exposure to fuel ethanol can occur by inhalation of vapour, getting it on the skin or in the eyes (skin adsorption), or accidentally swallowing it (ingestion) [19]. Therefore care must be taken in transportation and handling of ethanol just as done for other fuels.

Spills and fires involving E85 and other ethanol-petrol blends containing more than 10% ethanol should be treated differently than traditional petrol spills and fires. These mixtures are polar/water miscible flammable liquids and will degrade the effectiveness of fire fighting foam which is not alcohol resistant. Therefore alcohol resistant foam should be used to fight fires involving these fuel mixtures [19, 20]. Since ethanol is an organic product, should there be a spill, it will biodegrade more quickly and easily than petrol.

9. Downstream Marketing Constraints

Constraints surrounding the trade of ethanol can be of technical and economic constraints.

9.1 Technical Constraints

Handling, blending, storing and dispensing of fuel ethanol encounter technical problems. Components and equipment used for storing & dispensing conventional motor fuels do not have adequate compatibility with many of the new motor fuels, such as ethanol-petrol blends. The technology for storing and dispensing petrol can be applied to alcohol fuels such as E85 because alcohols and alcohol blends, like petrol, are liquid fuels at ambient pressures and temperatures. However, as mentioned earlier in this paper, only ethanol compatible materials should be used in the storage and dispensing systems. Consequently, choosing the right materials for fuel storage and dispensing systems and following proper fuel handling procedures are crucial for successfully operating ethanol-fuelled vehicles [13, 19]. "Handbook for Handling, Storing and Dispensing E85" [19] gives a comprehensive detail of the materials suitable for storage tanks, dispensers, nozzles, hoses piping etc.

To avoid potential problems with water and the risk of phase separation in the distribution and storage systems, all the systems must be kept dry and also neither ethanol nor ethanol-petrol blends may be transported by pipelines. Blending of ethanol and petrol to the required specification is matter of concern. There had been number of complains on retailing under specified fuel ethanol in the USA. At present blending is done mostly by "splash blending" to the final specification at distribution and storage terminals instead of at the refinery [21]. Ethanol blends are then transported by truck from terminals to retail service stations. Recently blender pumps in which the blending of the ethanol and petrol is done at the time of dispensing according percentage of the blend required have been introduced to the petrol retailers [22].

9.2 Economical constraints

Cost of ethanol is the major economic barrier in marketing fuel ethanol. Cost of production of ethanol in many countries is higher than the price of ethanol. However, number of countries has succeeded in fuel ethanol programs. Experience from those countries shows that active

government involvement is important for the development of biofuel programmes. Valuable lessons can be drawn from Brazil United States Sweden and Germany.

Biofuels are near the top of development agenda in Brazil. With the establishment of PROALCOHOL program in 1975 Brazil promoted petrol replacement with ethanol and various subsidies and tax reductions made the ethanol option highly attractive to consumers. Beginning in the 1970s, every gas station in Brazil was required to have at least one ethanol pump and the government mandated that all petrol be mixed with ethanol. Soft loans by the government funded the introduction of alcohol vehicles fuelled with hydrated ethanol. The United States has been active for some time. Congress and a number of States have provided robust support for biofuel development. Virtually every candidate for U.S. presidency has supported ethanol, and its federal tax incentive. Germany has become a leader in high-technology biofuel production, due to strong government commitment, viable policy and solid collaboration from the private sector. In 2002 the German Parliament decided to exempt all biofuels from the petrol tax and the exemption is in force only until the end of 2009 [23].

Countries like Sri Lanka with 0% fuel bioethanol in the market will have to consider their own situations, since the experiences of others may not be easily replicable where conditions may differ. However, strong government commitment, policy support, subsidies and tax incentive schemes are extremely important for the entry of bioethanol into the market as a motor fuel.

Consumer attitudes about fuel prices, relative fuel performance, bioethanol-capable vehicles, and the environment will affect the volume of bioethanol sold. Price, availability, and familiarity are the primary attributes by which many consumers judge the value of fuels. In most countries the cost of production of ethanol is higher than the price of petrol but tax reductions have made the ethanol option highly attractive to consumers.

10. Sri Lankan Perspectives

At present the total petrol consumption in Sri Lanka is about 500 million litres per annum and the production of ethanol is about 12 million litres per annum. Considering only the heat capacity, the existing ethanol can be used to replace about 8 million litres of petrol annually if all the ethanol is blended with petrol. This is a huge saving of foreign revenue at the present price of crude oil.

Sri Lanka can embark in fuel ethanol programme even with the existing ethanol by introducing fuel ethanol as an octane enhancer and also as an oxygenate like many countries in the world have done initially. This ethanol is sufficient to blend with petrol to make about 40% of the E5 requirement in the country. At the start E5 blends can be made available in selected regions in the country by following the method adopted by other countries. In order to establish a market for bioethanol functional bioethanol station grids and effective bioethanol supply has to be implemented.

In order to do this strong government commitment is required. Government policies, favourable tax and incentive schemes will significantly support the market breakthrough for bioethanol in the country. At the onset, fuelling of Government vehicle feet with E5 would break the myth and various concerns regarding the use of ethanol. This was practised in many countries like Brazil, UK and Sweden and has proven to be worked well.

11. Conclusion

Technological advances have made the production and utilization of ethanol blends in a more profitable and user friendly manner. Experience and evidence from other countries show that the use of ethanol blends gives triple benefits: energy security, less vehicle emissions and money saving. Cost of ethanol is the main barrier in marketing and therefore governmental support is required for the success of the fuel ethanol programs.

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Annex 1

Properties of ethanol compared with gasoline

Fuel property	Ethanol	Gasoline
Formula	C ₂ H ₅ OH	C ₄ to C ₁₂
Molecular weight	46.07	100–105
Density, kg/l, 15/15 °C	0.79	0.69–0.79
Specific gravity (Relative density), 15/15 °C	106–110	91
Freezing point, °C	–114	–40
Boiling point, °C	78	27–225
Vapor pressure, kPa at 38 °C	15.9	48–103
Specific heat, kJ/kg K	2.4	2.0
Viscosity, mPa s at 20 °C	1.19	0.37–0.44
Lower heating value, 1000 kJ/L	21.1	30–33
Flash point, °C	13	–43
Auto-ignition temperature, °C	423	257
Flammability limits, Vol %		
Lower	4.3	1.4
Higher	19.0	7.6
Stoichiometric air–fuel ratio, weight	9.0	14.7
Octane number		
Research	108.6	88–100
Motor	89.7	80–90

Annex 2

MATERIAL SAFETY DATA SHEET FUEL ETHANOL

May be used to comply with OSHA's Hazard Communication Standard, 29 CFR 1910.1200. Standard must be consulted for specific requirements.	U.S. Department of Labor Occupational Safety and Health Administration (Non-Mandatory Form) Form Approved OMB No. 1218-0072
IDENTITY (As Used on Label and List) FUEL ETHANOL	Note: Blank spaces are not permitted. If any item is not applicable, or no information is available, the space must be marked to indicate that.

SECTION I

MANUFACTURER'S NAME Archer Daniels Midland Company	EMERGENCY TELEPHONE NUMBER Chemtrec – 800-424-9300
ADDRESS 4666 Faries Parkway Decatur, IL 62526	TELEPHONE NUMBER FOR INFORMATION 217-362-3980
SIGNATURE OF PREPARER (optional)	DATE PREPARED 1/15/98

SECTION II HAZARDOUS INGREDIENTS/IDENTITY INFORMATION

Hazardous Components (Special Chemical Identity; Common Name(s))	OSHA PEL	ACGIH TLV	Other Limits Recommended	% (optional)
Natural Gasoline CAS 008-006-619				5%
Ethyl Alcohol (200 proof) CAS 0064-17-5				95%
*Benzene CAS-0071-43-2	1 ppm	10 ppm		< 1100 ppm
**A chemical known to the State of California to cause cancer				

SECTION III PHYSICAL/CHEMICAL CHARACTERISTICS

BOILING POINT (°F)	165-175	SPECIFIC GRAVITY (H ₂ O = 1) AT 60° F	.0789
VAPOR PRESSURE (mm Hg.) at 20°C	96	MELTING POINT	NA
VAPOR DENSITY (AIR = 1) AT 78°C	1.6	EVAPORATION RATE (Butyl Acetate = 1)	3.2
SOLUBILITY IN WATER	Complete		
APPEARANCE AND ODOR Colorless mobile liquid; characteristic odor			

SECTION IV FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (Method used) Minus -5°F, Tag Open Cup	FLAMMABLE LIMITS	LEL 3.3	UEL 19.0
EXTINGUISHING MEDIA CO₂ dry chemical or water for small fires. Polar solvent foam or large quantities of water for large fires.			
SPECIAL FIRE FIGHTING PROCEDURES None. Water is not effective until the alcohol contains approx. 80% water.			
UNUSUAL FIRE AND EXPLOSION HAZARDS Flammable liquid.			

SECTION V REACTIVITY DATA

STABILITY	UNSTABLE STABLE X	CONDITIONS TO AVOID None in normal use
INCOMPATIBILITY (Materials to avoid) Strong oxidizers		
HAZARDOUS DECOMPOSITION PRODUCTS Aldehydes, carbon monoxide		
HAZARDOUS POLYMERIZATION	MAY OCCUR WILL NOT OCCUR X	CONDITIONS TO AVOID None in normal use

MATERIAL SAFETY DATA SHEET FUEL ETHANOL

SECTION VI HEALTH HAZARD DATA

ROUTE(S) OF ENTRY:	INHALATION?	SKIN?	INGESTION?
	(A)	(B)	(C)
HEALTH HAZARDS (<i>Acute and Chronic</i>)			
(A) unconsciousness; coma, respiratory failure & death			
(B) removes natural oils & fats from skin			
(C) moderately toxic (LD50 > 5 Gm. / KG)			
CARCINOGENICITY:	NTP?	IARC Monographs?	OSHA Regulated?
	Not determined	Not determined	Yes
SIGNS AND SYMPTOMS OF EXPOSURE May cause dizziness, loss of balance and coordination.			
MEDICAL CONDITIONS Generally aggravated by exposure Not determined			
EMERGENCY AND FIRST AID PROCEDURES If swallowed, induce vomiting. If inhaled, remove person to fresh air. If breathing has stopped, give artificial respiration. Call a physician. If splashed in eyes or on skin, flush immediately with copious amounts of water.			

SECTION VII PRECAUTIONS FOR SAFE HANDLING AND USE

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED Eliminate all sources of ignition. Small spills should be flushed with large quantities of water. Large spills should be collected for waste disposal.
WASTE DISPOSAL METHOD Do not allow to enter sewers where vapors may become ignited. Incinerate in a furnace where permitted under appropriate federal, state & local regulations or dispose of in a site stipulated for hazardous materials.
PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING Keep away from heat, sparks & open flames. Keep contained closed. Use with adequate ventilation.
OTHER PRECAUTIONS Use explosion-proof electrical equipment and non-sparking tools. Ground electrical equipment.

SECTION VIII CONTROL MEASURES

RESPIRATORY PROTECTION (<i>Specify Type</i>) Air-supplied mask for high concentrations.			
VENTILATION	LOCAL EXHAUST	Preferred	SPECIAL
	MECHANICAL (<i>General</i>)	Acceptable	OTHER
PROTECTIVE GLOVES Rubber			EYE PROTECTION Goggles
OTHER PROTECTIVE CLOTHING OR EQUIPMENT Eye bath and safety shower			
WORK/HYGIENIC PRACTICES NA			

Annex-3

ASTM D 4806 Standard Specification for Denatured Fuel Ethanol

Property	Specification	ASTM Test Method
Ethanol, vol%. Min	92.1	D 5501
Methanol, vol% max.	0.5	
Solvent-washed gum, mg/100 ml max	5.0	D 381
Water content, vol% max.	1.0	E 203
Denaturant content, Vol% min Vol% max	1.96 4.76	
Inorganic Chloride content, mass ppm (mg/L) max	40	D 512
Copper content, mg/kg max.	0.1	D 1688
Acidity (as acetic acid CH ₃ COOH), mass% max	0.007	D 1613
pHe	6.5 – 9.0	D 6423
Appearance	Visibly free of suspended or precipitated contaminants (Bright & Clear)	

Annex– 4

ASTM D 5798 Standard Specification for Fuel Ethanol (Ed75–Ed85)

Property	Specification	ASTM Test Method
Ethanol + higher alcohols vol% minimum	70 – 79 ¹	D 5501
Hydrocarbon vol% ²	17-30 ¹	D 4815
Vapor Pressure, kPa	38-83 ¹	D4953 / 5190 / 5191
Lead, max, mg/l	2.6-3.9 ¹	D 5059
Phosphorus, max, mg/l	0.2-0.4 ¹	D 3231
Sulfur, mg/kg , max ⁴	210-300 ¹	D 1266 / 2622 / 3120 / 5453
Methanol, vol%, max	0.5	D 4815
Higher Alcohols (C ₃ -C ₈) vol%, max	2	D 4815
Acidity (as acetic acid), mass% (mg/l), max	0.005 (40)	D 1613
Solvent-washed gum Content mg/100 ml, max	5	D 381
pHe	6.5 – 9.0	D 6423
Unwashed gum content, mg/100 ml, max	20	D 381
Total chlorine as chlorides, mg/kg, max	2	D 4929 B
Inorganic chloride, mg/kg, max	1	D 512 / 2988
Copper, mg/l, max	0.07	D 1688 modified
Water, mass%, max	1.0	E 203 / E 1064
Appearance @ higher of ambient temperature or 21°C	Visibly free of suspended or precipitated contaminants (clear & bright)	

13. Discussion

Dr. Nanditha Hettiarachchi

This is about the phase separation of the liquids. Of the pictures you showed, how long does it take for the samples that were developed in your labs?

Dr. Sanja Gunawardena

1 day.

Dr. Nanditha Hettiarachchi

In your phase diagram with a triangle, it shows that it is for 24°C. It is Brazilian experience. In our context what will happen?

Dr. Sanja Gunawardena

As our temperatures are higher than them, we are in a better position. The curve will come further down.

Prof. S A Kulasooriya

On government and political support, I think you should put making land available for cultivation of feedstock as the first bullet point. Most of my private sector colleagues will agree with me that the real limitation to get enough feedstock grown in Sri Lanka is non-availability of land. By law, a private individual can own only upto 50 acres. So if we are thinking of whether it is Sugarcane, Jatropha, Pongamia or any other feedstock plantation, we need more land and all that land belongs to the government. Making land available on what ever conditions for cultivation of feedstock is required.

Md. L Rahman

You said Sweden is the major & highest consumer of Ethanol in the EU countries. You said major petrol pump stations have to sell Ethanol as well as Biogas. Is Biogas commercially saleable there?

Mr. Xavier Johnson

You can get Biogas, but it is not available everywhere. In certain municipalities where they have biogas plants, they have stations for cars and buses. Buses in many cities run either on Ethanol or Biogas. Except for small stations, most petrol stations have Ethanol. Because of tax, it is much cheaper.

Mr. S H Malik

Regarding the government and political support, I like to know about the legal environment. What is the specification of petrol and diesel fixed in Sri Lanka? Can you blend it now? Does law permit or you need any changes in law? Similarly, are there any specifications for motor vehicles?

Dr. Sanja Gunawardena

At present we are not blending. I think it is not allowed by law. Even Mr. Ambegoa, (Secretary to the Sri Lanka's Ministry of Petroleum and Petroleum Resource Development) asked if we produce Biodiesel, how to blend, how to market and how to sell.

Mr. Anwar Sadat

You said when Ethanol is blended with gasoline; its Octane number is reduced by 1 to 3. When the Octane number reduces, at the same time, it creases the engine knocking and reduces engine efficiency. In a commercial operation, what will be the impact? On one side you blend and reduce costs and on the other you also reduce the engine efficiency.

Dr. Sanja Gunawardena

The reduction happens when there is a phase separation. But because of blending, if there is a phase separation (if water layer separate), then ethanol moves into the water layer. But Octane number reduces if there is phase separation and not because of blending.

E. Applications

Biodiesel and Bio Ethanol Usage in IC Engines and Other Uses

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University of Ruhuna, Sri Lanka*

Abstract

Petroleum-based fuels are obtained from limited reserves which are highly concentrated in certain regions of the world. Therefore, those countries not having these resources are facing energy/foreign exchange crisis, mainly due to the import of crude petroleum. Hence, it is necessary to look for alternative fuels which can be produced from resources available locally within the country such as alcohol, biodiesel, vegetable oils etc.

Ethanol is an attractive alternative fuel because it is a renewable bio-based resource. Blends of ethanol and gasoline have been successfully used in gasoline engines. Since it is oxygenated, it has the potential to reduce particulate emissions in diesel engines also.

Biodiesel is methyl or ethyl ester of fatty acids made from virgin or used vegetable oils (both edible and non-edible) and animal fat. Just like petroleum diesel, biodiesel operates in compression ignition (CI) engines, and require very little or no engine modifications because biodiesel has properties closer to mineral diesel. It can be stored just like mineral diesel and hence does not require separate infrastructure. Biodiesel can be blended in any proportion with mineral diesel to create a biodiesel blend or can be used in its pure form. The use of biodiesel in conventional diesel engines results in substantial reduction in emission of unburned hydrocarbons, carbon monoxide and particulates.

This paper focuses on performance and exhaust emission of internal combustion (IC) engines when run on biodiesel and bio ethanol.

1. Introduction

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground-based carbon resources. The search for alternative fuels, which promise a harmonious correlation with sustainable development, energy conservation, efficiency and environmental preservation, has become highly pronounced in the present context. The fuels of bio-origin can provide a feasible solution to this worldwide petroleum crisis. Gasoline and diesel-driven automobiles are the major sources

2. Ethanol in Gasoline Engines

Blends of ethanol in gasoline are commonly used in vehicles designed to operate on gasoline; however, vehicle modification is required for alcohol fueling because its properties are different from those of gasoline. Ethanol has low stoichiometric air-fuel ratio and high heat of vaporization that requires carburetor re-calibration and increased heating of the air-fuel mixture to provide satisfactory driveability [1]. In order to make alcohol engines more practical, functional, durable, and economical, engineers have made several changes in the regular gasoline engines. These included

the following: [2]

- Since alcohol does not evaporate as easily as gasoline, the intake manifold had to be redesigned to provide more heating for evaporation
- The carburetor was regulated in order to change the air/fuel proportions
- The Tin and Lead coating of the fuel tank was changed to pure Tin
- The fuel lines (Zinc steel alloy) were changed to Cadmium Brass
- The fuel-filtering system was changed and re-dimensioned in order to allow greater fuel flow rates
- In order to take advantage of the alcohol's much higher Octane rating, the compression ratio was increased to about 12:1
- The valve housings, made of Cast-Iron, were changed to an Iron-Cobalt synthetic alloy. This also is compensated for the lack of lubrication resulting from the absence of Lead in the fuel.
- The catalytic converter's catalyst was changed from Palladium and Rhodium to Palladium and Molybdenum, helping further reduction of the alcohol engine emissions

The use of ethanol in gasoline engines in the early 1980s resulted in numerous materials compatibil-

ity studies, many of which are also applicable to the effect of ethanol–diesel blends in diesel engines and particularly in the fuel injection system. The quality of the ethanol has a strong influence on its corrosive effects. However, if a blend has been standing in a tank for sufficient time to allow the ethanol to absorb moisture from the atmosphere, it may tend to be more corrosive as it passes through the fuel injection system [3]. In addition, the fuel may stand in the fuel injection pump for a number of months, thus allowing the fuel enough time to corrode parts of the pump internally. Corrosion inhibitors have been incorporated in some additive packages used with ethanol–diesel blends. Nonmetallic components have also been affected by ethanol with particular reference to elastomeric components such as seals and O-rings in the fuel injection system. These seals tend to swell and stiffen. Resin-bonded or resin-sealed components also are susceptible to swelling and seals may be compromised.

3. Bio Ethanol experience of Brazil

Ethanol use in Brazil as a motor fuel has been largely promoted since the two oil shocks of the 1970s, either as a gasoline additive (anhydrous ethanol) or as a gasoline substitute (hydrated ethanol). As of today, the uncertainties in the international oil markets, the methyl tertiary butyl ether (MTBE) ban in the US and the growing concerns with global climate change, all justify the quest for a new role to be played by ethanol worldwide. The current prevailing view sees ethanol as a real threat to gasoline and, eventually, to oil itself. If Otto engines at compression ratios found in diesel engines are promoted, then E30 could become a suitable strategy for spreading the use of ethanol fuel in large volumes and also for saving gasoline. [4]

In 2006, the world market for ethanol fuel totaled 51 billion liters, with the two major producers being Brazil and the US, outputting 17 and 20 billion liters each, respectively, as shown in Figure 1.

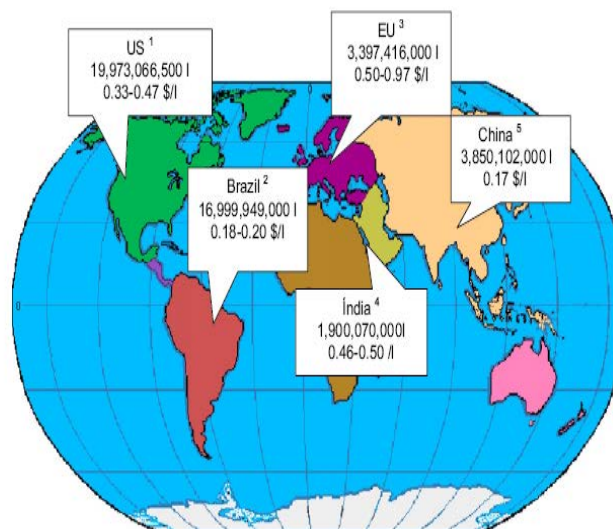


Figure 1. Ethanol motor fuel production costs

Source: (1) RFA, 2007; (2) RFA, 2007; (3) RFA 2007 and Hill and Glenn, 2007; (4) RFA, 2007; (5) ACFA, 2007. Note: World Ethanol Production in 2006: 51 billion liters

In the last two decades, productivity gains in the Brazilian ethanol industry averaged 33% in the agricultural phase and 14% in the industrial phase. Technological and technical advances in the agricultural phase include higher yield, more resistant sugarcane varieties and improved management practices in the field, and in the industrial phase include an increase in the mill's standard average capacity from 5.5 to 13.0 tons of sugarcane per day, the reduction of the fermentation duration time from 24 to 4–6 hr, and the improvement of boilers' efficiency from 66% to 87% [3]. The flex-fuel technology in Brazil gives users a freedom of choice, whether to use only hydrated alcohol or gasoline in their cars, or a mixture of these fuels in any concentration [5].

At the typical Brazilian average temperature of around 24 °C, the diagram of phases of ethanol–water–pure gasoline (Figure 2) shows two regions for the possible mixtures: one region where there is no phase separation, and another region where two phases are formed and separated: an upper ethanol-deficient gasoline layer and a lower ethanol rich water layer. After phase separation, the gasoline layer will have a lower octane number and may knock in the engine. The resulting fuel is also less volatile and the engine will not run on the water/ethanol layer. Finally, the ethanol–water layer can corrode the tank. In Figure 2, the dotted line represents quite well the Brazilian situation (gasohol E20–25). In this case, phase separation never takes place.[4]

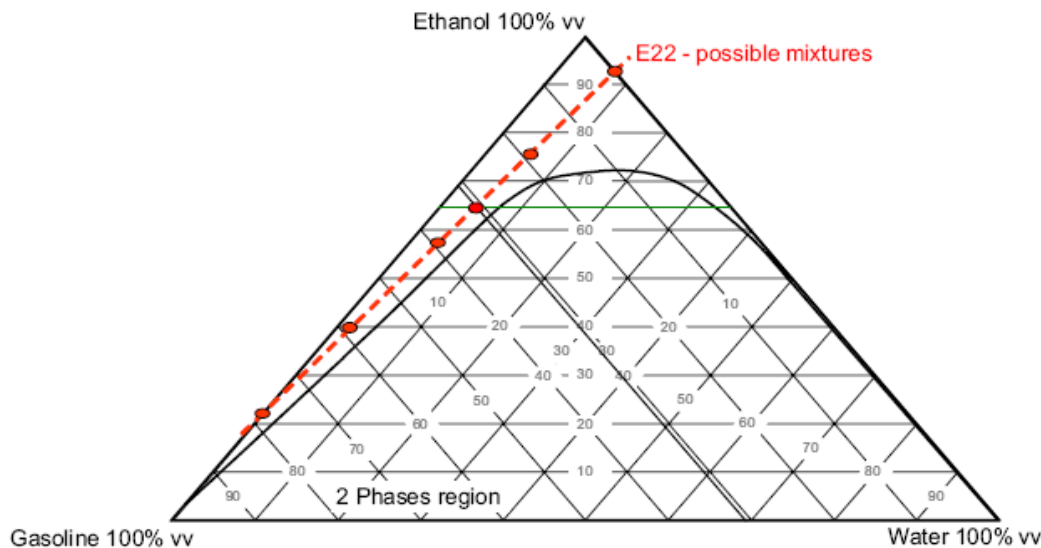


Figure 2 Diagram of phases (liquid–liquid equilibria ethanol of ethanol–water and pure gasoline at 24 °C).

Note: The red curve corresponds to gasohol E22. (Reproduced from [4])

4. Ethanol in Gasoline Engines

The effects of ethanol and gasoline blends on spark ignition engine emissions were investigated by Hsieh et al., [6]. In their study, test fuels were prepared using 99.9% pure ethanol and gasoline blended with the volumetric ratios of 0–30% (E0, E5, E10, E20 and E30). These percentages represent the ratios of ethanol amount in total blends. In the experiments performed at different throttle openings and engine speeds, nearly the same torque values were obtained when used different ratios of ethanol–gasoline blends compared with pure gasoline. Only the torque values obtained using E5 and E30 blends were lower than that of pure gasoline (E0) especially at high engine speeds (after 4,000 rpm) and partly opened throttle in 20%.

The effects of nine different volumetric percentages of ethanol–gasoline blends, ranging from 10% to 40%, on engine emissions were tested with six different cars which were manufactured between 1990 and 1992. In the experiments, linear variations of emissions were observed with respect to ethanol percentage. In the highest ethanol percentage which is 42%, the Hydrocarbons (HC) and CO emissions decreased by about 30% and 50%, respectively, and the fuel consumption was increased approximately by 15% [6]. The effects of gasoline blends containing Oxygen on emissions were tested with six cars manufactured in European countries. The experiments were performed on chassis dynamometer using ECE

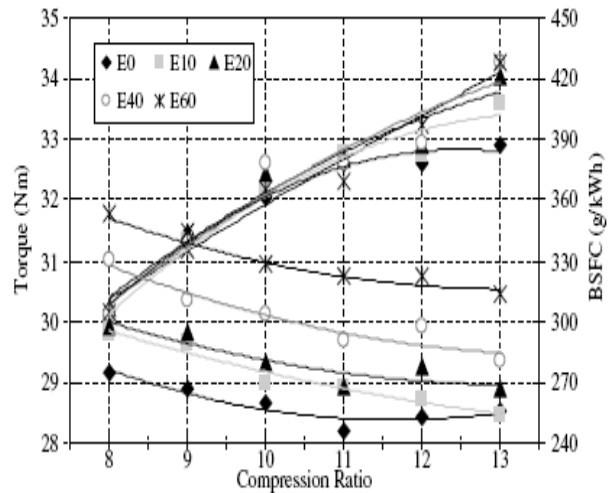
cruise cycle. In the cycle 10% MTBE, 15% MTBE and 5.2% ethanol were used as fuel, the CO emissions, HC emissions and NO_x emissions decreased by 15–30%, 10–20% and 1.3–1.7% respectively [7]. The effect of alcohol and gasoline blends contained by mass ratio of 1.25%, 2.5%, 3.75% and 5% oxygen on engine emissions was investigated experimentally by Taylor et al. [8]. Methanol, ethanol, i-propanol and n-propanol were used as fuel. When using alcohol and gasoline blends contained by mass ratio of 5% oxygen, the emissions of HC and CO decreased by 40% and 75%, respectively. Cowart et al. used methanol M85 and ethanol E85 as fuels [9]. When alcohols blended fuels were used, the engine performance increased. The engine torque and power increased with both the fuels M85 and E85 by 7% and 4%, respectively. Hydrogen, ethanol and gasoline blends were examined in a four stroke spark ignition engine [10]. In the experiments, ethanol blended gasoline in volumetric ratios ranging from 0% to 30% and hydrogen were added to the blend in mass ratios ranging from 0% to 20%. The addition of 8% of hydrogen with 30% of ethanol into a gasoline engine operating at nine compression ratios and 1,500 rpm causes a 48.5% reduction in CO emission, 31.1% reduction in NO_x emission and 58.5% reduction in specific fuel consumption. The engine power and thermal efficiency were increased by 4.72% and 10.1%, respectively. When ethanol was added to gasoline, NO_x and CO emissions decreased and specific fuel consumption increased. When hydrogen was added to the blend, CO emission decreased and

NO_x emission increased. In addition, thermal efficiency increased and specific fuel consumption decreased.

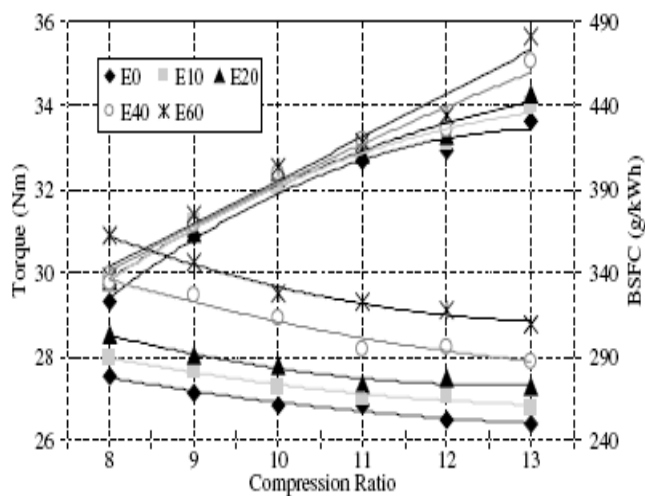
Effect of ethanol and unleaded gasoline blends on engine performance was investigated by Al-Hasan [11]. Ten different ethanol-gasoline blends were prepared for the experiments. The ethanol amount in the blend was in the range of 0–25% and the percentage of ethanol was increased by 2.5% in each blend. The ethanol was 99% pure. The results obtained from the experimental studies showed that the engine emissions and performance were improved. The engine power, brake thermal efficiency and volumetric efficiency were increased by 8.3%, 9% and 7% mean average values, respectively when the ethanol blended fuels were used. In addition brake specific fuel consumption decrease by 2.4% and equivalence air fuel ratio decrease by about 3.7%. The blends had positive influence on exhaust emissions. The CO and HC emissions decreased by 46.5% and 24.3%, respectively. The CO₂ increased by 7.5% nearly. The best performance and emissions results were obtained for 20% ethanol 80% unleaded gasoline blend.

The effects of gasoline ethanol blends and compression ratio on engine performance were investigated [12]. In the experiment 10%, 20% and 30% ethanol-gasoline blends were used as fuel. Optimum compression ratio which obtained maximum indicated power was determined for each blend. For the 10%, 20% and 30% ethanol-gasoline blends, the optimum compression ratios of 8, 10 and 12 were obtained. Wu et al. [13] investigated the effect of air-fuel ratio on Spark Ignition (SI) engine performance and pollutant emissions using ethanol-gasoline blends. The result of engine performance tests showed that torque output improves when using ethanol-gasoline blends. However, there is no appreciable difference on the brake specific heat consumption. CO and HC emissions reduced with the increase of ethanol content in the blended fuel. Their study found out that using 10% ethanol fuel can reduce pollutant emission efficiently.

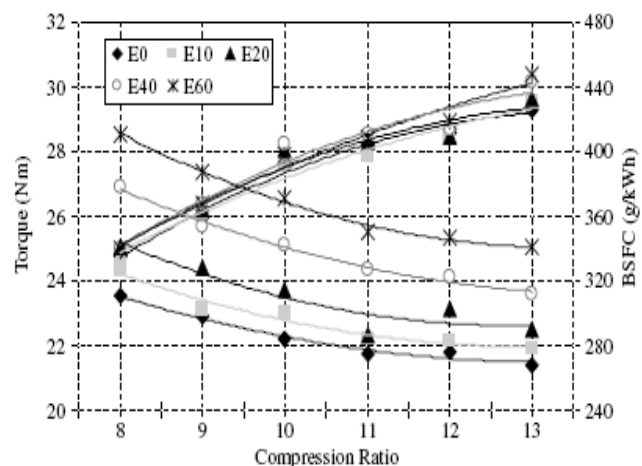
Experiments were performed at three different engine speeds which were 2,000, 3,500 and 5,000 rpm and with wide open throttle. The aim of this work was to clarify best working conditions at different compression ratios [6]. Figure 3 shows the variation of torque and brake specific fuel consumption (BSFC) at various compression ratios for the different blends of fuel.



(a) Engine Speed : 2,000 rpm



(b) Engine speed: 3,500 rpm



(c) Compression ratio: 5,000 rpm

Figure 3 Variation of BSFC and engine torque versus compression ratio at different speeds [6]

Figure 4 shows the Variation of detonated ignition timing versus compression ratio at the engine speed of 2,000 rpm.

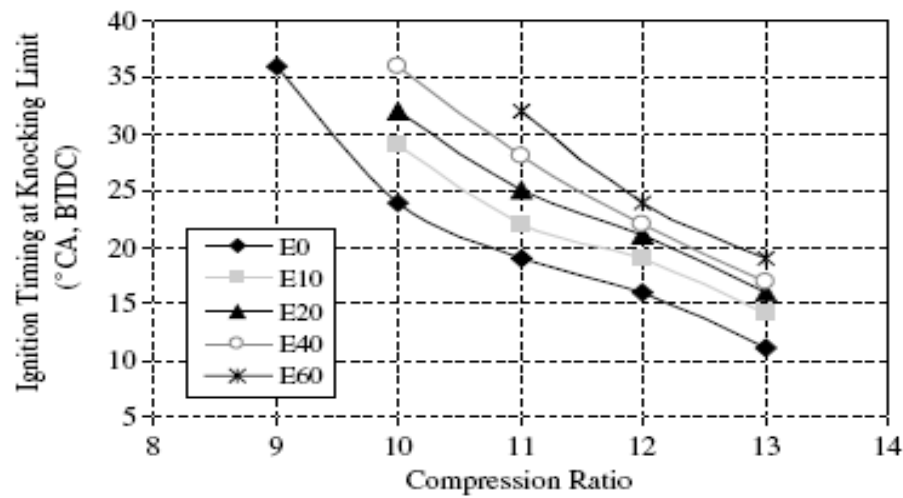


Figure 4 Variation of detonated ignition timing versus compression ratio (engine speed: 2,000 rpm).[6]

Figure 5 shows the variation of CO emission versus compression ratio for different blends of gasoline and ethanol. Variation of HC emission versus compression ratio is shown in Figure 6.

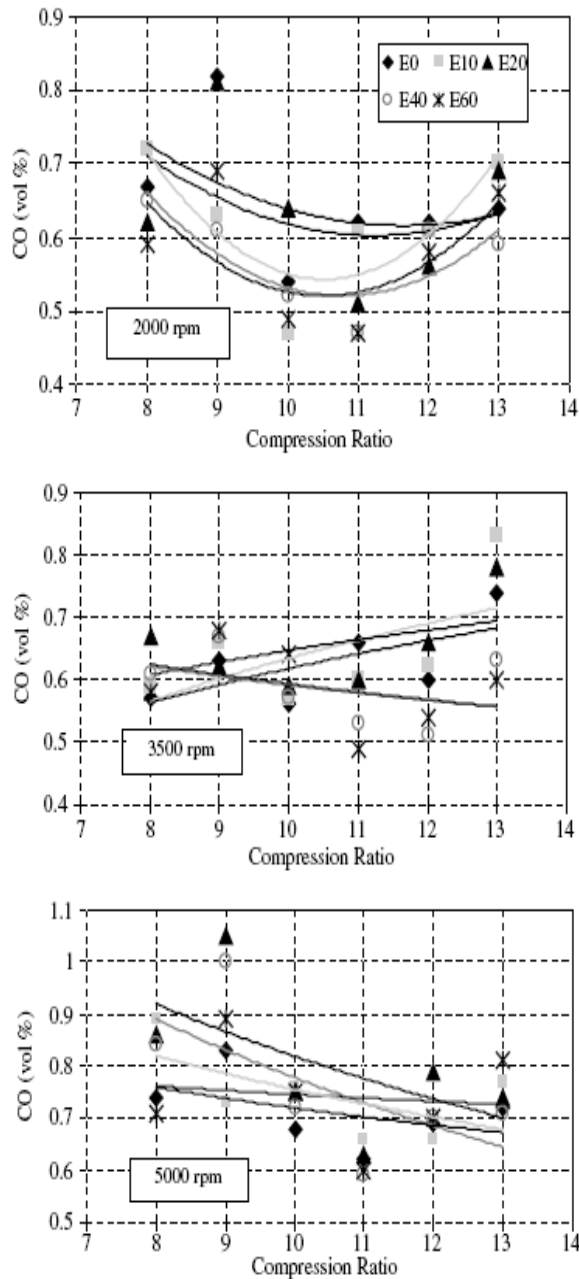


Figure 5 Variation of CO emission versus compression ratio.[6]

5. Ethanol in Diesel Engines

Ethanol is one of the possible alternative fuels for partial replacement of mineral diesel in CI engines. The effect of using different blends of ethanol–diesel (diesohol) on engine power, brake-specific fuel consumption, brake thermal efficiency, exhaust gas temperatures, and lubricating oil temperature has been analyzed. The results indicate no significant power reduction in the engine operation on ethanol–diesel blends (up to 20%) at a 5% level of significance. Brake-specific

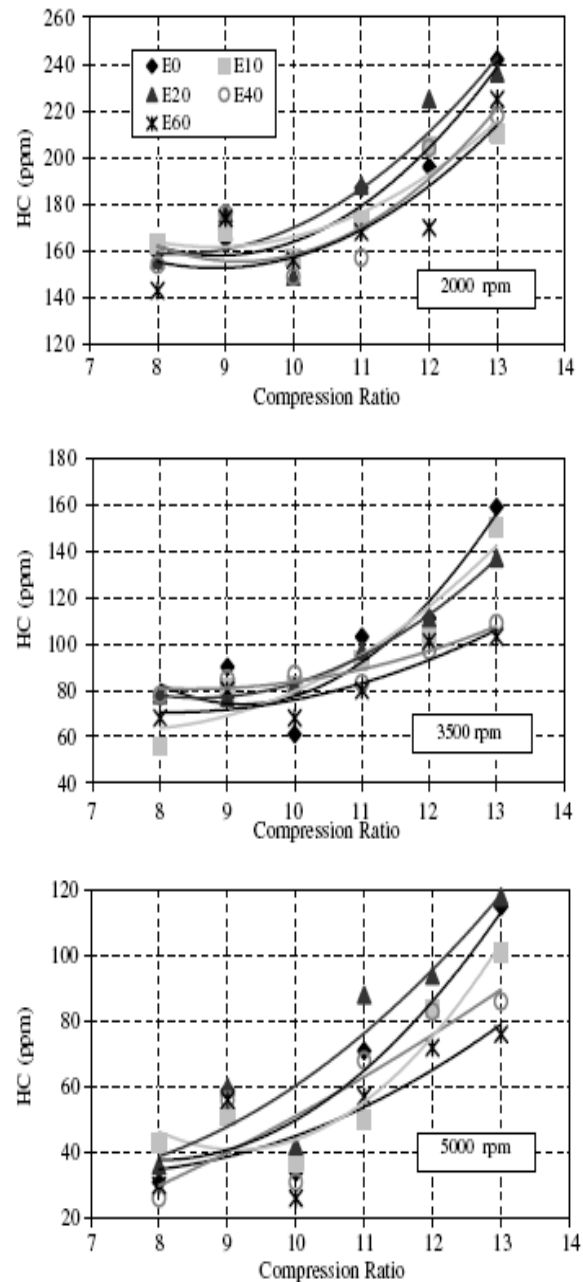


Figure 6 Variation of HC emission versus compression ratio.[6]

fuel consumption is increased by up to 9% (with ethanol up to 20%) in the blends as compared to mineral diesel. The exhaust gas temperature, lubricating oil temperatures and exhaust emissions (CO and NO_x) were lower with operations on ethanol–diesel blends as compared to operation on diesel [14-16]. Ethanol–diesel blends up to 20% can very well be used in present day constant speed CI engines without any modification [17-19]. The brake-specific fuel consumption is slightly increased as shown in Figure 7, when higher blends of ethanol are used. There is no

significant difference in the power produced and the thermal efficiency of the engine. Exhaust gas temperatures were lower for ethanol–diesel blends than mineral diesel. The engine could be started normally both hot and cold. Up to a 62% reduction in CO emission is possible with the use of ethanol–diesel blends as compared to diesel alone. The NO_x emissions is also reduced (up to 24%) when ethanol–diesel blends were used [14].

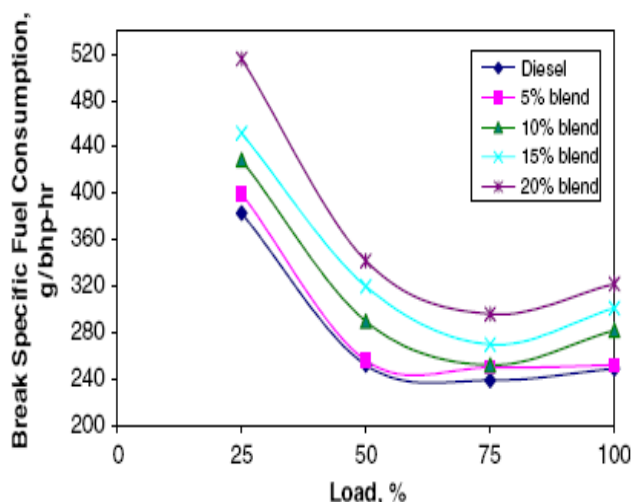


Figure 7 Brake specific fuel consumption for

6. Vegetable Oil in Diesel Engines

Dr. Rudolf Diesel invented the diesel engine to run on a host of fuels including coal dust suspended in water, heavy mineral oil, and, vegetable oils. Dr. Diesel's first engine experiments were catastrophic failures, but by the time he showed his engine at the World Exhibition in Paris in 1900, his engine was running on 100% peanut oil. Dr. Diesel was visionary. In 1911 he stated that "the diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries, which use it". In 1912, Diesel said, "the use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time". Since Dr. Diesel's untimely death in 1913, his engine has been modified to run on the polluting petroleum fuel, now known as "diesel". Nevertheless, his ideas on agriculture and his invention provided the foundation for a society fueled with clean, renewable, locally grown fuel [20].

7. Direct use of Jatropha Oil in Diesel Engines

The use of pure Jatropha oil–fossil diesel blends has been tested in a single cylinder, water-cooled open combustion chamber diesel engine [21]. BSFC and Exhaust Gas Temperature (EGT) of the blends were found to be higher compared to fossil diesel and tended to increase with increasing proportion of Jatropha oil in the blend. The opposite applies for the Brake Thermal Efficiency (BTE). However, blends of 30% Jatropha oil and 70% fossil diesel by volume and of 40% Jatropha oil and 60% fossil diesel by volume showed BSFC and BTE close to the values of fossil diesel. Both BSFC and BTE were found to be acceptable up to 50% by volume of Jatropha oil [21]. Furthermore, the study concluded that the long-term durability of the engine using bio-diesel as fuel requires further study.

Retarding the injection timing with enhanced injection rate of a single cylinder, constant speed, direct injection diesel engine, operating on neat Jatropha oil, showed to improve the engine performance and emission level significantly [22]. The measured emissions were even lower than fossil diesel. At full output HC emission level was observed to be 532ppm against 798ppm for fossil diesel, NO level was 1,163ppm against 1,760ppm and smoke was reduced to 2.0 British Standard Units (BSU) against 2.7 BSU. However, the achieved BTE with Jatropha oil (28.9%) was lower than with fossil diesel (32.1%) [22]. From the above-summarized studies it can be concluded that Jatropha Methyl Ester (JME) generally achieves the best results in comparison to the use of pure Jatropha oil, straight or in a blend, although the scope for the use of the pure Jatropha oil cannot be underrated.[23]

Certainly in tropical developing countries, the use of pure Jatropha oil, straight or as a blend, is believed to have great potential [24]. The diesel engines in those countries, including those of old four-wheel-drive vehicles, rely on older technology, are easier to adapt to the characteristics of the used fuel. Further, the tropical temperatures lowers the viscosity of the oil close to that of diesel [24]. Stationary diesel engines running at low speed, such as irrigation pumps and electricity generators, are believed to be suitable to pure Jatropha oil without a too high environmental burden. Pre-chamber diesel engines are more suitable for the use of pure oil than direct injection engines, but simple conversion to a direct injection two-tank system can overcome their problems [24]. Despite the reported difficult use of pure

vegetable oils [25-28], there is still scope for improvements. Further research is recommended [23].

Tests with a low heat rejection diesel (LHR) engine showed that the use of pure Jatropha oil results in a higher brake specific energy consumption (BSEC), lower brake thermal efficiency (BTE), higher exhaust gas temperature (EGT) and lower NOx emissions in comparison with fossil diesel. Preheating and increasing the injection pressure decreased BSEC, increased BTE, increased EGT and increased NOx emissions only marginally [29]. Kumar et al. [30] compared the use of Jatropha oil and fossil diesel in a single cylinder 4-stroke water-cooled diesel engine and concluded that the soot (hydrocarbon) emission is higher with Jatropha oil as compared to fossil diesel. At maximum output an increase from 100 ppm, for fossil diesel, to 130ppm for Jatropha oil, was measured and similar trends were observed in the case of CO emissions. Smoke level was higher with Jatropha oil (4.4 BSU) compared to fossil diesel (3.8 BSU) as well. Furthermore they observed an increase in ignition delay and combustion duration with Jatropha oil in comparison to fossil diesel [30].

8. Performance of Ethanol Blends in Gasoline Engine – Our Experience

Engine speed, Dynamometer Torque, Throttle Position, Exhaust Gas Temperature, Engine Lubricating oil Pressure and Temperature, Intake Manifold Pressure, Intake Air Flow, Fuel Consumption, Carbon Monoxide Concentration, Hydrocarbon Concentration and other data were recorded while running on 100% petrol, 100% Ethanol, and their blends. The engine speed and

the throttle position were kept constant while other parameters were recorded for each type of fuel used (Table 1)

As the calorific value of Ethanol was 40% lower than that of Petrol, a corresponding reduction of torque and power output could be expected. But actual differences of torque and power output with 100% Ethanol were around 40% lower than that of Petrol. The reasons for this difference are the lower calorific value and the lower Stoichiometric air/fuel ratios when using alcohol as fuel. This could be overcome by enlarging the main fuel metering jet which is situated inside the carburetor. By doing so, and when running on 100% petrol the fuel consumption will be doubled.

We found that the engine ran well on Ethanol having a composition of 97%–100% by volume. The observations made from these tests are that to obtain the same amount of mechanical energy from 1 litre of petrol, we required nearly 1.8 litres of absolute (100%) ethanol. We also observed that up to 5% of water could be added to Ethanol without adversely affecting the engine performance.

The “Kasippu” (a type of home made alcohol in Sri Lanka) samples K1 and K2 received from the Kuliapitiya area (North Western Province) contained about 40% and 55% of water by volume respectively. We are not sure whether water is added to the samples after distillation. Due to the presence of water in samples K1 and K2, we faced difficulties in starting the engine as well as to keep running. (These samples were sent to Industrial Technology Institute (ITI), Colombo for further testing for chemical properties and it was found that around 60% of water was present in both samples).

Table 1 Experimental Data for gasoline - ethanol blend tests

Fuel Type	Engine Speed = 3,000 rpm (constant) Throttle Position 60% (constant)			
	Dynamometer Torque [Nm]	CO - Concentration	HC - Concentration [ppm]	Fuel Consumption [g. /min]
P100	103	1.80	820	91.0
E100	61	0.13	205	93.5
P75E25	101	0.30	451	91.2
E95W5	51	0.13	292	94.2
E90W10	26.2	0.19	400	93.1
E85W15	19.1	0.22	445	94.7
E80W20	Engine was highly unstable and data was not recorded			
K1	Engine did not start at all			
K2	Engine did not start at all			

As far as the fuel consumption is concerned for tested fuel types (Table 1) it remains around the same level, but engine torque and power output decrease rapidly when increasing the percentages of alcohol, by volume (Figure 8). With the P75E25 blend as the fuel, the torque, power output and the fuel consumption remains equal to that of 100% Petrol. And at the same time the emissions of Carbon Monoxide (CO) and (HC) are much lower with the fuel blend (Fig. 9). The decrease in CO and HC emissions could be attributed to the presence of oxygen inside the fuel itself and the latter taking part in the combustion process, which improves the combustion efficiency.

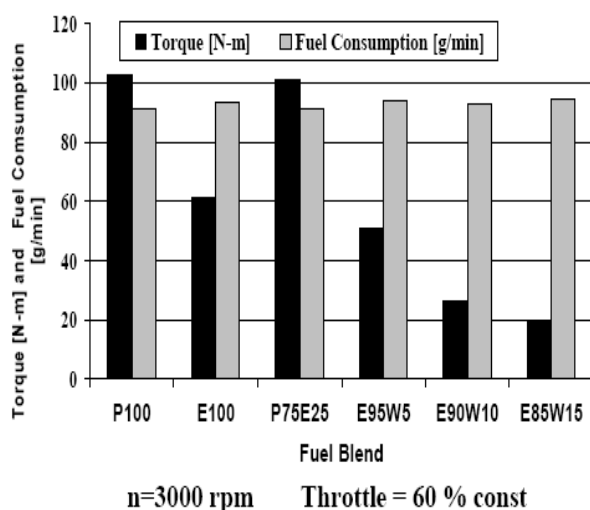


Figure 8 Comparison of torque and fuel consumption

It can be observed that the patterns of CO and HC appear very favourable for alcohol blends as shown in Fig. 9. And, in particular, the P75E25 blend has great potential, as the exhaust gas emission of CO and HC are much lower. In addition, Ethanol is renewable and therefore more environmentally friendly.

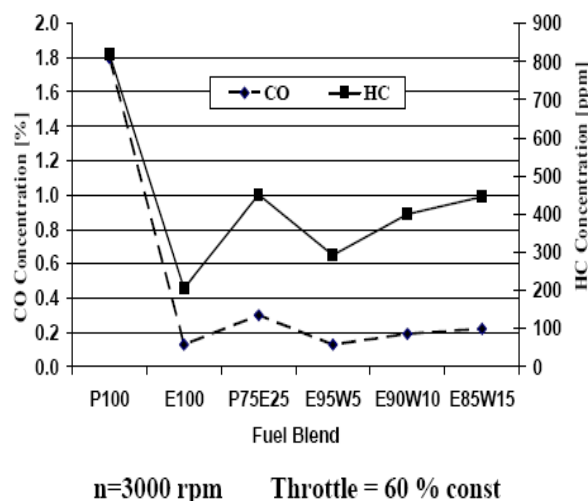


Figure 9 Comparison of CO and HC concentration in exhaust gas

Performance of Jatropha oil blends in a diesel engine –our Experience.

A comparison of Jatropha oil properties is shown in Table 2.

Table 2 Comparison of Jatropha Oil Properties

Properties	units	Experimental Value	Indian Standard Value	Diesel
Density	g/cm ³	0.9098	0.9200	0.836-0.850
Specific Gravity	-	0.9135	0.9186	0.839-0.853
Viscosity	Pa.s	29.8	40-50	4-8
Saponification Value	-	230.7	195.0	-
Acid Value	-	3.64	3 - 38	-
Flash Point	°C	170.5	240/110	45-60
Calorific Value	MJ/kg	39.3	41.73	42.57

Results are presented (Figure 10) on tests on a single-cylinder direct-injection engine operating on diesel fuel, blends of diesel and Jatropha oil in proportion of 95%5% (J5), and blends of diesel and Jatropha oil based bio-diesel in proportions of 95%5%(B5), 90%10%(B10). The results covered a range of operating loads on the engine. Values are given for the specific fuel consumption. The test showed that Jatropha oil based bio-diesel as well as Jatropha oil could be conveniently used as a diesel substitute in a diesel engine. The technical specification of the engine is shown in the Table 3.

Table 3 : Specification of the engine	
Make	Yanmar Diesel Engine, Japan
Type	Single cylinder, Direct Injection, CI engine
Con. Output	6.3 kW @ 2,400 rpm
Max. Output	7 kW @ 2,400 rpm
Displacement	0.450 l
Loading device	Electrical resister bank

The test results further showed a reduction of specific fuel consumption for Jatropha oil and its blends with diesel. The results also suggest that Jatropha oil can be used as an ignition-accelerator additive for diesel

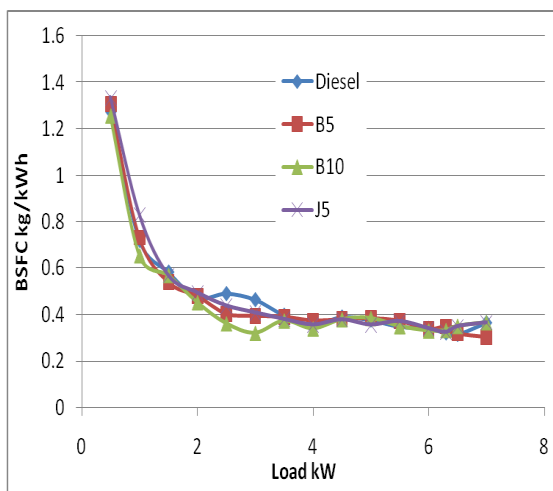


Figure 10 Brake specific fuel consumption Vs Load for various fuel blends

9. Conclusions

In order to make alcohol engines more practical, functional, durable, and economical, several changes in the regular gasoline engines should take place. Intake manifold, carburetor, fuel tank, fuel lines, fuel filtering system, valve housing and catalytic converter are some notable components that need attention. In order to take advantage of the alcohol's much higher octane rating, the compression ratio can be increased to about 12 : 1

Possible phase separation should be avoided when blending hydrous ethanol with gasoline to prevent corrosion of parts and to ensure smooth running of the engine.

The blends had positive influence on exhaust emissions. The CO and HC emissions decreases significantly, the best results were obtained for 20% ethanol with 80% unleaded gasoline blend. The result of engine performance tests showed that torque output improves when using ethanol–gasoline blends. However, there is no appreciable difference on the brake specific heat consumption. CO and HC emissions reduce with the increase of ethanol content in the blended fuel.

The important chemical and physical properties of Jatropha Curcas oil were determined by standard methods and compared with diesel. The results show that the density of the Jatropha oil compared to the diesel oil is slightly higher than the diesel fuel. However, the kinematics viscosity and the flash point of Jatropha Curcas oil are higher than tat of the diesel oil. The Density and Specific Gravity of the Jatropha oil in Sri Lanka are 0.9098 g/ cm³ and 0.9135 respectively and the Indian values are 0.9200 g/ cm³, 0.9186 respectively. So the Density, Specific Gravity of Jatropha oil in Sri Lanka is slightly lower than those vales of the Indian standard values. The remarkable observation is the viscosity of Jatropha oil is very much lower than the Indian standard value.

The main aim of the present investigation was to reduce the viscosity of Jatropha Circus oil and make it close to that of conventional diesel fuel to make it suitable for use in a compression ignition engine and to evaluate the performance of the engine with the modified oils. Significant reduction in viscosity was achieved by delusion of Jatropha oil with diesel in varying proportions. Pure Jatropha, pure diesel and blends of Jatropha and diesel oil exhibited similar performance under comparable operating conditions. The Jatropha oil can be used as an ignition-accelerator additive for pure diesel fuel.

It has been established that *Jatropha Curcas* oil can be substituted for diesel for use in a CI engine without major operational difficulties. However, the proportion of the blends may be further improved to make use of higher percentage of *Jatropha* oil in the blend using *Jatropha* oil purer grade which may be obtained by pretreatment of the oil. Moreover, the long term durability of the engine using bio-diesel as fuel requires further study.

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11. Discussion

Prof. S A Kulasooriya

In the comparison between Bioethanol & Biodiesel, is it correct to presume that Biodiesel blends are easier with less engine modifications than with Bioethanol?

Prof. Nanditha Hettiarachchi

Is it Biodiesel with Diesel and Ethanol with Petrol?

Prof. S A Kulasooriya

Yes, because you showed so much of engine modifications are necessary if you are going to use Ethanol, replacing steel, replacing the linings of the fuel tank, the delivery pipes, o rings. With the Biodiesel blends, these were less.

Dr. Nanditha Hettiarachchi

They say that all the new vehicles are made thinking about the blends and the rubber parts etc are already compatible for Ethanol. In terms of Biodiesel, again the facts of economics come in. I saw in one reference in which it was suggested not to go for Biodiesel but to run on neat oils with a 2 tank system.

Prof. S A Kulasooriya

In your presentation, I was more modifications that are needed for Ethanol than Biodiesel.

Dr. Nanditha Hettiarachchi

Modifications refer to the existing engines. We use a lot of old vehicles. Many manufacturers now produce flexi fuel vehicles. I am not sure about the vehicles that come to Sri Lanka. From the results we got, they were very similar, but from the literature, there were some divergence.

Mr. M U Ranasinghe

Have you tested usage of Biodiesel or Ethanol on static engines?

Dr. Nanditha Hettiarachchi

What were tested were the 2 wheeled tractor engines. We will be testing for durability soon, running the whole six months for ploughing and agricultural use.

Prof. S A Kulasooriya

Have you tested water pumps and generators or things like that?

Dr. Nanditha Hettiarachchi

The engines that we tested run a generator, and that is how we get the power output. There were no problems.

Prof. Ajith de Alwis

Did you check the Ethanol content of 'Kasippu' (a local liquor produced illegally in Sri Lanka in the informal sector)? If there is more water, it would be a problem.

Dr. Nanditha Hettiarachchi

Yes, water content is too high.

F. Research and Development

Priorities in Biofuel Research & Development

Dr. C.S. Kalpage, and Prof. Ajith de Alwis

University of Peradeniya, Sri Lanka; University of Moratuwa, Sri Lanka

Abstract:

Biofuels offer number of economical (energy independence, carbon credit benefits, foreign exchange), environmental (carbon neutral, lower toxic emissions), and social (jobs, entrepreneurship, rural development) advantages. Objections are also raised as biofuel production could divert agricultural production away from food crops (resulting food shortage and food price escalations) and deforestation (resulting draughts and global warming). However, if biofuel programmes are carefully planned and implemented, bio-resources can be enhanced for future prosperity and energy security. Being in and around the tropical region, South Asian countries are blessed with great diversity of bio-recourses; therefore, pose the highest potential for successful bio-energy industry in the world.

To generate new knowledge that can catalyze the development of bio-fuels (for the well known benefits), to address the gaps in knowledge and problems within these areas, and to implement successful applications, it is essential to perform multidisciplinary collaborative research and development (R&D) programmes. These R&D programmes need focused mainly on

- Feedstock production (plantation, harvesting, pre-processing, transportation, purchasing, etc.)
- Biofuel production (raw material conversion into final product, quality control and quality assurance)
- ApplicationsPolicy, commercialization and socio-economics

Reliable and sustainable feed stock supply has been identified as the key to success of any biofuel programme. Second and third generation biofuel sources cultivated in arid and semi-arid lands would minimize deforestation as well as the land competition with food crops. Identification of high yield crops and yield enhancement by bioengineering and agricultural practices will also help in this course. Incorporating new technological advances in biofuel processing will improve the production (quality and quantity) while minimizing cost and unfavourable environmental impacts. It is R&D which will earth applications where the most significant cost-effective gains can be made from using bio-energy, and insists Governments to have established favourable policies for the development of this sector.

Keywords: Biofuels, biofuel feed stocks, biofuel research.

Priorities in Biofuel Research & Development

Open Discussion

For a sustainable biofuel economy for South Asia, required research and development were identified from 8 priority areas as follows for the future.

1. Policy
2. Agronomy
3. Process & Technologies
4. Products
5. Quality & Standards
6. Environment & Ecology
7. Services
8. Socio Economics

At the discussions, each of the priority areas were sub-divided

1. Policy

- Legal & institutional framework
- Influence of Northern NGOs & social infrastructure
- Common statement for advocacy & influencing
- Position paper of biofuels and pros & cons
- Conflicting interests of SAARC member states

2. Agronomy

- Fuel plants / feedstock, cross breeds, high breeds
- Breeding practices re-designed
- No mono cultures, bio diversity
- Straw for butanol
- 1: 1 ratio with improved varieties
- SWOT feed stock capability
- Food nutritional aspects
- Residues Vs energy crops
- Map & land allocations
- Integrate GIS into use like Philippines
- Team work
- Land use

3. Process & Technology

- Spectrum , conventional > State of the art

- Manage IPRs
- Central serving lab with experts in it, both researchers & industry
- SEA
 - Industry getting rebates for research at Universities
 - Database of research ongoing & investors interested
 - University-Industrial Cells available at each University for this
 - R & D network planned by SEA (Individuals & institutions)
 - Coordinating authority to fairly distribute
- R & D policy (tax rebates)
- By-products (sugar, ethanol)
- Regional benchmarks
- Centre for bioenergy research & information (refer biotechnology policy)

4. Products

- Compositions (Products) (Chemical)
- Take spectrum (for economical benefits) (including by-products)
- Is traditional biomass as a fuel forgotten
- Energy balance, because food is also energy intensive (irrigation)

5. Quality / Standards

- Own standards / specifications or adopt / adapt ASTP etc?
- Carry out an research on sensitivities on acceptance / reluctance by users
- Warranty & acceptance of insurance by manufacturers
- Modified or as it is vehicles
- Uniform guidelines / specifications for SAARC? (including blends, long process!)
- Guidelines – optional ; Standards – mandatory, we may have to go for mandatory

6. Environment & Ecology

- Improved seeds / cultivars and water

requirements

- Flora & Fauna policies, invasion species quarantine
- Plant protection ordinance
- Human-animal conflicts, habitat diseases
- If monoculture, pest attacks, therefore IPM, integrated pest management
- Life cycle analysis
- Monitoring is an issue despite standards being in place
- Identify issues even the locals can monitor
- Social aspects

7. Services

- Blending 100% & performance index with blending (of existing engines)

8. Socio-Economics

- Bottom line
- Media, Northern Based NGOs, Lobby
- Fiscal & regulatory regimes
- CDM manipulations
- Consultations seen a reducing trend (30% to 3%)
- Break-even policy points (Ex. 1 Ton > minimum 200 jobs>, 1 Ton biofuels > how many employment opportunities)
- Subsidy requirements (ex. Fertilizer) & cutting down (chicken & egg issue)
- Awareness & information
- Financing researches
- Pricing mechanisms (cross / direct subsidies)
- Seeds etc for thermal power plants

G. Economics of Biofuels

Economic Background of Biofuels: Emergence as a Viable Option

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Abstract

Biofuels have emerged in recent years as a strategic element in the global transition to sustainable energy, based on a confluence of factors—higher oil prices, climate change, and the need for renewed emphasis on the agricultural sector in the developing world. The economics of biofuels are, however, more complicated than almost any other class of energy sources, because they are dependent on land and water availability as well as being dynamically intertwined with the supply and prices of many agro-industrial products and socio-economic variables. They are also a class of energy resources whose implications—and in some cases—complications—have spread from the local to the national to the global. In this paper, an overview of the economics of biofuels is discussed from a broad historical perspective but also from a micro-perspective for the case of individual fuels and regions. Some key examples are reviewed and some of the main linkages across scales and sectors are considered.

Keywords: Biofuels, sustainability, economics, environmental impacts.

1. Introduction

Biofuels have been used in the transport sector for over a hundred years, and have historically been quite important in times of conflict when oil supplies were reduced. More recently—in the past few decades—it has been recognised that they are not only valuable in terms of energy security but also that they can make a significant contribution to reducing greenhouse gases and addressing other environmental impacts of fossil fuels. Biofuels are also linked to the emerging bio-economy, since various co-products can find useful markets and further substitute for non-renewable resources, thereby making an additional contribution to the overall sustainability transition. Biomass resources can provide food, feed, fuel, fibre and many other types of products and services.

The role envisioned for liquid biofuels for transport has come under increased scrutiny in the past few years, due to the potential social and environmental impacts associated with scaling up biofuels production and use from its low level—currently representing about 1% of transport fuels globally. At such low levels, the amount of land and resources required is relatively low, but if biofuels were to be expanded to ten times that amount or more, there are legitimate concerns about the impacts on the food supply, deforestation, socio-economic changes, and other impacts that are associated with large-scale use of land resources.

The economics of bio-ethanol from sugar cane are well understood from the experience in Brazil, which began its program in the early 1970s. Today, most cars produced in Brazil are flex-fuel and more than half of the fuel used in gasoline engines in Brazil is bio-ethanol, a major economic advantage since ethanol is much cheaper at today's oil prices. The economics of other biofuels are less favourable but are similar in structure and over time can benefit from the same type of learning curve and cost reductions that comes with experience.

The GHG balances from biofuels are generally positive, since carbon is sequestered and thereby cycled back from the atmosphere; however some biofuel crops have much better GHG balances than others. The use of first generation biofuels in temperate climates is land-intensive and inefficient in technical and environmental terms, whereas first generation biofuels in tropical climates and second generation biofuels in general can offer a much more effective use of land resources.

The calculation of GHG emissions associated with biofuels is complicated by the addition of factors associated with land use change, since the GHG impacts of land use change are beset by uncertainty both in physical terms as well as in the attribution of particular changes to production of particular biofuels. A further complication is introduced when indirect land use changes are incorporated, since these occur through combinations of market forces, illegal land use transformation, and regulatory efforts. More analysis and

research is needed in order to improve the incorporation of land use change into estimates of GHG emissions from biofuels.

The socio-economic impacts of biofuels production depend on many factors, including the crop, scale of operations, and resource management approach. Some impacts—such as wages and conditions faced by labourers—are similar in many respects to any type of agricultural operations, while other impacts may be related to the industrial structure in the case of larger-scale operations. Since harvesting will often be manual in less developed countries, most social impacts are associated with the agricultural side. Other social impacts are associated with land tenure in the case of small farmers, the possibility of expropriation of land by companies or government agencies, and the more general conditions of access to technology and credit for smaller farmers and businesses.

This paper begins with some historical background on the emergence of biofuels and reviews the experiences in some of the key regions where biofuels markets are expanding. A review of economic aspects and cost calculations is considered, followed by a discussion on environmental impacts and socio-economic factors. A discussion on land use change is provided, including the controversies concerning the calculation of GHG emissions from direct and indirect land use change. Other aspects considered briefly are the issue of accounting for co-products and also the carbon finance implications associated with biofuels and bioenergy under the Clean Development Mechanism. In the final section, a review of biofuels sustainability criteria efforts is given.

2. Historical Background

Biofuels have been around for over a hundred years, and bio-ethanol in particular saw significant use in the early part of the twentieth century. Before the era of cheap oil and during times of conflict such as World War II, biofuels have been recognised as a valuable domestic alternative to imported oil. The resurgence of interest in biofuels in recent years is in part for similar reasons of energy security, but now the added issues of rural development and climate mitigation make the case for biofuels even more compelling. An interesting historical note is that the Model T introduced by Henry Ford during 1908-1926 could run on either petrol or ethanol; consequently the dual-fuel vehicles introduced in recent years are simply a somewhat more sophisticated re-

introduction of a capability that was already available at the dawn of the auto age!

2.1 Ethanol

Ethanol fuel played a key role in the first four decades of the 20th Century. By the mid-1920s ethanol was widely blended with gasoline in many industrial countries. In the Scandinavian countries, a 10-20% blend was common, produced mostly from paper mill waste; in most of the continental Europe ethanol was obtained from surplus grapes, potatoes, wheat, etc.; in Australia, Brazil, and many other sugarcane producing countries, ethanol was produced from cane juice and molasses.

After WW II, few countries showed any interest in ethanol as there was plentiful cheap oil around. In the 1970s, after the oil shock, many countries began to again consider the ethanol fuel option, notably Brazil. During most of the 1990s the low price of oil again had a negative effect on ethanol fuel programmes, with many schemes being either abandoned or scaled down significantly. The past several years have witnessed a growing interest in fuel ethanol as a substitute to petrol in the transportation sector on a global scale; this is due to a combination of factors, ranging from environmental and social benefits to climate mitigation and energy security.

There are three broad market categories for ethanol—fuel, industrial, and potable—with the largest volume market today being for fuel. The industrial market is generally associated with chemical and pharmaceutical industries that require ethanol as a feedstock for fine chemicals and various products. The industrial market generally has greater purity requirements than fuel alcohol, since it is directed to specialised production processes rather than combustion as a fuel. The potable market includes distilled spirits and liquors. However, surplus wine alcohol is sometimes re-directed to other markets, such as is the case in some Caribbean countries, which re-process the wine alcohol for export to the U.S. under special trading arrangements.

Table 1 World ethanol production by country/region

	2000	2001	2002	2003	2004	2005	2006	2007
Brazil	10.6	11.5	12.6	14.7	14.7	16.1	17.0	19.0
U.S.A.	7.6	8.1	9.6	12.1	14.3	16.2	18.4	24.6
EU	2.4	2.6	2.5	2.5	2.5	2.7	3.4	3.6
Asia	5.9	6.1	6.2	6.7	6.6	6.8	7.2	7.2
other	5.2	5.5	5.5	5.5	5.6	5.8	5.9	7.0
Total	31.7	33.7	36.5	41.5	43.6	47.6	51.9	61.5

Source: F.O. Licht's, 2007; EBIO 2008; NRF 2008

Note: Figures include bio-ethanol and synthetic ethanol; about 80-90% of total world ethanol market is bio-ethanol; about 80% of total world ethanol market is for fuel; some ethanol is processed into ETBE for blending particularly in EU.

Not all ethanol is bio-based. Synthetic fuels—both diesel and ethanol—can be produced from coal or natural gas through the Fischer-Tropsch process, as is common in South Africa. Synthetic ethanol is often used in the industrial market, due to specific purity requirements. Synthetic ethanol is chemically identical to bio-ethanol, and market data is not necessarily reported separately; consequently Table 1 gives total ethanol production. Although synthetic ethanol production is generally not cost-competitive with bio-ethanol, the higher levels of purity required can acquire a price premium for certain applications. Production in South Africa was initially a result of the political isolation against the apartheid regime in the 1970s; trade sanctions required greater reliance on domestic energy sources where feasible, and South Africa has plentiful supplies of coal. Having all the infrastructure in place, South Africa has continued for many years now after apartheid with its synthetic production. The process for gas-to-liquids is analogous to the production of second-generation biofuels in the future via gasification of biomass.

As illustrated in Table 1, world ethanol production has increased significantly in recent years. The two largest producers—Brazil and USA—have generally been responsible for 60-70% of world ethanol production. All ethanol produced in Brazil is bio-ethanol, as is nearly all ethanol produced in the U.S. Synthetic ethanol is produced in a number of European countries as well as in Middle Eastern countries, South Africa, and some Asian countries. Ethanol can also be processed into ETBE (ethyl-tertio-butyl-ether) by reaction with isobutylene, a refinery by-product. Such re-processing is popular in the EU due to the fuel

standards adopted by the automobile industry in EU markets and the preferences of oil distributors in the EU for ETBE rather than bio-ethanol as a final product for blending. In a few EU countries such as Sweden, ethanol is blended directly rather than using ETBE. Sweden is also one of the few countries to run a significant fleet of E100 vehicles; much of the bus fleet runs on ethanol, using specially-designed engines.

2.2 Biodiesel

The process of trans-esterification for making bio-diesel has been known for well over a hundred years, although bio-diesel as it has come to be known emerged only in the past twenty years, in terms of the use of refined vegetable oils on a large-scale. Rudolf Diesel first demonstrated his breakthrough engine design in 1893, and it was powered by peanut oil. He believed that the utilization of a biomass fuel represented the future for his engine. In 1911, he said “The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it.” The emergence of cheap fossil fuels, however, encouraged the diesel engine manufacturers to alter their engines to utilise the lower viscosity petroleum diesel.

Research into the use of trans-esterified sunflower oil and refining it to diesel fuel standard was initiated in South Africa in 1979. By 1983 the process to produce fuel quality engine-tested bio-diesel was completed and published internationally (SAE, 1983). An Austrian Company, Gaskoks, obtained the technology from the South African Agricultural Engineers, put up the first pilot plant

Table 2 Global Biodiesel Production by country/region (million litres)

	2000	2001	2002	2003	2004	2005	2006	2007
Germany	250	315	511	813	1176	1897	2343	2543
France	373	364	416	406	395	559	654	767
EU-total	813	912	1210	1630	2265	3618	4303	5027
U.S.A.	8	19	57	76	95	284	948	1706
other	125	190	256	284	273	307	368	405
World	945	1121	1523	1989	2633	4209	5619	7138
Sources: estimated based on European Biodiesel Board, 2008; National Biodiesel Board, 2008.								

of the first industrial bio-diesel plant in April 1989, with a capacity of processing 30 000 tons of rapeseed as feedstock per annum. Throughout the 1990s, plants were opened in many European countries, especially in the Czech Republic, France, Germany, and Italy.

Globally, production of bio-diesel is concentrated in a few countries, with Germany and France accounting for nearly half of global production and consumption, as shown in Table 2. Global production has been increasing at a tremendous pace, with most of the growth in the EU as a result of fairly generous tax benefits and subsidies. From 2000 to 2007, biodiesel production increased globally more than seven-fold, from under 1 billion litres to over 7 billion litres; production in Germany alone increased more than ten-fold over the same period. New financial incentives in the U.S.A. starting in 2005 have significantly stimulated production there.

2.3 Other Biofuels

There are other biofuels and other applications, such as the use of unrefined oils or straight vegetable oils, but unlike ethanol and biodiesel they are not global fuel commodities with specific properties. Biogas is also considered a biofuel, although it also has less relevance for international trade and is therefore not treated here in detail. Other fuels such as butanol have also sparked some interest.

3. Regional Overview

3.1 Biofuels in Brazil

The rapid development of ethanol production capability in Brazil took place only after the creation of the Brazilian Alcohol Program, known as PROALCOOL, in 1975, with the purpose of producing anhydrous ethanol for blending with gasoline. After the second oil shock in 1979, the government decided to expand production to include

hydrated ethanol to be used as neat fuel in modified engines. Sugarcane and ethanol production has increased several-fold during the past three decades.

The continued expansion of the sugarcane industry in Brazil, particularly in the last decade, has been the result of various factors, ranging from high demand for sugar and ethanol both in the domestic and international market to continuous improvements in productivity. Such improvements include the whole chain system, ranging from better varieties, soil management, pest and disease control, transportation, technical improvement in conversion, to end use.

With dozens of new industrial units in different stages of construction, ethanol production capacity is set to expand considerably in the coming years. Brazil has the capacity—land, technical know-how and even finance—to expand its ethanol production capacity 8-10-fold in the next 20-30 years. The implications of such an expansion are being evaluated at the University of Campinas, one of Brazil's premier research Universities (Cortez, 2006).

With the lowest cost of production in the world, Brazil has become the largest exporter of ethanol. The main priority in Brazil has thus far nevertheless been to supply the domestic market. Alcohol is used as an octane booster blended with gasoline, alone as “neat” fuel, and in flex-fuel vehicles, and also as a chemical feedstock and other industrial applications. The flex-fuel vehicles, introduced in 2003-2004 run on any combination of gasoline and alcohol.

3.1.1 Biodiesel in Brazil

A Brazilian programme for biodiesel has been initiated, with similar objectives to those of the bio-ethanol programme. However, the approach will be different, in that small farmers are expected to provide feedstock for the industrial

producers of biodiesel. A regulatory instrument will be used to enforce the social and environmental profile, known as “The Social Fuel seal,” which will be awarded by the Ministry of Agrarian Development, as a condition for industrial producers of biodiesel to obtain tax benefits and credits. In order to receive the seal, an industrial producer must purchase feedstock from family farmers, enter into a legally binding agreement with them to establish specific income levels, and guarantee technical assistance and training (PNPB, 2005).

Unlike the large-scale approach used in the case of ethanol from sugarcane, the benefits of building a new industry could be better distributed. Economies-of-scale are somewhat different for biodiesel, and so a different approach may be useful. However, it is not clear whether the small-scale approach will ultimately prove to be economic in a global market. Government legislation will provide security for the market demand; a blend of 2% (B2) will be mandatory for all diesel fuel as of 2008, while 5% (B5) will be mandatory starting in 2013 (MDA, 2005). There are support schemes for research and development, in addition to the support for implementation, via the tax credits associated with the Social Fuel seal. There is growing criticism within the business community of the conditions imposed by government, which seems more concerned with social development rather than energy at competitive price. They argue that the conditions attached to biodiesel production, particularly in the Northeast will make biodiesel uncompetitive.

3.2 U.S.A.

Ethanol is produced mainly from corn in the U.S., and domestic producers receive a subsidy of \$0.52/gallon (\$0.14/litre). Partly as a result of these support schemes and the recent rise in oil prices, U.S. production exceeded Brazilian production for the first time in 2005. Ethanol is sold in most States as an octane enhancer or oxygenate blended with gasoline, and in the Midwest there are also E85 or ethanol-only vehicles, including buses.

Bio-diesel production has also been increasing significantly due to the generous tax credits provided by legislation enacted during 2004-2005. The tax credit is \$0.50/gallon (\$0.13/litre) of biodiesel made from waste grease or used cooking oil and (\$0.26/litre) for biodiesel. If the fuel is used in a mixture, the credit is 1 cent per percentage point of agribiodiesel used or 1/2 cent per percentage point of waste-grease biodiesel. For

small biodiesel producers (i.e. production capacity of less than 60 million gallons annually), an additional \$0.10 (\$0.03/litre) tax credit is provided for each gallon of biodiesel produced by small producers. This tax credit is capped after the first 15 million gallons produced annually (US-DOE, 2004).

In September of 2005 Minnesota became the first state to require that all diesel fuel sold in that state contain part biodiesel. The Minnesota law requires at least 2% biodiesel (B2) in all diesel fuel sold. In March 2006, Washington State became the second state to pass a 2% biodiesel mandate, with a start-date set for December 1, 2008 (WA, 2006).

3.3 EU Biofuels Policies

EU policies with respect to biofuels are relevant with respect to international trade, as it is recognised that a rapid increase in biofuels within the EU cannot be achieved without imports. Biomass and bio-energy are promoted through a variety of programmes and policies within the EU, and is widely recognised that bio-energy will be among the major renewable energy sources in the near-term. The policies and strategies adopted include liquid biofuels, solid biomass, and biogas. The sector coverage includes heat & power production, transport, and direct uses in households and businesses. A biomass action plan was released by the EC in late 2005 and a biofuels strategy in early 2006 (EC, 2005; EC, 2006).

In 2001, the EC launched its policy to promote biofuels for transport, the motivation for which includes several dimensions:

- to reduce greenhouse gas emissions;
- to reduce the environmental impact of transport
- to increase the security of supply;
- to stimulate technological innovation; and
- to promote agricultural diversification

The policy was to be market-based, but would include indicative (i.e. non-binding) targets and financial incentives in order to maintain progress. The targets were to be based on the percentage of biofuels in the transport market, which was only 0.6% in 2002.

The EU Directive on biofuels came into force in May 2003, under which Member States shall ensure a minimum 2% share for biofuels by 31 December 2005 and 5.75% by December 2010 (EC, 2003a). Only Sweden with 2.2% and Germany

with 3.8% exceeded the 2% target in 2005 (EC, 2006); Sweden accomplished this mainly through bio-ethanol, while Germany relied on bio-diesel. The biofuels component within the overall road-map for renewable energy has been revised somewhat in light of the slow progress by Member States; a more recent policy document acknowledges that the 2010 targets will be difficult to meet, but nevertheless proposes a target of 10% for 2020, with the assumption that policy instruments must be made more effective (EC, 2006). The integrated energy-climate package that was put forth by the Commission also retains biofuels as a major component of strategies aimed at the goals of energy security, competitiveness, and sustainability (EC, 2007).

Another component of the EU biofuel legislation relates to fuel quality. In 2003, the environmental specifications for market fuels were amended to establish specifications for gasoline and diesel. The previous Fuel Quality Directive was thus amended, and applies to biofuels as well as to petrol and diesel (EC, 2003c). The European Committee for Standardization (CEN) has set limits on biodiesel blending to no more than a 5 percent share by volume for technical reasons. This strict technical requirement represents an obstacle to achieving the targets set in the Biofuels Use Directive. Consequently, it is proposed that the Fuel Quality Directive be revised again in order to remove such technical barrier as well as to address related issues that may constrain the use of biofuels.

The EU currently has a special aid programme for energy crops grown on non-set-aside land, i.e. land that is not already within the 10% of land that farmers are requested to set aside under the EU Common Agricultural Policy (CAP). The energy crops can receive a premium of Euro 45 per hectare, within a maximum guaranteed area of 1.5 million hectares. In 2005, an estimated 0.5 million hectares received the energy crop payment. The generous support mechanisms available for bio-diesel have resulted in twenty of the twenty-five Member States of the EU producing biofuels, as of the end of 2005 (EUobserver, 2006).

EU biofuels production is generally not cost-competitive, due mainly to high-priced feedstocks, which is rapeseed in the case of biodiesel and sugar beet, corn, or wheat in the case of bio-ethanol. In spite of recent sugar sector reforms, the EU internal sugar prices are expected to remain substantially above international market prices and consequently sugar beet will continue

to be an expensive feedstock. With recent significant increases in world oil prices, biofuels have become more competitive, particularly biodiesel. Imported bio-ethanol will generally be cheaper than EU-bioethanol, particularly from Brazil, which is very cost-competitive at current oil prices. However, since most EU countries continue to charge customs duties based on the higher agricultural tariffs, even imported ethanol can be more expensive.

In early 2006, the EC released a biofuels strategy, in which the overall aims of the biofuels initiatives were reviewed, progress was assessed, and specific implementation issues were addressed in terms of meeting future targets (EC, 2006). It was recognized that only about half of the target for 2010 could be met through production within the EU, and the remainder would need to be met through imports.

In early 2008, the Commission included new targets of 10% by 2020 for renewable transport fuels in its proposal for a new Renewable energy Directive. The targets would be binding on member states. Sustainability criteria were also proposed, including a minimum GHG reduction of 35% and prohibitions on biofuels grown in ecologically sensitive regions. Since that time, the European Parliament has voted in favour of scaling back some aspects of the biofuels proposal, increasing the required GHG reductions, mandating an interim review of the targets, and setting a target of 5% for 2015, which is lower than the 5.75% target in the previous Directive.

3.4 Biofuels in Other Countries/Regions

A number of other regions are significant producers of biofuels or could become significant producers in the near-term. Countries with large domestic markets (U.S., China, and India) are unlikely to become exporters. Other regions could become major exporters in the future, particularly southern Africa and some parts of Southeast Asia. Smaller African producers such as Malawi are discussed in section 5 along with the other summary case studies. The situation in China and India are briefly mentioned below, since these countries could be major producers but also potentially major importers in the future, depending on market developments.

3.4.1 China

Although China cannot be regarded today as a major player in biofuels, this could change dramatically in the near future. China is potentially a

hugely untapped vehicle market; in 2004 there were only 27 million privately owned vehicles, most of them concentrated in large cities (Brown, 2004), which is very low by western standards. The Chinese automobile use has been growing faster than in any other country; during the past 5-6 years, automobile use has nearly doubled. If this trend continues, the size of the Chinese automobile industry will have significant implications for fuel demand, and some of this demand may very well be met through biofuels.

3.4.2 India

With the growing mobility of India's increasing population, demand for crude oil long ago surpassed domestic production; diesel demand is much higher than petrol, due to the significant amount of freight transported by road. Bio-diesel production offers the possibility for fuel produced from renewable sources to sustain the growing demand. Some oil-bearing crops such as jatropha, can be grown on degraded lands, which are not well-suited to traditional agricultural crops. Over 65 million hectares of land has been declared "wasteland" in India, and another 174 million hectares are close to being called wasteland, and this may present an excellent opportunity for energy crops like Jatropha.

In April 2003, the national committee on development of Biofuel recommended a major multi-dimensional programme to replace 20% of India's diesel consumption. The National Planning Commission has integrated the Ministries of Petroleum, Rural Development, Poverty Alleviation and the Environmental Ministry and others. One objective is to blend petro-diesel with a planned 13 Million t of bio-diesel by 2013, produced mainly from non-edible Jatropha oil, a smaller part from Pongamia. For this end, eleven millions ha of presently unused lands are to be cultivated with jatropha. One of the difficulties is lack of experience with large scale production of Jatropha, compounded by its low productivity in terms of fuel produced per hectare.

3.5 International Trade in Biofuels

The case of bio-ethanol is of particular interest for international trade, as it is different from other biofuels and especially from biomass generally in several respects. First, the opportunity to export a value-added product such as ethanol rather than raw biomass is important for developing countries. Second, there are many significant potential producers of bio-ethanol; any of the more than 100 countries that grow sugarcane could enter the

market fairly easily in the absence of protectionist measures. Third, the most economical biomass source or feedstock, sugarcane, is found almost exclusively in the developing world. Fourth, unlike biomass or wood products, ethanol markets are impacted significantly by trade barriers and tariffs. While many small sugarcane-producing developing countries are potential producers, both sugar and ethanol are protected products in most markets. Preferential sugar prices have been a disincentive for developing countries to switch to ethanol, since they can obtain more money from subsidised sugar exports.

Some projections suggest that ethanol trade will increase by a factor of 3-4 by 2010 (Rosillo-Calle & Walter, 2006). Between 2010 and 2015, trade is expected to more than double (F.O.Lichts, 2006). More significantly, the number of exporting countries/regions will increase significantly, with countries other than Brazil and U.S.A. making up about 30% of the total, compared to less than 5% in 2005. Exports are increasing as a growing number of countries are developing ethanol fuel policies and programmes, due to several driving forces:

- Progress on climate change: implementation of Kyoto and further post-Kyoto decisions
- Clearer long-term policy in U.S.A. in favour of alternative transport fuels
- Improving attitude of the automobile industry toward alternative fuels
- Technological progress, including cellulose-based ethanol
- Interest in supporting rural development in developing and developed countries alike

International trade of fuel ethanol also faces some specific barriers, including:

- Tariff and non-tariff trade barriers
- Focus on domestic rather than the external market in most countries
- New investments in infrastructure and adaptations to new programmes.
- Direct domestic production subsidies actually hinder longer-term market development because of market risk perceptions in light of political uncertainty of future support schemes.

Present trends indicate that it would be possible to create sizeable production and consumption centres outside the USA and Brazil, e.g. EU, China, India, Japan, Thailand, and Southern Africa. It is relatively easy and cheap to transport ethanol by ship, just as oil is transported; the transport cost is generally between 1-2 US\$/litre. Currently, between 3 and 4 billion litres of ethanol is traded annually, with Brazil and the USA being the main exporters, and Japan and EU the main importers. The EU and Japan could become the major importers in the future, given the interest in creating renewable fuels markets based on environmental and energy security reasons, and the low availability of cost-effective domestic production. Although in the case of the EU the strong agricultural lobby is pushing for domestic production rather than imports.

estimated at 633 B/l/yr (14.5 EJ/yr or about 20% of the estimated projected world gasoline demand in 2050). This scenario considers only a maximum of 10% of the cropland area to be used for sugarcane (excluding Brazil). Brazil accounts for nearly half of the total ethanol production in this scenario. It is estimated that 3,460 new industrial plants would have to be built up to 2050, of which 1,720 will be in Brazil; the cumulative associated investment is estimated at US\$215 billion. This appears to be an optimistic scenario in terms of a total market size equal to 20% of gasoline demand; on the other hand, the estimated amount of cropland required may in fact be less, given the historical improvement in yields and the possibility to focus production on the most high-yielding regions and the varieties best-suited to those regions.

Fulton (2005) has studied the potential large-scale ethanol production from sugarcane up to 2050,

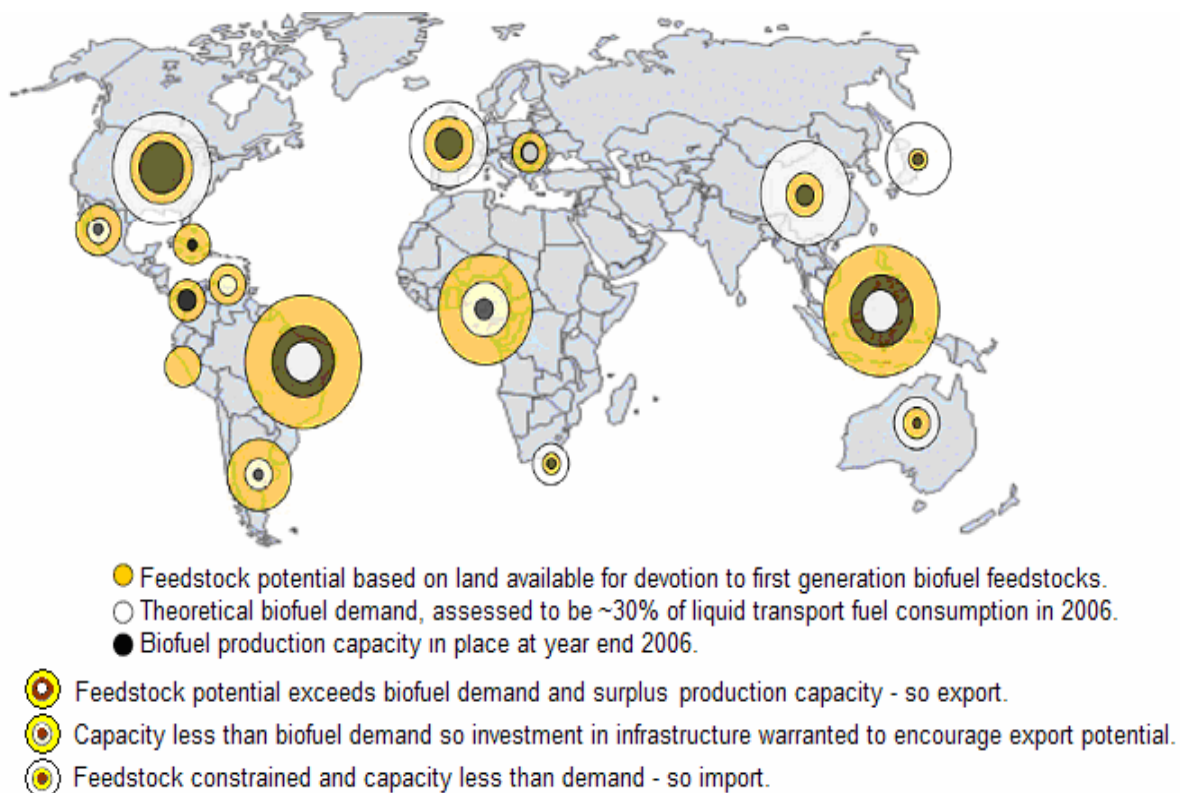


Figure 1 Estimated biofuel supply and demand in relation to capacity for various world regions

An estimate of potential global trade in biofuels in relation to supply capacity and demand is shown in Figure 1. The high potential in the region of sub-Saharan Africa is coupled with very low demand there (except for South Africa) and consequently there is an excellent opportunity to become a major next exporter; indeed, without

exports, biofuels will be less competitive due to the low liquid fuels demand and subsequent lower economies of scale that would result from focusing on domestic demand (Johnson and Matsika, 2006).

Consequently, the notion that countries should meet domestic demand first comes in conflict in many cases with the market/trade principles of comparative advantage. Low demand and high potential is also found in Southeast Asia and parts of Latin America, which would also therefore suggest increased investment in capacity in those regions. High-consuming regions in temperate climates such as North America and Europe will need to import under nearly any cost-competitive scenario with relatively free trade in biofuels.

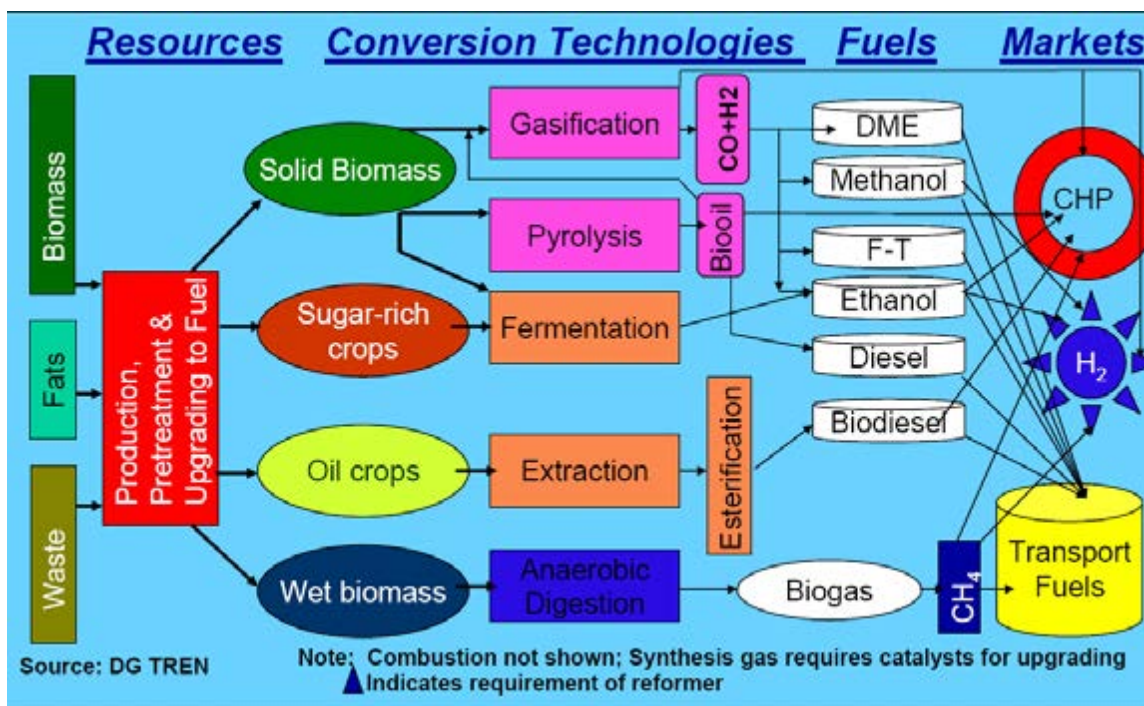
4. Resources and Conversion

There are many different routes for converting biomass to bioenergy, involving various biological, chemical, and thermal processes; the major routes are depicted in Figure 1. There can be intermediate steps and the various processing routes are not always mutually exclusive. Furthermore, there are often multiple energy and non-energy products or services from a particular conversion route, some of which may or may not have reached commercial levels. Figure 1 shows only the energy-related products or fuels; simple combustion is assumed and not pictured, in order to simplify the diagram. So-called second generation biofuels include those produced through Fischer-Tropsch synthesis (F-T in Figure 1) as well as ligno-cellulosic conversion to ethanol. First-

generation biofuels include oil crops esterified into biodiesel and direct fermentation of sugar and starch crops.

Due to the variety of conversion options and final products, it is more difficult to make comparisons of efficiency in biomass utilization than it is for other energy options; bioenergy extends across all energy carriers and involves many different pathways and processes. The efficiency of biomass and bioenergy production needs to be assessed across the various parts of the chain—from the land and inputs used for cultivating biomass through intermediate processing to the useful energy that can be harnessed for particular products and applications.

On the agricultural or resource side, efficiency depends on choosing crop species and varieties well-suited to local soils and climate. In Brazil, for example, over 500 varieties of sugar cane are used for bio-ethanol production, some of which are designed and developed for optimal growth in particular micro-climates. The productivity of biomass crops grown in tropical and sub-tropical regions, in terms of energy per unit of land, is 4-6 time higher on average than typical crops grown in the temperate climates of Europe. But even within Europe, there is considerable variation in the productivity of different energy crops



Source: EC DG-TREN, 2006

Figure 2 Steps and resources in biomass conversion to energy products and fuels

In terms of minimising overall losses in the industrial conversion side of the production chain, the most efficient use of biomass for energy is for heat, including combined heat and power, where overall system efficiencies can be as high as 80-90%. Matching conversion systems to the scale and structure of demand for heat and power is necessary to minimise costs. Some conversion systems are technologically mature for use of biomass, such as steam turbines and steam engines. Other systems are still under development, such as Stirling engines and the Organic Rankine cycle. Systems differ in scale efficiencies, service requirements, and other characteristics; choice of the optimal system is thus often site-specific (Vamvuka et al, 2007).

Liquid and gaseous biofuels are useful in extending the value of biomass to other sectors, including transport sector or in substituting for natural gas. The efficiency in conversion tends to be on the order of 55-65%. Biogas from animal wastes and other types of "wet" biomass is produced through anaerobic digestion, which is the decomposition of biomass using micro-organisms in a low-oxygen environment. Biogas can be used for many different applications: direct use for cooking or heating, electricity generation, compression for use in transport, or it can also be fed into the natural gas grid after clean-up or purification.

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6. Discussion

Dr. Muhammad Pervaz,

For South Asia, edible oils may not be a good option to use for Biodiesel. Ethanol, I think at least for the countries having sugar cane like Bangladesh, Pakistan, India and Sri Lanka etc can adopt for Bioethanol. I think, here, the role of having countries is to share the best practices and aspects such as where the technologies are available (in which countries) with each other (South-South cooperation). For example, in the morning, it was mentioned that India is having molecular sieve technology in getting ethanol.

Mr. Xavier Johnson

In the South Asian region where there is a dense population, you want to go for the non-edible oil to avoid conflicts. As you move into a regional assessment of opportunities, it would become important to think about supply and demand for the region as a whole. Clearly, some regions would be in surplus and other in a deficit. You can have the advantage of economies and so rather than just keeping buying oil from rich countries, we can buy biofuels from each other. I think it is a better solution.

Mr. N de S Cooke

What are the non-edible sources (Crops) of Ethanol? What are the implications of using edible crops for fuel production with respect to the Kyoto Protocol and Carbon Credits?, What is Sweet Sorghum and is it edible?

Mr. Xavier Johnson

In terms of agricultural crops, because it is a biological process of starches, Ethanol sources are mostly edible. It is different from Biodiesel in that respect. Once you go the 2nd generation, you are using woody sources which are all non-edible. For the 2nd generation you have less conflicts arising. Sweet Sorghum is a different variety from Gram Sorghum. It grows quite a lot in Africa and US. I am not sure how much it is grown in Asia, and I guess it is less popular. There is in India and China, who have developed some varieties that are promising. The distinction between edible and non-edible is not made in the Kyoto Protocol yet. From Biofuels getting credits from the Kyoto Protocol is quite complicated. Reasons for some might be medical, some might be political, and some people say that the chairman of the CDM is a Brazilian, there can be political reasons. The analytical reason is that they have to have a baseline, and they have to have a defined system, and complication in the case of Biofuels is because you have to account for where the fuels are going

and where they are going to be used. It may be one country produces and fuel is used elsewhere. In the global commodity markets, it is more difficult to develop the methodologies for the CDM and difficult to get credits. It is necessary to remember that replacing oil is not as good as replacing coal because of the big difference in Carbon impact.

Dr. C S Kalpage

(Referring to the slide 25) What I have heard is, for Ethanol, energy balance is about 1.25 maximum.

Mr. Xavier Johnson

It is not the life cycle cost. The figure 7 is too high (as per slide 25). This is without considering the plantation and processing. Whole chain is included and you need fossil fuels such as petrol 0.85 to 0.9 to run the machines and fertilize. They are included

Biofuel as a Carbon Asset: A New Link in Value Chain

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*Department of Public Enterprises; **Nature Solutions Private Ltd, Sri Lanka

Abstract

Carbon assets created as a result of the development and use of sustainable biofuel as an alternative to can be traded in the new international carbon market introduced by the Kyoto Protocol. The Kyoto Protocol to United Nations Framework Convention on Climate Change (UNFCCC) adopted in 1997 has provided rules and guidelines for this new international market of Carbon trading. Under this new market mechanism, reductions of emissions of Green House Gases (GHG) by industries or any entity can be traded at international market that is around tons CO₂ 5.5 billion at competitive prices. The emission reductions due to the development and use of Bio-fuels are eligible for carbon trading. Therefore this new market is an opportunity for promoting bio-fuels particularly the second generation bio-fuels that are economically not viable at present. When developing bio-fuel under the carbon trading, the source of the biological material and the energy cost for the processing of such materials should be considered seriously. Studies have illustrated that unsustainable bio-fuels emit more emissions than fossil fuels. Therefore the life cycle analysis (LCA) of bio-fuel should be undertaken to see whether the bio-fuels has net emission reductions. The biofuels that have net emission reductions are eligible for carbon trading. The revenues of trading the emission reductions of biofuel use should be recognized as value chain of the biofuel in order to attract investors for this industry.

Key words: Carbon assets, Green House Gas Emissions, Certified Emission Reductions.

1. Introduction

Bio-fuel has been widely promoted throughout the world as a marketable alternative to fossil fuel in order to combat global warming and climate change. Increase use of fossil fuel and resulted emission of green house gases (GHG) is the major reason for global warming. During the last century atmospheric concentration of carbon dioxide (CO₂) has increased from 270 ppm in 1870 to 360 ppm in 1990. Carbon dioxide (CO₂) is considered as major Green House Gas (GHG) in the atmosphere. Burning fossil fuel is the major source of CO₂ emissions which cause great environmental impacts. The bio-fuels derived from sustainable sources of green matter are considered as carbon neutral. There are no environmental impacts from using bio-fuel. Therefore the use of bio-fuel has become a world trend.

Bio-fuel can be broadly defined as solid, liquid or gas fuels that are derived from recently dead biological material. There are two common strategies of producing biofuels. One is to grow crops that have high level of either sugar (sugar cane, sugar beet, and sweet sorghum) or starch (corn/maize), and then use yeast fermentation to produce ethyl alcohol (ethanol). The second is to grow plants that contain high amounts of vegetable oil, such as oil palm, soybean, algae, or jatropha. When these oils are heated, their viscosity is reduced, and they can be burnt directly in a diesel engine,

or the oils can be chemically processed to produce fuels such as biodiesel. Wood and its byproducts can also be converted into biofuels such as wood gas, methanol or ethanol fuel. It is also possible to make cellulosic ethanol from non-edible plant parts, but this can be difficult to accomplish economically.

Biofuels can be divided into few generations. The first generation biofuels include Vegetable Oil, Biodiesel, Bioalcohols, Biogas, Solid biofuels and Syn gas. The common types of raw materials used for the first generation biofuels are a) for biodiesel, Jatropha, Algae, Copra, Soy beans, Sunflower, Sugar cane, Rubber seeds, Sesame & Vegetable waste; b) for Bio Ethanol Sugar cane and Starch; c) for Biogas municipal solid waste and solid waste. The second generation biofuels which derive from non-food crops (Bio mass to Liquid fuel) include DMF – Dimethylfuran, Biohydrogen, Biomethanol, DMF, Bio-DME, Fischer-Tropsch diesel, Biohydrogen diesel and mixed alcohols and wood diesel. Algae fuels are considered as the 3rd generation fuels. Algae are low-input, high-yield feedstock to produce biofuels. It produces 30 times more energy per acre than land. With the higher prices of fossil fuels (petroleum), there is much interest in algaeculture (farming algae). The 1st generation biofuels are used at present. The 2nd and 3rd generation biofuels are also known as advanced biofuels and they are still at under developing. The fourth generation biofuels

convert vegoil & biodiesel into gasoline.

A higher percentage of fuel is consumed in transport section. Therefore biofuels in liquid form can be used for the transportation. At present most of the 1st generation biofuels are replacing the traditional or non-conventional fuels since they are commercially viable. It has already created social issue as a result of using food crops for producing bio-fuel. This has raised the “Food vs. Energy” debate.

In order to combat the effect on Global Warming & Climate Change due to carbon dioxide emission it is better to use biofuels rather than the use fossil fuel. However, not all biofuels protect climate system. Even though the use of some biofuels reduces carbon dioxide emission in some cases the carbon emission in the biofuel life cycle is approximately same as that of the fossil fuels.

The GHG savings associated with a bio-fuel vary greatly depending on the area where the input material grows and how the feedstock is converted to biofuel. The emissions due to collection and processing of biological materials that are used for producing biofuel should be estimated to understand the effectiveness of biofuel for mitigation of GHG emissions. In the case of some biofuels when all the emissions related to processing of biological materials used for producing biofuels are added together the final biofuel can actually lead to more GHG emissions than that of fossil fuel. This is the situation in the case of some bioethanol produced in the USA. Nevertheless many biofuels can result in reduction of emissions and some can lead to significant reductions. The 2nd generation biofuels can reduce carbon emission more than fossil fuel. However the second generation biofuels are still not economically viable. Even though some bio-fuels are not economically viable, internationally they are promoted due to various reasons including a) Renewable Energy Source, b) More Carbon Neutral, c) Reduce Reliance of Oil Imports; d) Enhance National Security; e) Economic Opportunities; f) Can grow domestically and g) Reduce Emissions. In view of these benefits, various economics and policy instruments are being used by countries to promote biofuels. The carbon trading under the Clean Development Mechanism (CDM) provided the Kyoto Protocol can provide opportunities for the development of biofuels in the world. This paper undertakes an analysis on how carbon trading benefits can be used to promote bio-fuel in the world.

2. Kyoto Protocol and Carbon Trading

The Kyoto Protocol is an international treaty adopted under the United Nations Framework Convention on Climate Change (UNFCCC) to strengthen the international response to climate change. Adopted by consensus at the third session of the Conference of the Parties (COP-3) to the UNFCCC in December 1997 in Kyoto, Japan, it has imposed legally binding emission reduction targets for 39 developed countries (Annex 1 countries) for the post-2000 period. Developed countries have committed themselves to reducing their collective emissions of six key greenhouse gases (GHG) by at least 5.2% from their total GHG emission in 1990. The key GHGs of which emission reductions have been agreed under the Kyoto Protocol are Carbon Dioxide (CO₂), Methane (CH₄), Nitrous Oxide (N₂O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulfur hexafluoride (SF₆). This emission reduction will be achieved through emission cuts of 8% by most Central and East European states and the European Union, 7% by the USA, and 6% by Canada, Hungary, Japan, and Poland. Russia, New Zealand, and Ukraine have 0 targets while Norway may increase emissions by up to 1%, Australia by up to 8%, and Iceland 10% during the commitment period 2008-2012. Developing countries that have no legal commitments under the Kyoto Protocol can assist the 39 developed countries to reduce GHG emissions by implementing emission reduction projects and charge a price for their emission reduction from developed countries. This is called Clean Development Mechanism (CDM) or carbon trading (www.unfccc.int/cdm) [9].

3. Clean Development Mechanism

The Kyoto protocol introduced three flexibility mechanisms for developed countries to implement their emission reduction targets. They are Clean Development mechanism (CDM), Joint Implementation (JI), and Emission Trading (ET). Of these three mechanisms, only CDM is applicable for developing countries.

Clean Development Mechanism (CDM) is defined in the Kyoto Protocol (Article 12) as a mechanism for North- South cooperation. The objective of the CDM is to “assist countries included in Annex 1 (developed countries) in achieving compliance with their quantified emission limitations and reduction commitments under Article 3” and to support “sustainable development” in developing countries (www.unfccc.int/cdm). The Clean

Development Mechanism (CDM) and associated carbon trading between developed and developing countries have received great international attention since it is the only mechanism that both developed and developing countries can participate. Implementing projects in developing countries, that reduces emissions of GHG or absorbs GHG from the atmosphere and selling the amount avoided or absorbed to developed countries is called CDM or carbon trading.

Carbon trading can be undertaken by implementing two types of projects: Emission avoidance projects and Green House Gas Removal or sink projects. Therefore, Projects on energy, industries, agriculture, waste water and forestry are eligible for Carbon Trading. The type of projects that have been submitted for carbon trading include biomass-fired co-generation, landfill gas capture, wind power, hydropower, biomass-fired power generation, fuel switching, energy efficiency, waste to energy, technology upgrading in cement industry and HFC Control project.

4. Project Development Process and Institutional Framework for CDM

The process of development of a project for carbon trading includes the following steps:

1. Project developer or investor develops the project concept note on CO₂ emission reduction project
2. The Designated National Authority (DNA) which is the Ministry of Environment and Natural Resources issues a letter confirming that the project meets the sus-

tainable development criteria of the country

3. The project developer prepares the Project Design Document (PDD), details of emission reductions and monitoring of the project
4. The Designated Operational Entity (DOE) which is accredited by the UNFCCC CDM Executive Board validates the PDD and send it to the UN Executive Board for registration
5. The CDM Executive Board (EB) registers the project, if it is eligible
6. The project developer implements the project
7. After one year of project implementation, the project developer contacts again a Designated Operational Entity (DOE) for verification of actual emission reductions during the previous year
8. The Designated Operational Entity (DOE) sends the verification report to the CDM Executive Board (EB)
9. The CDM Executive Board (EB) issues the Certified Emission Reductions (CERs)
10. The project developer sells the CERs through bi-lateral agreement or carbon trading exchanges

The Marrakech Accord agreed the CDM Project Cycle for the implementation purpose (Figure 1).

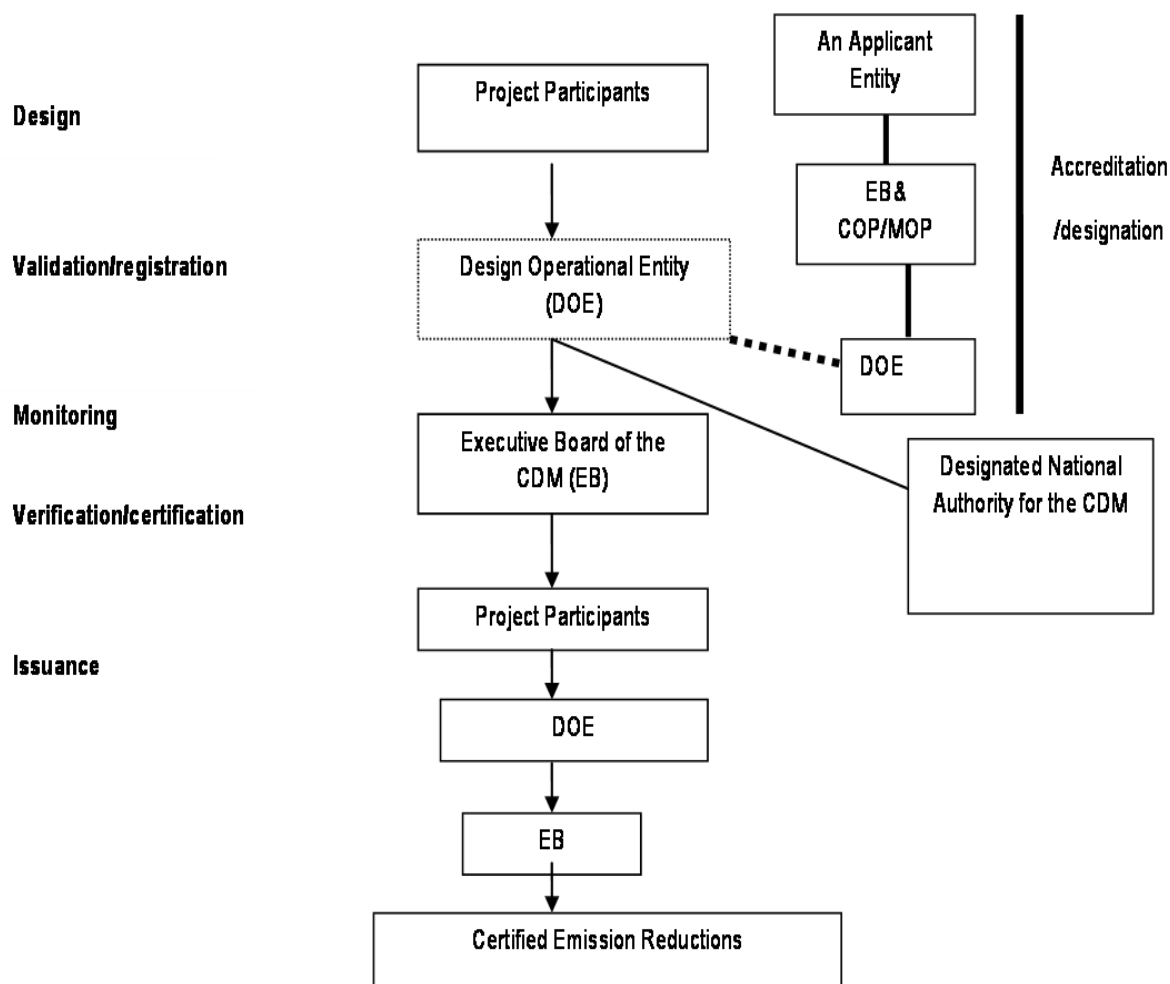


Figure 1 CDM Project Activity Guide

5. International Carbon Market

The Kyoto Protocol has created a large international market for emission reductions of about 5.0 to 5.5 billion tons of Carbon Dioxide equivalents (CO₂e). The regulatory framework of the carbon market has been established considerably with the enforcement of Kyoto Protocol on February 16, 2005. With the registration of more than 950 Clean Development Mechanism (CDM) projects by the CDM Executive Board by March 2008, the CDM market is now certain. The 950 CDM projects registered up to March 2008 are expected to reduce 1170 M t/CO₂ e by 2012 at the rate of 193 M t/CO₂ e per year. Figure 1 illustrates the distribution of CDM project in developing countries. The estimated market potential of the carbon trading is 250 MtCO₂e (range from 50 to 500 MtCO₂e) per year at a price of \$15.00 tCO₂e (range ± 50%). This represents a total demand of 1250 MtCO₂e by 2012. The minimum demand by industries in

Europe and the planned purchases by governments yield an annual demand of at least 100 MtCO₂e. The median demand by industries in Europe combined with the estimated government purchases yields a potential demand for Certified Emission Reductions (CERs) and Emission Removal Unit (ERUs) of roughly 230 MtCO₂e in 2010.

In order to tap this emerging international carbon market, various countries including multi-lateral organizations have established Carbon Funds i.e World Bank- Prototype Carbon Fund, Community Development Carbon Fund, Bio-carbon Fund, Dutch Carbon Fund, The Netherlands Carbon Development Fund, Andean Development Bank, European Bank for Reconstruction and Development, Denmark JI/CDM Fund, Development Bank of Japan, Japan Bank for International Corporation, Spanish Carbon Fund, Belgium Carbon Fund. In addition to these funds individual private companies also purchase emission reductions

from developing countries. Several emission trading exchanges have been established to facilitate private sector to engage in this market, i.e. Chicago emission trading exchange. The annual transactions of these markets are around US\$ 1000 M. Therefore, this has become a large international market opportunity for developing countries like Sri Lanka [1]. Table 1 presents the

estimated total national potential for carbon trading including biofuel CDM potential.

Many developing countries including India, Malaysia and Brazil have established mechanisms to reap the benefit of this emerging international market

Table 1 Sri Lanka National CDM Potential by Sectors for strategic development

Sector	Annual Energy Reduction/ Substitution potential/year	Annual CO ₂ Reduction Potential tons CO ₂ /year
Hydro Power	250 MW	613,200
Wind	480 MW	672,768
Biomass (Grid Power)	300 MW	1,680,000
Biomass (Industrial Heat)	162 toe	512,000
Biomass (Absorption Refrigeration)	100 MW	400,000
Energy Conservation: Electricity (Industry)	20,400 toe	64,700
Energy Conservation: Petroleum (Industry)	36,000 toe	113,800
Transport	206,000 toe	600,000
Agro Residue-Rice Husk	20 MW	112,000
Agro Residue-Sawdust	20 MW	112,000
Municipal Solid Waste	500000 toe	500000
Forestry	100000 ha	1,352,000
Total		6,732,468

Toe: Tonees of oil equivalent
Source: Batgoda et al. 2007

6. Biofuels as Carbon Assets

Biofuels developed using sustainable sources of biological materials and other forms of renewable energy are assumed to be carbon neutral or even carbon negative. Carbon neutral means that the carbon released during the use of the fuel, e.g. through burning to power transport or generate electricity, is reabsorbed and balanced by the carbon absorbed by new plant growth. These plants are then harvested to make the next batch of fuel. Carbon neutral fuels lead to no net increases in human contributions to atmospheric carbon dioxide levels, reducing the human contributions to global warming. A carbon negative aim is achieved when a portion of the biomass is used for carbon sequestration. Calculating exactly how much greenhouse gas (GHG) is produced in burning biofuels is a complex and inexact process, which depends very much on the method by which the fuel is produced and other assumptions made in the calculation.

The carbon emissions (Carbon footprint) produced by biofuels are calculated using a technique called Life Cycle Analysis (LCA). This uses a "cradle to grave" or "well to wheels" approach to calculate the total amount of carbon dioxide and other greenhouse gases emitted during biofuel production, from putting seed in the ground to using the fuel in cars and trucks. Many different LCAs have been done for different biofuels, with widely differing results. The majority of LCA studies show that biofuels provide significant greenhouse gas emissions savings when compared to fossil fuels such as petroleum and diesel. Therefore, using biofuels to replace a proportion of the fossil fuels that are burnt for transportation can reduce overall greenhouse gas emissions. The well-to-wheel analysis for biofuels has shown that first generation biofuels can save up to 60% carbon emission and second generation biofuels can save up to 80% as opposed to using fossil fuels.[2] However these studies do not take into account emissions from nitrogen fixation, deforestation, land use, or any indirect emissions. A study reported that the burning of biofuels derived from rapeseed and corn (maize) can contribute as much or more to global warming by nitrous oxide emissions than cooling by fossil fuel savings. Nitrous oxide is both a potent greenhouse gas and a destroyer of atmospheric ozone. But they also reported that crops with lower requirements for nitrogen fertilizers, such as grasses and woody coppicing will result in a net absorption of greenhouse gases. [3][4]

Two articles were published in Science In February 2008, which investigated the GHG emissions effects of the large amount of natural land that is being converted to cropland globally to support biofuels development.^[5] The first of these studies, conducted at the University of Minnesota, [6] found that converting rainforests, peatlands, savannas, or grasslands to produce food-based biofuels in Brazil, Southeast Asia, and the United States creates a 'biofuel carbon debt' by releasing 17 to 420 times more CO₂ than the annual greenhouse gas (GHG) reductions these biofuels provide by displacing fossil fuels.

This study not only takes into account removal of the original vegetation (as timber or by burning) but also the biomass present in the soil, for example roots, which is released on continued ploughing. It also pointed out that biofuels made from waste biomass or from biomass grown on degraded and abandoned agricultural lands planted with perennials incur little or no carbon debt and can offer immediate and sustained GHG advantages.^[6]

The second study, conducted at Princeton University, [7] used a worldwide agricultural model to show that:

...corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years.

Both of these studies highlight the need for sustainable biofuels, using feedstock that minimizes competition for prime croplands. These include farm, forest and municipal waste streams; energy crops grown on marginal lands, and algae. These second generation biofuels feedstock are expected to dramatically reduce GHGs compared to first generation biofuels such as corn ethanol". In short, biofuels done unsustainably could make the climate problem worse, while biofuels done sustainably could play a leading role in solving the carbon challenge. [7]

The Figure 2 presents the carbon intensity of bioethanol and fossil fuels used in the United Kingdom [8]

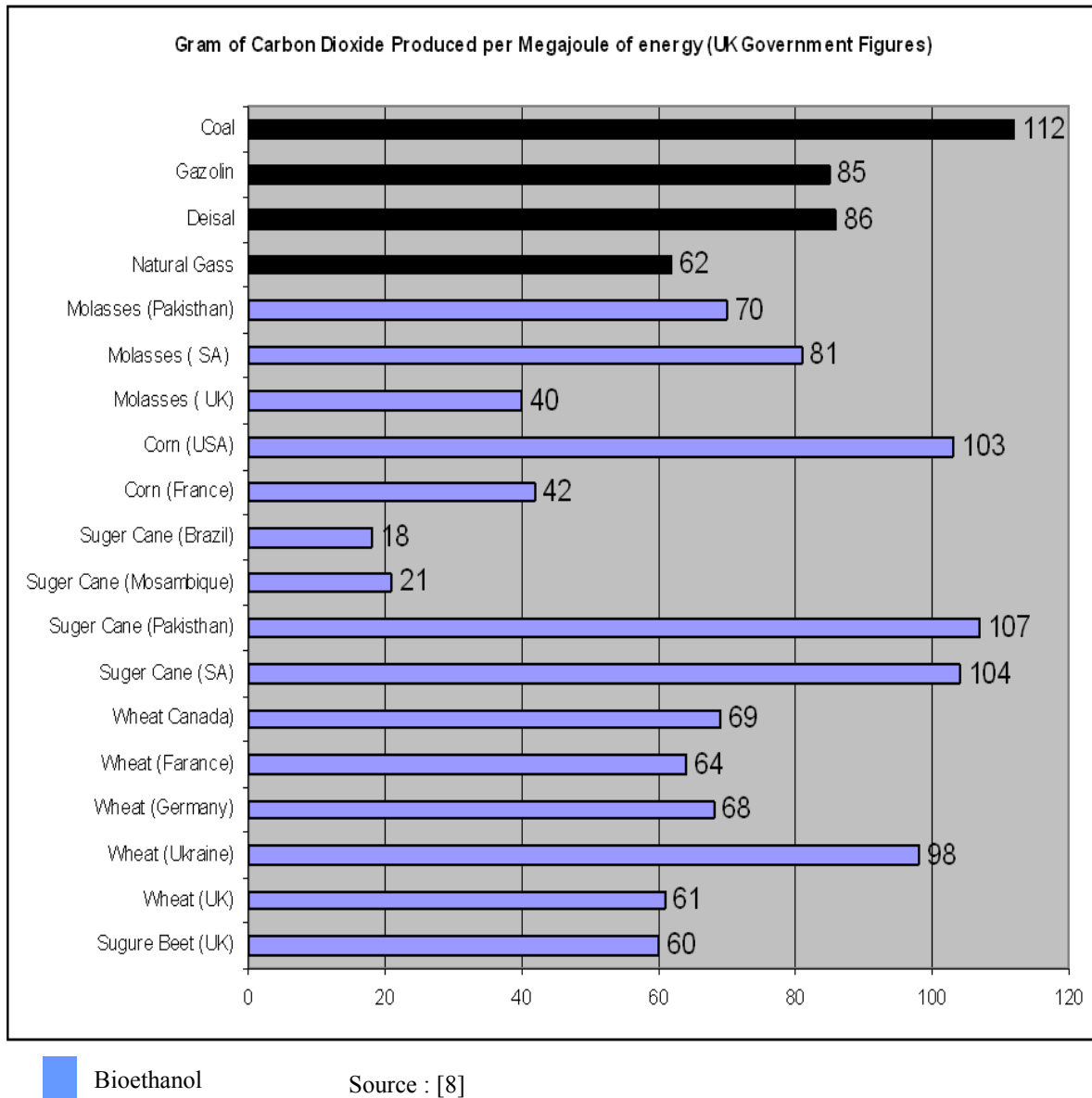


Figure 2 Carbon emissions

The Figure 1 indicates that some bioethanol produced more carbon dioxide than from fossil fuel.

The rule of thumb for carbon trading is that the proposed project activity should reduce the GHG emissions from the business as usual scenario. As illustrated in the previous section therefore only the sustainable biofuels can reduce GHG emissions and can be qualified for carbon trading benefits. Unsustainable bio-fuels that really increase the GHG emissions with compared to fossil fuel create a “biofuel carbon debt” are not qualified for carbon trading under the Kyoto Protocol.

Therefore the use of sustainable bio fuels as substitutes for fossil fuels would result in substantial emission reductions. Bio diesel (treated vegetable oil); bio ethanol (ethyl alcohol) and bio methane (from anaerobic digestion of perishable biomass) are being used in varying extent in many countries as substitutes for fossil fuels in transport application. These exercises are carried out not for economical reasons but as strategies to ensure energy security and for environmental considerations.

In Sri Lanka, all three options of bio diesel, bio ethanol and bio methane could be applied in varying extent. Bio diesel and bio ethanol production

would compete for land for food and solid fuel production. On the other hand the vast amount of agro residues such as straw, animal dung, perishable municipal wastes etc. could be deployed to generate bio methane and utilized as fuel for the transport sector. The bio residues produced annually in the country could generate 3200 cubic meter of biogas equivalent to 1.6 million tonnes of diesel. This is nearly 75% of our national fossil fuel used in the transport sector. As mentioned earlier, Sri Lanka could target a 10% reduction of the transport sector emissions, which amounts to approximately 600,000 tonnes of CO₂ emission reductions under CDM [1].

According to the Energy Balance 2003 provided by the Energy Conservation Fund the transport sector consumed 2,060,000 tonnes of petroleum fuels in 2003. This is growing at around 8% per annum. Emissions from the above quantities of fuels amount to 6.5 million tonnes of CO₂ per year. If this could be reduced by 10%, 600,000 tonnes of CO₂ reductions could be sold as CERs [1].

7. Fuel Wood as Biofuel

Petroleum fuels consumed by the industrial sector are utilized entirely for industrial heat applications. These could be replaced by sustainable fuel-wood from dedicated energy plantations. In fact several industries have already implemented a scheme to replace part of the furnace oil consumed for industrial drying with sustainable fuel-wood. In order to implement this proposal the industry concerned could introduce a biomass gasifier to convert fuel-wood into a combustible gas and use this gas in the equipment (furnace or boiler) that earlier consumed petroleum fuels or replace the equipment (furnace or boiler) with one suitable for fuel-wood directly. The former option is lower in capital cost but cannot be implemented in all situations. The second option is applicable to all cases, but has a much higher capital cost. Moreover, switching from petroleum fuels to fuel-wood may not be feasible in congested urban locations.

From a technical and economical point of view almost all the heat energy requirement of the industrial sector could be met from renewable resources, particularly by the use of bio fuels. The only exceptions are applications where electrical heating is the only option due to hygienic conditions. At the prevailing costs of fossil fuels and fuel-wood from sustainable energy plantations, on an energy equivalent basis, fuel-wood costs one fourth to one seventh the cost of fossil fuel

(depending on which fuel- furnace oil, diesel or LPG is used).

Assuming 10% of the present fossil fuel consumed by the industrial sector is reduced by energy conservation measures, and 50% of the balance is replaced by bio fuels, the potential for GHG emission reduction amounts to 512,000 tonnes of CO₂.

8. Municipal Solid Waste as Biofuel

The average quantity of municipal solid waste generated is estimated to be 0.5 kg/person/day. The total tonnage of municipal waste generated in Sri Lanka is estimated as 2,838 tonnes per day. Direct burning of municipal garbage is not appropriate for two reasons. Firstly the moisture content of garbage as received is very high, resulting in very little net energy out put. Secondly, some of material in the waste such as plastics and nitrogenous materials are not suitable for combustion. The average composition of Sri Lankan municipal garbage is as follows:

Combustibles (wood etc.):	25%
Organic (vegetable wastes, leaves etc.):	59%

Attempts made to dispose municipal garbage in sanitary land fills have not materialized due to failure to identify suitable land fill sites which could be acceptable to the surrounding communities. A project has been initiated to utilize the Colombo garbage to extract methane and to utilize it to generate electricity to be sold to the national grid. Garbage landfills emit methane and carbon dioxide by the anaerobic decomposition of organic materials, and contribute to GHG in the atmosphere. By inserting pipes of appropriate sizes at appropriate locations in the garbage pile, it is possible to capture these gases and utilize it to generate electricity and feed it to the national grid.

The avoided methane emission from municipal solid waste is used as baseline when developing waste management project for carbon trading. Following equation [11] is used for estimating the methane emissions and equivalent carbon dioxide from open dumping of municipal waste.

$$BE_{CH_4,SWDS,y} = \phi \cdot (1-f) \cdot GWP_{CH_4} \cdot (1-OX) \cdot \frac{16}{12} \cdot F \cdot DOC_r \cdot MCF \cdot \sum_{j=1}^y \sum_{x=1}^y W_{j,x} \cdot DOC_j \cdot e^{-k_j(y-x)} \cdot (1-e^{-k_j})$$

Where:

$BE_{CH_4,SWDS,y}$	= Methane emissions avoided during the year y from preventing waste disposal at the solid waste disposal site (SWDS) during the period from the start of the project activity to the end of the year y (tCO ₂ e)
ϕ	= Model correction factor to account for model uncertainties (0.9)
f	= Fraction of methane captured at the SWDS and flared, combusted or used in another manner
GWP_{CH_4}	= Global Warming Potential (GWP) of methane, valid for the relevant commitment period
OX	= Oxidation factor (reflecting the amount of methane from SWDS that is oxidised in the soil or other material covering the waste)
F	= Fraction of methane in the SWDS gas (volume fraction) (0.5)
DOC_r	= Fraction of degradable organic carbon (DOC) that can decompose
MCF	= Methane correction factor
$W_{j,x}$	= Amount of organic waste type j prevented from disposal in the SWDS in the year x (tons)
DOC_j	= Fraction of degradable organic carbon (by weight) in the waste type j
k_j	= Decay rate for the waste type j
j	= Waste type category (index)
x	= Year during the crediting period: x runs from the first year of the first crediting period ($x = 1$) to the year y for which avoided emissions are calculated ($x = y$)
y	= Year for which methane emissions are calculated

For this equation following values were used to estimate the results in Table 2.

For this calculation values for the above parameters are as follows:

$$\Phi = 0.9, \quad OX = 0.1, \quad F = 0.5, \quad f = 0, \\ DOC_r = 0.5, \quad MCF = 0.8, \quad GWP_{CH_4} = 21$$

Table 2 presents the annual methane emissions and equivalent CO₂ from one ton of municipal waste from Colombo municipal council for a 20 year period. If bio-fuels are produced using one ton of municipal waste the amount of CO₂ in the Table 2 can be traded as certified emissions reductions under the Clean Development Mechanism (CDM) or carbon trading.

Table 2 Methane (CH₄) emission from 1 ton of waste for a period of 20 years

Year	Ton CH ₄ / ton of waste	Tons CO ₂ equivalent/ ton of waste
1	0.01	0.216
2	0.0081	0.170
3	0.0067	0.140
4	0.0055	0.115
5	0.0045	0.095
6	0.0037	0.078
7	0.0031	0.065
8	0.0026	0.055
9	0.0022	0.047
10	0.00188	0.040
11	0.001645	0.035
12	0.00141	0.030
13	0.001269	0.027
14	0.001128	0.024
15	0.001034	0.022
16	0.00094	0.020
17	0.000846	0.018
18	0.000799	0.017
19	0.000752	0.016
20	0.000705	0.015
Total emission for 20 years	0.058808	1.245

The carbon trading potential of production of biofuel varies depending what fuel it replaces (Table 4) and how much energy it consumes for the processing of the biofuel. In other word if a particular biofuel is used to replace diesel the amount of emission reduction is higher than if the same biofuel is used to replace the natural gas. Similarly the project emission or the energy used to process the biofuel has significant impacts on the total net emission reductions. Table 3 presents the biofuel processing efficiency and total emission reductions, which are useful for estimating the carbon trading potential of biofuels.

Table 3 Biofuel processing efficiency and total emission reduction

Fuel	Feedstock/ location	Process	Well-to-tank		Well-to-wheels	
			Process energy efficiency (energy in/ out)	Percent efficiency	CO ₂ -eqv. GHG emissions g/km	GHG% reduction v. gasoline/ diesel
Diesel	Petroleum	Refining	1.10	91%	198	
Biodiesel	Rapeseed (local)	Oil to FAME (transesterification)	1.60	62%	123	38%
Biodiesel	Soybeans (local)	Oil to FAME (transesterification)	1.43	70%	94	53%
Diesel	Biomass – eucalyptus (Baltic)	HTU biocrude	1.47	68%	79	60%
Diesel	Biomass – eucalyptus (Baltic)	Gasification/ F-T	2.35	43%	-16	108%
Diesel	Biomass– Eucalyptus (Baltic)	Pyrolysis	3.31	30%	72	64%
DME	Biomass – eucalyptus (Baltic)	Gasification/ DME conversion	1.78	56%	22	89%
Gasoline	Petroleum	Refining	1.20	83%	231	
Gasoline	Biomass– eucalyptus (Baltic)	Gasification/ F-T	2.71	37%	-10	104%
Ethanol	Biomass– poplar (Baltic)	Enzymatic hydrolysis (CBP)	1.94	51%	-28	112%
Ethanol	Biomass– poplar (Brazil)	Enzymatic hydrolysis (CBP)	1.94	51%	-28	112%
Ethanol	Biomass– poplar (local with feedstock from Brazil)	Enzymatic hydrolysis (CBP)	1.94	51%	-3	101%
Ethanol	Com (local)	Fermentation	2.25	45%	65	72%
Hydrogen	Biomass – eucalyptus (Baltic)	Gasification	2.41	42%	11	95%
CNG	Biomass – eucalyptus (local)	Gasification	1.69	59%	39	83%

Note - CBP: combined bioprocessing. F-T: Fischer Tropsch process

Source: [10]

Table 4 Carbon trading potential of biofuel

Source of Biofuels	Biofuel	Possible fuels avoided by using biofuel
Sustainable Fuelwood	Solid fuel	Industrial Heat – Diesel
		Industrial Heat - Fuel oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft -Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
		Bioethanol - Transport – Petrol
Unsustainable Fuelwood	Solid fuel	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
		Bioethanol - Transport – Petrol
Municipal Solid Waste	Biogas	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
		Transport – Petrol
	Bioethanol	Transport fuel additives
		Transport Petrol
	Compressed Methane	Transport Diesel
		Industrial Heat –Diesel
	Solid fuel	Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
	Compost	Chemical Fertilizer
Sugar Cane	Bioethanol	Petrol - Transport
		Fuel Additives
Sugar Molasses	Bioethanol	Petrol - Transport
		Fuel Additives
Corn	Bioethanol	Petrol - Transport
		Fuel Additives
Cassava	Bioethanol	Petrol - Transport
		Fuel Additives
Sweet Sorghum	Bioethanol	Petrol - Transport
		Fuel Additives
Cellulose (Saw dust/ wood/ straw/ grasses)	Bioethanol	Petrol - Transport
		Fuel Additives

Table 4 Carbon trading potential of biofuel (Cont'd)

Source of Biofuels	Biofuel	Possible fuels avoided by using biofuel
Jatropha	Biodiesel	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
Pongamia	Biodiesel	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
Sunflower	Biodiesel	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
Soyabean	Biodiesel	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
Algae	Biodiesel	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
Copra	Biodiesel	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
Waste Vegetable Oil	Biodiesel	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power

Table 4 Carbon trading potential of biofuel (Cont'd)

Source of Biofuels	Biofuel	Possible fuels avoided by using biofuel
Combustible Agricultural Waste	Solid fuel	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
	Bioethanol	Transport – Petrol
		Transport fuel additives
Digestible Agricultural Waste	Biogas	Industrial Heat –Diesel
		Industrial Heat -Fuel Oil
		Industrial Heat – LPG
		Industrial Heat - Grid Electricity
		Industrial Shaft - Grid Electricity
		Industrial Shaft – Diesel
		Utility Grid Power
	Bioethanol	Transport – Petrol
		Transport fuel additives
	Compressed Methane	Transport - Petrol
		Transport - Diesel

9. Conclusions

The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) adopted in 1997 has created a new international market of Carbon trading. This new market has a demand of 5.5 billion tons of GHG emission reductions equivalent to Carbon Dioxide (CO₂). The emission reductions due to the development and use of Bio-fuels are eligible for carbon trading under the Kyoto Protocol. This new market is an opportunity for promoting bio-fuels particularly the second generation bio-fuels that are economically not viable at present. When developing bio-fuel under the carbon trading, the source of the biological material and the energy cost for the processing of such materials should be considered seriously. Studies have illustrated that unsustainable bio-fuels emit more emissions than fossil fuels. Therefore the life cycle analysis (LCA) of bio-fuel should be undertaken to see whether the bio-fuels has net emission reductions. The bio-fuels that have net emission reductions are eligible for carbon trading. The revenues of carbon trading can support the biofuel development initiatives in the world.

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11. Discussion

Dr. Saman Fernando

Can you please tell us how many projects in Sri Lanka have obtained this Carbon Credits, how many have obtained PIN umbers and if there is any minimum tonnage to qualify for CDM?

Dr. Suren Batagoda

CDM is a process consisting of project design, validation, registration, verifications and so forth. We have only 5 projects completed all the steps, eligible and registered with the UNFCC. Those 5 projects generate about 200,000 tons. They are about 15 small hydro projects bundled together. 3 projects which were gone to the UNFCC have been rejected, they were identical projects, with identical timing, identical financing & identified by the owner. These have been rejected for simple reasons, IRR being put wrong, some words being wrong etc. The projects are being reviewed by the panels of different countries. Around 15 projects have been marketed or traded already. Japanese and Norwegian buyers have purchased. But those are still going on the process of validation, registration and not yet completed. There are 10 projects under validation, 4 projects under registration (they have passed the validation phase) and the PIN stages about 75 projects. Around 25 have completed the PDD. The process is so long and the lead time is about 3 years.

Dr. Muhammad Pervaz

Thank you for giving the reality because people should not be in the dark that we will get so much

of benefits. Coming to Kyoto Protocol itself, after Bali convention, they could not come to what would be the fate of the Protocol after 2012. For South Asian countries, we would be happy if you could suggest some thing the countries can share in this sea of trading. You rightly mentioned about Pakistan's Gasohol or Alcohol, but sugar industry has conducted a baseline data and there is one project for Cogeneration. They say it is a very good project. You say their emissions are high and taking their baseline. So are you proposing a CDM project on Cogeneration?

Dr. Suren Batagoda

Cogeneration is okay. But here we are not talking about Cogeneration. The graph shown is for Ethanol. Ethanol is the issue I think. Depending on what you produce, form where and for what, situation would be completely different. Something I could mention in my presentation is the Voluntary Emission Reductions (VERs). I said 3 projects were rejected. Those still can be used in the VER market, which is a voluntary Carbon market. When CER is traded at \$ 20 per ton, VER would be about 25% of it, say \$ 5. VERs are less stringent than the CERs, therefore many projects that are disqualified for CDM market due to very little issues can be still traded at the VER market. If you have 1 MW hydropower, you can reduce easily about 4,000 tones. This means at \$20, almost \$80,000 per year. 1 MW is \$80,000. Still people are not going for it, either may be they know or they do not know, probably they are not exposed to like in India, where India has done a lot of projects. Even though, they can see a big benefit, \$ 80,000 for nothing, still they are not going for it. For this targeted training has to be done. That is why Sri Lanka started with a Carbon Fund as a government initiative with the private sector, which is still struggling to take off.

Mr. P M Kancharla

CDM is more Europe oriented, more regulated by Europe. USA & Australia are reluctant to go along with the CDM protocols. Those markets do not comply with most of the CDM protocols. UK has its own set up. I am trying to give you a generalised picture with my experience with CDM where Cogeneration is a major industry. Biomass projects have been rejected; there is no certainty that a project which was accepted earlier would eventually be a role model for other projects to be accepted. Now most of Biomass projects have been rejected. Though they are rejected, you have the eventuality to go for VERs, which eventually would cover your entire cost of the project. VER presently is about \$12, CER is about \$30. This depends actually if you are trading on any of the

Platforms. There is eventually a cost that accrues with it. If you sell to your buyer directly, like in the Asian region, Japan gives you the best pricing with it. If you sell to your buyer directly, like in the Asian region, Japan gives you the best pricing mechanism and much better than most of the European countries. If you have a direct seller, you negate all the cost that accrues with middle man. It is like you sell on a spot basis or sell on a long term basis. If you are willing to take the risk, you wait for the spot. There is one critical factor. If any emissions savings are due to enforcement of law, it is not acceptable. We have lost CNG conversion in Delhi. It should be voluntary. You should understand the distinction between voluntary and enforcement. You should articulate and clever enough to manipulate within the system and get due advantage.

Dr. Suren Batagoda

Every project is not eligible because it depends on the rules.

Mr. Buddika Gunaratne

What is the best stage to start the application? Is it possible to assume that we start a project and after starting the project, after designing of it in the half way through, we realise that there will be a CDM potential, then can we go and start the process for applying for CDM?

Dr. Suren Batagoda

Ideally it is not possible. CDM rules say you must think about the project with the CDM. In other words, the project is not taking off because of so many reasons and project becomes feasible only if CDM credits come in. But over the last 6-7 years, the CDM executive board did not take this seriously. Even the projects that were commissioned were considered supported with a justifiable additionally. But now they are strict. You need to prove that this project has taken off because of CDM and project started expecting CDM revenue to come in. According to the new rules, within 1 year you have to have the PDD and if not, the validator shall not accept it.

Mr. Buddika Gunaratne

Once you go for CDM process and if the government comes half way through and implements a law what happens?

Dr. Suren Batagoda

That is okay. Otherwise, what will happen is in the whole world, these progressive decisions shall not be taken. If not, once the governments make the decisions, if CDM projects become ineligible.

Therefore, they have decided that any such decision taken prior to 2002 or some where only must be considered.

Mr. Buddika Gunaratne

How do you estimate the Carbon absorption? How do you give value to it, for example in a plantation?

Dr. Suren Batagoda

There are simplified formulae. They give the type of tress, classifying the trees and annual absorption and harvesting rotations etc. You substitute the values and estimate the carbon absorption. For forestry, you are given the default values. This is well established.

Mr. Buddika Gunaratne

When you are looking for a project and doing its feasibility, is it a prudent practice to predict the CDM revenue to see the project's feasibility and if yes, does executive board of CDM look at a minimum IRR kind of a thing to approve a project?

Dr. Suren Batagoda

If you want to make a project feasible, CDM doesn't work. Maximum CDM revenue can be around 20% of your investments; best figure is about 5%. It can capture only about 5% of your investment which is very small. You can't justify the investments with the CDM. Some projects give a good IRR, but the projects are not taken off. IRR calculation is again a hypothetical one. But a developer or a businessman may not care about IRR. Even with a small IRR, a developer may go for it. If you put an IRR of about 30% in the PDD, the project may not get accepted. There are several ways of finding additionally. One reason you may have to prove for not taking off the project would be lower IRR. If so, must bring it (show in the PDD). If you have a high IRR, then do not mention about the IRR, forget it and you talk about something else. You may show technical, policy, investment or environmental barriers.

Mr. Harsha Wickramasinghe

Our country yields under a high cost of urea, which is given a high subsidy. So if we try to convert this urea input into organic compost fertilizer, will that qualify and can we have CDM benefits?

Dr. Suren Batagoda

If you produce compost using a biological method, there are methodologies, justifying avoided dumped methane by producing compost by various methods or avoided chemical fertilizer usage. The idea is if you can use compost for avoiding urea, you can think of CDMs. Unfortu-

nately, the question is there is no methodology so far developed. You have to come up with a new.

Mr. Harsha Wickramasinghe

Urea is a very energy intensive product. So if that kind of energy saving is realised through compost, can we account for the energy saving by avoiding some urea somewhere?

Dr. Suren Batagoda

You have to estimate how much of CO₂ emissions are associated with production of 1 ton of urea, which would be the baseline. If you replace urea with compost, how much of it is reduced. If you could prove CO₂ has reduced, then you can go for CDM. Unfortunately someone else has not developed a methodology and got acceptance by the UNFCCC, so you have to do it new. Developing new methodologies are some times time consuming and complicated. Many people always try to look for what has been done by the other countries.

Mr. P H Kancharla

I am answering Dr. Parvez's comment. There is quite certainty that CDM would go beyond 2012.

Dr. Suren Batagoda

This market is well established. Even by 2012, ideally this should end. But the way it has built up, it is impossible to stop it. It should continue even in some other form. There are many people living on it, many institutions have been built, in every country there are institutions and trained people. It will grow in some other form

Mr. Buddika Gunaratne

What are the trading mechanisms in the market? If we have a CER certificate, what I understand is, I will get annual revenue by selling that amount of CER. What are the kinds of mechanisms or models available because what we notice is that CER prices are going up? If sell my CER certificate to a buyer today, will I get a fixed revenue every year or will I get the price escalation of the market?

Dr. Suren Batagoda

It depends on the way how you trade. At the moment what is happening is when the CDM markets started; developers had no clue about this. Therefore what happened was a buyer who knew the subject got the projects upfront, signing the agreements for about say 20 years at say \$5 saying the proponent has no cost and buyer does the development, validation and everything at no cost. Some people have signed on a 7 years basis, after 7 years, it is renewed after negotiations.

Some people have taken an upfront from 7 years total revenue, say 20% and the balance annually on delivery. There are various other models. Changing the price every 3 years, not fixing the price, but looking at the world price trends and then fixing the price etc depending on the way we like. If you have CERs, you can submit it through any agent or anybody or yourselves, at the carbon Exchange, where at-least 20 such organisations are known by me who trade everyday like the stock exchange. Once you sell, you don't have it any more. Annually you verify your emissions and get a certificate and trade like any other commodity, judging yourself whether to hold it, fix it or not. In case the prices fall, an agreement signed for 20 years would be better. So it is not different to trading any other commodity.

Mr. Buddika Gunaratne

Can a project that got rejected re-apply or put an appeal?

Dr. Suren Batagoda

You can appeal. For example Holcim Puttalam has been rejected and they have appealed. There are appealing procedures. Generally, it is hard for a rejected project to be approved after an appeal, but they can be converted to VERs

Prof. S Subasinghe

In our countries, Nitrogen use efficiency is very low. When you apply for example 100 kg of urea, plants may use only 50 kg or less. If we can improve the use efficiency, may be by granulated urea or mix with organic matter or compost, can we apply for Carbon Credits?

Dr. Suren Batagoda

Theoretically yes. There is something called monitoring. You must have a strong monitoring mechanism as an independent party come to verify you annually. You must have baseline and information and a methodology to quickly verify, when you apply 1 ton of urea what happens to it. You may apply for several farms in many districts, so verifications become difficult if your project becomes too big. You should come up with a nice programme as to how to monitor in the PDD, and then project may get eligible. In some projects, the baseline emissions are important and in some others project emissions are important.

Md. S Rahman

If they sell the certificate and later if the characteristics of the project are changed or if you shut down your project, what would be the consequences?

Dr. Suren Batagoda

Buyers don't take risks. They generally assess the company profile and take due diligence. Upfront payment can be an issue. They may pay only on delivery once verified and UNFCCC issues with the certificate. This is same as any other commodity. There can be insurance coverage, bank guarantees and clauses to protect the buyers from such risks in the contractual sales agreements. There have been instances where even the World Bank has lost \$500,000 upfront payment by taking such incidents.

Mr. Lalith Gunasinghe

In the case of Sri Lanka, Ceylon Petroleum Corporation (CPC) does the refining. Suppose, Lanka Indian Oil Company (LIOC) wishes to bring in diesel with bio Butanol, are they eligible to get credit, even if imported from another country? Or otherwise, they buy it here, but they are not refining here. So will they be eligible to get these credits?

Dr. Suren Batagoda

If they import, I am not sure. If India produces Bioethanol, and we import to Sri Lanka, then that may not be, but it depends. I think I have to look at it

Mr. P M Kancharla

Oil corporates won't get. The distiller will get. The person who manufactured Ethanol would benefit, not the oil corporate. No oil corporate shall benefit from this mechanism.

Dr. Suren Batagoda

Butt you can't say 'no' also.

Mr. N de S Cooke

The retailer of the Biofuel will not, but the end users can earn the Carbon credits as opposed to using fossil fuel

Dr. Suren Batagoda

Not that really. What happens is who is eligible to receive Carbon credits are not defined yet. What is important is the whole process. A first criterion is whether the project avoids some emissions. Then who get the credit is a matter for the involved parties to decide, based on their understandings and conditions. But when two countries are involved, I am not sure. A developed country can go for 'joint implementation' with a developing country. But for 2 developing countries working together, there is still no provision to do a project. I think they are still negotiating on that.

Mr. Amitab Rajouria

Yesterday we came to know that Sri Lanka is planning to construct a transmission line between Sri Lanka and India. So you will be importing as well as exporting power. Nobody will be able to track where the power comes from whether from a thermal power plant or hydro. Say, if Sri Lanka imports from India, it will obviously replace its fossil fuel power generation. So, would Sri Lanka be able to get CDM benefits out of that? We (Nepal) may export to India, so I just wanted to make sure.

Dr. Suren Batagoda

Here we consider the baseline. We consider the entire installed capacity of Sri Lanka, which is about 65% thermal and 35% hydro, where the thermal comes from diesel, furnace oil or heavy fuel. We get average emission factor. There is a methodology to get this using the total power divided by some factors. When we import from India or export to India, the baseline would change and according the emission factor. Also, the Indian installed capacity would now come into the picture. We must get the installed capacity of the Indian system (which applies to this among many grids India may have) and get its average emission factor. The whole picture actually becomes complicated. Rules are there, at the moment we are not using because we don't need to. As for Indian PDDs they sue as they are importing from Bhutan and Nepal. But, CDM is for power projects, how can transmission lines be considered under CDM?

Mr. Amitab Rajouria

I mean, you are constructing a CDM project, transmission line as you are going to replace your fossil fuel and you are avoiding construction of new power plants by importing power.

Dr. Suren Batagoda

I have the think about it. You are thinking Sri Lanka will not generate from coal power because we can cheaply import. I don't think it is possible. In the project to build a transmission line which is to reduce the total emissions jointly by Sri Lanka & India, you have to demonstrate clearly, without the transmission line, what the emissions of the both countries would be relevant to the project. If you can prove that this transmission line reduces 'x' number of emissions either from Sri Lanka or India, yes, then you can look for Carbon benefits.

Biofuel as a Source of Clean Energy: Challenges and Prospects

Prof. J.M.R.S.Bandara
University of Peradeniya, Sri Lanka

Abstract

Hotter days, heavy monsoons (Floods in Bihar, India), strong hurricanes and gusty winds (IKE in Houston, USA), and melting ice in the polar (arctic) regions, are the events resulting from the changes in climate due to the increase in greenhouse gas emissions from modern human activity. These are the direct results of burning of fossil fuels that has led to an increase in the concentration of carbon dioxide (CO₂) and other gases which causes global warming, the warming of Earth's atmosphere due to the greenhouse effect. Deforestation also affects the balance of atmospheric CO₂ since trees utilize this gas during photosynthesis and trap in photosynthate as carbohydrate. Greenhouse gases emitted at natural levels however maintain Earth at an average temperature of 15°C and make Earth more habitable to humans and animal. If not for this natural level of Green house gases in the atmosphere, the average temperature of Earth would be about -17.55°C. An alternative fuel based on renewable biomass is considered eco-friendly compared to petroleum fuels. This renewable biomass such as wood, along with bio-fuels (such as ethanol, methanol, and bio-diesel) also emit CO₂ when burned, the amounts of CO₂ produced is comparable to fossil fuel per unit of energy obtained. However, unlike fossil fuel, biomass based biofuels, when produced in a sustainable manner form a complete carbon cycle. Fossil fuel burning not only causes Greenhouse effect but create an hazardous toxic environment by emitting many hazardous gases to the environment. The heavy metals and toxic gases emitted are the major health hazards. The major structural component of plant cells, lignocellulose is the main source of renewable biomass. Large amounts of lignocellulose is generated as agricultural and forestry residue. At present it is mostly disposed off by burning which in turn pollute the environment leading to global warming. This biomass could be easily converted to biofuel, chemicals and human and animal nutrients. Biofuel mostly ethanol, butanol bio-diesel and biogas can replace the hazardous fossil fuel. Most biofuel derived from biomass which is renewable is low cost and available in plenty, and it carries no commitment on foreign exchange. Among the biofuel, bioethanol is at present the most dominant and visible component in the industry, where Brazil produces 13.5 billion litres compared to 6.4 billion litres produced in USA. However, butanol is rapidly gaining importance as it could replace petrol (gasoline) on litre for litre basis in the existing internal combustion engines. Recombinant DNA technology and better understanding of the molecular basis of fermentation and genes involved along with the introduction of Biorefinery concepts is enhancing the production of butanol by fermentation of agricultural residues and main products. Two step fermentation processes to convert glucose butyric acid and butanol is now available. Biodiesel though a popular alternative to diesel one of the drawbacks is its utilization of agricultural production land area for biodiesel biomass production. Thus butanol would be the most acceptable biofuel which is promising with the development and improvement of the fermentation and extraction technology, in the very near future.

Keywords: alternative fuel, biofuel, fermentation, lignocellulose, ethanol, butanol.

Discussion

Dr. Muhammad Pervaz

It is good if we have another side of the picture. One fundamental question is, as you said, is about the emissions from Butanol. If we have 100% ethanol, chemistry is, it has 2 Carbons and Butanol has 4 Carbons. So CO₂ is more.

Prof. J M R S Bandara

In the existing engines, Ethanol has to be blended with petroleum so that it would be petro-ethanol that will be used and 100% Ethanol cannot be used as a Biofuel. To use 100% Ethanol, we have to invest quite a lot. Today, there is an urgent

requirement. We could go for Butanol using the existing vehicles. On a litre by litre basis, we can get the same mileage. This is a very interesting experiment. Ohio State University is working on this in great detail. Of course, Ethanol has its own problems. In the Ethanol production, the total conversion will take quite some time. Can we afford this time!

Dr. C S Kalpage

I do not agree with your comparison between Ethanol and Biodiesel. Life cycle energy balance of Ethanol is 1.25 compared to 3.5 for Biodiesel. That is, when we burn 100 kJ of fossil fuel, we get only 1.25 kJ as usable energy on the other side.

With Biodiesel, you can get 350 kJ. In this context, we generate more energy from Biodiesel. So compared to Bioethanol, Biodiesel is environmentally friendly. Total hydrocarbon emissions will be cut down by 50% by Biodiesel compared to crude oil based diesel. CO by 30%, PPM by 95%, Sulphate by 80% and Ozone by 40%. So Biodiesel is better than Ethanol or Butanol.

Prof. J M R S Bandara

The problem with Biodiesel is its variable quality. That is one of the major problems because you cannot start with any quality of Biodiesel. Different raw materials are used in processing Biodiesel & Biodiesel is not homogeneous. It is very unlikely that we can maintain the same standard. For example, even from the petroleum, when we consider the Sulphur levels, we can know where it comes from and from which refinery. As a biologist and a biologist's view, if we can get a homogeneous product, then everybody can go for a single system. The existing Biodiesel in use (not what is at laboratories) is contributing to a higher environmental pollution level according to the environmental pollution information. One quality Biorefinery concept is one of the schools of thoughts in the USA. They are thinking of bio refineries for producing one specific set of Biodiesel.

Dr. C S Kalpage

None of the Biodiesel contains Sulphur at all. They are free of Sulphur.

Prof. J M R S Bandara

I did not say that Biodiesel contain Sulphur. I am not saying that you should go for total Ethanol, Butanol or Biodiesel. The question is of the critical pollutants. They come out when you are burning the material, which is Biomass based. If you take Biodiesel, (which is a tri-glycerate compound) it will carry all the pollutants. It is due to the way how it is presently used just like any other Biomass. But, these are released to the environment only when they are burnt.

Prof. S A Kulasooriya

Getting Butanol is essentially by the processing of the 2nd generation feedstock like straw, other crop residues, grass or any thing that has converted the solar energy into chemical energy. Then you have to subject these materials to microbial or biotonical or molecular biological genetically modified material composition process. Breaking the complex carbohydrates to simpler carbohydrates and then to Butanol. The 2nd generation feedstock research is going on all over the

world to know about the conversion of the complex feedstock and raw material to processing feedstock that can then produce Butanol. Once you produce Butanol, there is no question as it is as good as gasoline. But that process is still at the experimental stage. Within the next 20 years, due to most research labs, the 2nd generation feedstock based biofuel production will overtake the 1st generation oil feedstock like Jatropha or whatever. Today, we have gasoline vehicles and diesel vehicles. Similarly, different biofuels would go hand in hand.

Prof. J M R S Bandara

We are at the production state of Butanol and at least a pilot project is running. We have no problems in producing. It has just grown above the research level and it is available.

Mr. M U Ranasinghe

There is no argument whether Biodiesel or Butanol. We have used these as well as Petrol and Ethanol in vehicles. Butanol can be directly applied in engines and others need to be mixed with petroleum with my personal experience. Cost of production is going to be around LKR 20 which is produced using straw.

H. Case Studies

Successes & Failures in Realization of Economic Potential of Biofuels:

Sugarcane Success in India

Phani Mohan Kancharala, India

1. Introduction

Indian Sugar Industry has made a turn around in last 5 years from being a seasonal and cyclic Industry to a bio refinery model. Sugar, distillation, cogen and bio fertilizer are produced optimizing their resources. With CDM taking shape since 2004, some of these also have utilized opportunity of cogen by enhancing boilers and generating additional power to be sold to grid and also benefit from CER / VER realization. Few of them have also realized CDM for distillation (Methanation). If UNFCCC provides benefit of CDM realization to ethanol manufacturers, then there is additional benefit that could accrue.

Indian sugar industry operates in zones allocated to them; they are well networked with farming community of that zone sharing on all areas of inputs from seeding, crop management, harvesting, and logistics and even in loan disbursement from banks. For two crop years, once planted, the farmer is relieved of sale and pricing of produce and is attracted to this crop as long as it does not pinch his wallet. Harvesting cost of sugarcane is of growing concern and its timeliness, as Sucrose content deteriorates if not done at appropriate time. There has been marked improvement in farm equipment too in this segment. Using water shoots and Tops as Fodder has been prevalent for centuries.

Indian sugar industry's success is also due to contribution from Sugar Breeding Institute-SBI (Coimbatore), Vasant Dada Institute, Regional Bodies in sugarcane research and others. SBI is one of the two world repositories (the other being at Miami, Florida state, USA) of sugarcane germplasm.

India is the world's largest consumer of cheap liquor and is a major revenue source of state Governments, with potable alcohol growing above 10% each year and its impact on social fabric catastrophic and not taken seriously; Energy & chemical value addition has lot of relevance that need to have support of all. There is another menace of illicit liquor from Jaggery. India occupies 40% of global sugar market. Of the total cane produced, 12% go in to seed production, 5% to chewing and Juice, 25-30% to Khandasari (Jaggery). Only 60% would be used for actual

sugar production. Per capita consumption of sugar in India is 20 kg and 5kg Jaggery.

Plant/Ratoon ratio is usually 45/55 to 55/45, but almost after 3 decades, it is shifting to 30/70 and to overcome this additional 14-15 milling plantation is required for Sugar alone. Most of mills have gone for semi automation of milling and Honeywell, Echogoa, Rockwell, OA, ABB, Siemens and several others entered this Domain. As future is unfolding to smart grid and Plug-in technologies, this Industry would see more of development. With CNG being produced of spent wash and this also being worthy template for CDM, we would see rural landscape buzzing with flex fuel vehicles and vibrant innovations. Today most Molasses trading Companies like UMC, SVG, Peter Cremer, and Toepfer have no sellers at all and domestically present Indian molasses prices are above 7000 INR, so factories without distillation too are generating good revenues. Bagasse is also being completely utilized for self cogeneration and as future is moving to whole cane crushing with sugars induced in cane leaves no trash would go waste or burnt in field. Bioplastics is another area which is catching the attention of industry and bagasse is the raw material with sugar as binder and this also generates CDM. Some have been using bagasse for paper and particle board manufacturing.

With Agronomy being the prime focus to bring better yields, crop sciences have also taken centre stage and companies like Syngenta, Monsanto, and DuPont and several others conducting lot of research. Indian Companies like NFL, Nuziveedu Seeds have also seen Success. Traditional Practices like Black Gold agriculture which enhances carbon content and soil health have again come back to centre stage. VAM fungus has also seen success in Sugarcane cultivation. Optimizing fertilizer, water, insecticides, pesticides, herbicides and mapping crop has also taken precedence. For seed treatment of cane, renewable resources like solar power for steam and temperature are being utilized. Future cultivation should enable more ratoon years to bring down cost as well stop soil erosion.

5,000 tons per day (TPD) Sugarcane Crushing mill with a 9 MW Cogeneration and 60 kilo litres per day distillation would cost around INR 3,000 million and the sugar manufacturing cost from

this plant is about INR 365 per Metric ton while the cogeneration would cost about INR 2.37 / kWh. It is anticipated that 4.2 MWh can be internally used while 3.6 MWh can be exported through long term contract and electricity could be sold to the government at INR 6.50 / kWh on spot basis. For this plant, Ethanol Manufacturing cost would be INR 24.6 / litre. (Based on reasonable assumptions)

2. Sweet Sorghum Alternate Dry Land Crop under Propagation

Sugarcane molasses is currently the main raw material for Ethanol production in several countries. The sweet sorghum also can be used for Ethanol production whose growing period is about 4.5 months) and water requirement is 8,000 m³ over two crops) (Soltani and Almodares, 1994) which is 4 times lower than those of sugarcane (12–16 month's duration and 36,000 m³ of water per crop). The cost of cultivation of sweet sorghum is four times lower than that of sugarcane. Sweet sorghum juice is better suited for ethanol production because of its higher content

of reducing sugars as compared to other sources including sugarcane juice. These important characteristics, along with its suitability for seed propagation, mechanized crop production, and comparable ethanol production capacity vis a vis sugarcane molasses and sugarcane makes sweet sorghum a viable alternative raw material source for ethanol production (Table 2). The daily productivity of sweet sorghum is twice than that of sugarcane 416 vs. 205 kg/ha respectively. Also, the cost of ethanol production from sweet sorghum is more economical as compared to sugarcane molasses at the prevailing prices.

Sweet sorghums are similar to grain sorghums, have rapid growth, wider adaptability and high biomass producing ability with sugar-rich stalks, known to have good potential for ethanol production (Reddy et al., 2005). The brown midrib sorghums (bmr) are also similar to grain sorghums and produce both grain and Stover. Sweet sorghum is more profitable (23%) to the farmer than the grain sorghum (Table 1). Table 2 compares Ethanol production from sugarcane, its molasses and sweet sorghum.

Table 1 Economics of sweet sorghum production

	Sweet sorghum	Grain sorghum
Grain yield (t ha ⁻¹)	1.6	2.5
Stalk yield (t ha ⁻¹)	20	4 (dry)
Grain value (US\$ season ⁻¹)	234	365
Stalk value (US\$ season ⁻¹)	293	50
Total value (US\$ season ⁻¹)	527	415
Leaf stripping (US\$ season ⁻¹)	15	-
Net value (US\$ season ⁻¹)	512	415
Gain from sweet sorghum (US\$ season ⁻¹ ha ⁻¹)	97 (23%)	

Adapted from Rajasekhar (2007), UAS, Dhar-

Table 2 Comparative advantages of sweet sorghum vs. Sugarcane /sugarcane molasses for ethanol production in India.

Crop	Cost of cultivation (USD/ha)	Crop duration (months)	Fertilizer Requirement (N-P-K Kg/ha)	Water Requirement (m ³)	Ethanol Productivity (litres/ha)	Av. Stalk yield (T/ha)	Per day biomass productivity (kg/ha)	Cost of Ethanol Production (USD lit ⁻¹)
Sweet sorghum	435 over two crops	4	80 - 50 - 40	8000 over two crops	4000 year ⁻¹ over two crops(a)	50	416.67	0.32 (d)
Sugarcane	1079 crop ⁻¹	12-16	250 to 400 – 125 -125	36000 crop ⁻¹	6500 crop ⁻¹ (b)	75	205.47	
Sugarcane molasses	-	-	-	-	850 year ⁻¹ (c)	-	-	0.37 (e)

a) 50 t ha⁻¹ millable stalk per crop @ 40 l t⁻¹ (b) 85- 90 t ha⁻¹ millable cane per crop @ 75 l t⁻¹ (c) 3.4 t ha⁻¹ @ 250 l t⁻¹ (d) Sweet sorghum stalk @ US\$ 12.2 t⁻¹ (e) Sugarcane molasses @ US\$ 39 t⁻¹ Source(d,e): Dayakar Rao et al. 2004

3. CO₂ Absorption and Energy Inputs -Outputs of Sweet Sorghum

Due to its high productivity (20-40 dry ton/ growing cycle) and fast plant cycle (120-150 days) sweet sorghum has an impressive capacity to absorb a large amount of CO₂ from the atmosphere during the 4-5 months growing cycle, with a small amount of CO₂ (~ 4 % of the total absorbed), emitted for the use of conventional energy during its cultivation. During the pre-treatment, conversion and utilization (combustion), further CO₂ emission is produced,

but sweet sorghum closed schemes are CO₂ neutral presenting a total CO₂ balance = 0. The details of CO₂ emissions by sweet sorghum are given in Table 3. The data (unpublished) from Institute for Energy and Environmental Research (IFEU) shows that utilization of sweet sorghum first generation ethanol saves 11 t greenhouse gasses (CO₂ equivalents) yearly per ha. This wide variation is attributed to changes in crop management, fertilizer dose and extent of mechanization etc.

Table 3 CO₂ absorption and emissions by sweet sorghum

CO ₂ absorption	CO ₂ emission
By the crop ~45 t CO ₂ /ha during the growing cycle	~1, 5 t CO ₂ /ha (growing cycle)
	~8,5 t CO ₂ /ha for conversion
	~35,0 t CO ₂ /ha for utilization (combustion)
	~45 total tons CO ₂ / ha
One ha of sweet sorghum plantation can substitute ~11 TOE of net energy without any negative CO ₂ emission into the atmosphere. Source: LAMNET and EUBIA, 2001.	

As per the studies by LAMNET and EUBIA, the energy utilized for cultivation and the energy produced in the form of feedstock is another important factor. The estimated energy inputs for cultivation of 1 ha sweet sorghum is 4,850 Mcal/ha compared to the energy output 74'500 Mcal/ha from the total biomass.

Table 4 The potential of ethanol yields for some of the feedstock.

Feedstock	Litres ethanol ton-1
Bagasse	500
Maize/sorghum/rice stover	500
Forest thinning	370
Harwood sawdust	450
Mixed paper	420

**Source: Planning commission.nic.in/reports/genrep/cmtt_bio.pdf*

The biggest challenge in use of sweet sorghum for ethanol production is availability of feed stock for longer periods. Owing to the short harvest window (one month per season) it is difficult to supply the feed stock with the centralized model (farmers supplying stalks to the distillery directly). To increase the feed stock availability for extended periods, ICRISAT is working for development of cultivars with different maturity durations and promoting sweet sorghum planting in wider areas, establishment of decentralized syrup making units and harvesting the stalks one week after cutting the panicles to increase the harvest window. Also an innovative decentralized model is worked out at ICRISAT. Under decentralized model, the crushing and syrup making units are established in villages it self. The harvested sweet sorghum stalks are crushed in the village and the juice is boiled to produce syrup. The syrup is transported to distillery that can be used as feed stock for ethanol production in the lean season. Thus a combination of both centralized and decentralized models augment the distillery's feed stock requirement for ethanol production. In decentralized model, the farmers can harvest the grain; take Bagasse after crushing stalks for use as animal feed/compost.

Impacts are several folds. Besides reducing pollution problems, dependence on non-sustainable fossil fuels, and total water demand (when compared to corn and sugarcane feed stocks; refer Table 2), sweet sorghum cultivation fetches farmers an additional net income of US \$ 97/ha (per season) as indicated earlier (refer Table 1) over the traditional system of grain sorghum

cultivation. There is no trade off with food if the farmer harvests the crop at physiological maturity. The risks from cultivating sweet sorghum are negligible in the sense, even during the drought years, farmer can harvest more fodder from sweet sorghum compared to grain sorghum. He can get additional income from sweet sorghum cultivation when there is a tie up with the industry. If for some reason the tie up fails, the farmer is not the loser because the crop provides grain, similar in quantity and quality to grain sorghum. Furthermore, he/she gets more fodder when compared to normal grain sorghum and the quality of fodder in terms of digestibility is better than normal grain sorghum fodder.

Note:

ICRISAT has also tied up with Praj to take ahead Distillation of Sweet Sorghum.

Commercial Scale and acceptability is slow from Agronomists. This can be propagated along with Cane if Sugar Industry believes in its Ethanol substitution. That would give impetus to this Crops propagation.

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5. Discussion

Mr. Buddika Gunaratne
What is Tapioca?

Mr. P M Kancharla
Casava.

Combating Energy Poverty in Sri Lanka

H.V.P. Wijewardena, University of Peradeniya, Sri Lanka

1. Introduction

Energy inadequacy is one of the key factors that Sri Lanka faces at present which mitigate in reaching millennium development goals. In overcoming this issue, projects on manufacturing energy using biological sources like agricultural residue, gliricidia and other biological by products are one possible way. Use of wastes on energy production in enhancing development activities and in combating waste dumping and poverty is common all over the world and implementation of such would be efficient and worth. Manufacturing bio fuel using paddy waste is one possibility in Sri Lanka as more than 40% of the farmers are engaged in paddy cultivation, mostly in the dry zone of the country, producing about 2.7 million metric tons of paddy resulting almost same amounts of paddy straw annually (Champaign et al, 1999). Further, most of paddy by products is wasted with no use creating much environmental harm. Converting paddy wastes and by products into energy would benefit in many ways. Environmental cleanliness, reduction of global warming, income generation to the rural poor, industrial development are some the apparent benefits.

Recently, renewable biomass has attracted fresh interest as a resource for electricity generation due to its potential as a low cost, indigenous supply of power, and the potential environmental and developmental benefits. Biomass conversion is seen as one option for reducing CO₂ build up. Local benefits could be identified as poverty alleviation in the rural sector, development of livestock industry, reduced soil erosion, restoration of degraded lands, and amelioration of local impacts from fossil fired power generation. For developing countries, renewable biomass energy systems may offer a number of social benefits from employment to entrepreneurship.

Rice (*Oryza sativa L.*) is the main food crop in Sri Lanka and the staple food for more than 80% of the country's population. When the actual extraction rates of cereals (the fraction of each grain utilized as food) are considered, rice is calculated to produce more food energy per hectare than the other cereals. Total food protein production per hectare is also high for rice, second only to that of wheat. In Sri Lanka, annual production of rice is 2.7 million metric tons per year, and the calculated per capita consumption of rice is 100kg per person. (Department of Agriculture, Sri Lanka)

Hence the total requirement of paddy per year at present is 2.0 million metric tons. Therefore 0.7 million metric tons are available as excess and it creates a downward trend of paddy price, especially during the harvesting season. On the other hand it is very high when compared to the world's consumption of 57.8kg per person (Juliano 1985). However as to the many findings much of the energy is wasted with out any usage (Table 1).

Table 1 By-products from rice industry

Product	Percent-age	Country total
Straw	100%	2.7 million metric tons
Husk	20%	0.54 million metric tons
Broken, bran and polish	18.5%	0.50 million metric tons
Bran oil	1.5%	0.04 million metric tons
Calculated according to Juliano (1985)		

2. Energy Resources of Sri Lanka

The major forms of primary energy used in Sri Lanka during the year 2000 were biomass (46%), hydro electricity (10%) and petroleum oil (44 %). The reality is that over the years, in the absence of fossil fuel resources, Sri Lanka has no option but to rely on the locally available energy resources of hydro and biomass that together contributes 61.2% of the total energy consumption.

Almost all electricity in Sri Lanka is generated and managed by the Ceylon Electricity Board (CEB). According to CEB's own statistics, supplies depend almost equally on hydropower and thermal sources both in terms of installed capacity and gross power generation. While households hold the majority (some 2.65 million) of accounts, and consume an approximately equal amount of electricity (about a third) to industrial consumers, average industrial consumption per day is at 200 units almost 100 times as high as domestic consumption (Ceylon Electricity Board, 2003). Table 2 shows the average consumption of electricity by various sectors of the country. Also, as to the energy conservation fund of Sri Lanka

further electricity generation through hydro-power is minimal, as it would cost much environmental lost.

Table 2 Average consumption of electricity by different sectors

	Average consumption (KWh/consumer/day)
Domestic	2
Religious	5
General	9
Industrial	190
Small industrial	15
Medium industrial	930
Large industrial	17,798
ALL CONSUMERS	5.66

Source: Power to people, EFL policy paper, June, 2005)

Almost all of the biomass is used in rural sector, especially for domestic energy supply. However, consumption patterns of biomass energy are inefficient in one way leading for many health

impacts, and in other causing many damages to the environment. With the increasing population and higher process of cleaner energy those impacts become serious if an alternative approaches are not met. Petroleum energy plays the same type of role where a significant amount of foreign exchange is spent. With unrestricted policies of vehicle importations, the demand for petroleum fuels increases losing more foreign exchange and harming environmental qualities.

Paddy is our main crop that cannot be given up although the farmers are not being better off. By approaching in the sense of total energy utilization betterment of the farmers as well as other food and energy consumers could be reached simultaneously. The main objective of this concept is to calculate the potential use of by products and wastes of paddy cultivation (paddy straw) in meeting the energy demand of the country.

3. Methodology

The applying methodology of manufacturing bio fuel is as the Figure 2.

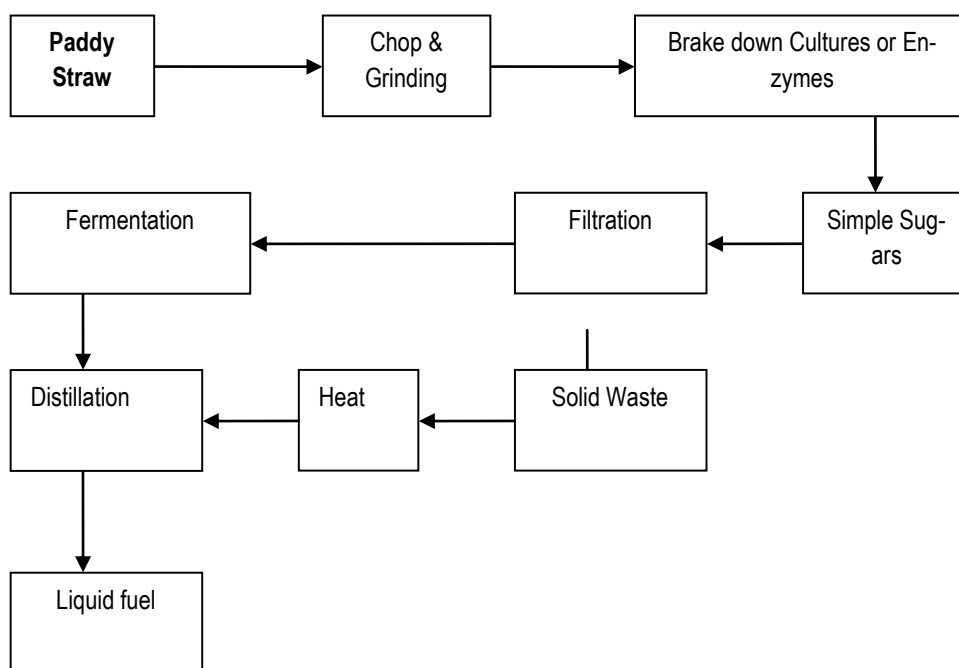


Figure 2 Flow chart of energy manufacturing process

Paddy straw contains 64% of cellulose and hemicellulose (Juliano, 1985). These cellulose and hemicellulose is a complex compound of simple sugars. Enzymatic or acid hydrolyze methods can be used for hydrolyze such complex sugars into pentose and hexose's sugars. The mixture of simple sugars, lignin and other compound subjected to the process of filtration. It differentiates the soluble and insoluble fractions of the mixture. Soluble fraction undergoes fermentation process. To achieve the butanol genetically modified *Clostridium acetobutylicum* must be used. (Ramey and Yang, 2004) Fermented liquor should be dis-

tilled to separate butanol available. Solid fraction can be used as the energy source for distillation process.

4. Results and Discussions

As to the above methodology, descriptive calculations of producing energy and carbon emission reduction are as to the Table 3 below. In Carbon Emission reduction (CER) calculation unit selling price was considered as 10 US\$ per tone of CO₂ eq.

Table 3 CO₂ emission reduction from biofuels

No.	Description	Notation	Value	Unit	Source
			Gasoline		
1	Net Calorific Value	NCV	44.8	MJ/kg	1*
3	Oxidation Factor	f ₀	0.99		IPCC, 1996 : Table 1.6
4	Carbon Emission Factor	CEF fuel	18.9	ton of Carbon/TJ	IPCC, 1996 : Table 1.4
	Emission Factors for fuel used	[NCV fuel] X [CEF fuel] X f ₀ X 44/12			
5	Emission Factors for fuel used		3.0736	kg of Carbon / kg	
	Bio fuel will be produced using paddy straw of proposing concept				
6	Alternative Fuel		Bio Butanol		
7	Annual Production		1,350,000	ton per annum	
	Specific Gravity		0.82		
	Bio fuels will be used as an alternative fuels for Gasoline for vehicles.				
8	Petro fuel Amount to be displaced		1,350,000	ton per annum	
9	Equivalent Amount of CO ₂ Emission		4,149,351	ton of CO ₂ per annum	
10	Total Amount CER		4,149,351	ton of CO ₂ per annum	
	Carbon in bio fuel emissions is recycled from carbon that was already in the atmosphere.				
11	Therefore CO ₂ Emission due to bio fuel			0	ton of CO ₂ per annum
12	Therefore Net CO₂ Emission Reduction			4,149,351	2*
	Market price of CER	10	US\$/CER		
	Annual income from CER	41,493,514	Rs		
	Total Energy Replacement	60,480,000	GJ		

1* - IPCC guideline for National Greenhouse Gas Inventories, Volume III (1996)

2* - Ton of CO₂ per annum or certified Emission reduction Units (CER) Per annum

5. Conclusions

Under the consideration of using whole paddy straw available in Sri Lanka, it could produce about 60 million Giga Jules, which is enough to cover almost all the annual energy requirement of the country at present rate of energy demand while the CER gain would become Rs.41million US \$ per annum. However even under significant utilization of available paddy straw country could boom its economy, which leads for better phase of development.

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7. Discussion

Prof. Ajith de Alwis

Looking at Sri Lanka, if you have Butanol and elephant dung, that will be a fantastic story as well. But when you are talking about patenting, are you patenting the microbial consortium as well as the process?

Mr. Priyantha Wijewardena

We can't get patents for microbes; we are going to get patents for the process

Prof. Ajith de Alwis

But you are thinking about the local patent only?

Mr. Priyantha Wijewardena
International

Prof. Ajith de Alwis

International patents, you can patent

Mr. Priyantha Wijewardena

Not microbes

Prof. Ajith de Alwis

So you are confident of these costs being low. Even if we subject to what ever the inflation, you are well within 43% of IRR

Mr. Priyantha Wijewardena

Normally when I present these, everybody asks where we have done before. We started work in 2004 and till now we have spent LKR 10 million. Now we are somewhat in a successful story. This invention is so simple and once we inform after patenting, you would laugh

Mr. Anwar Sadat

Do you have plans to mass produce Butanol soon?

Mr. Priyantha Wijewardena

Not soon. After 2010.

Mr. Anwar Sadat

Do you think your customers or vehicle owners would be willing to buy such a new type of fuel?

Mr. Priyantha Wijewardena

Initially, it will be a problem, but with this cost and without any fuel supply problems, as you know this country is full of strikes, it will be successful. Fuel will be easily marketed and it will not be a big issue although initially there will be a problem. In our experience, we don't have knocking when starting the vehicle, may be due to the temperature in our country.

Prof. S A Kulasooriya

You are going to produce is Butanol. So it will be for Gasoline engines, not for Diesel. Then, with this technology, you can easily extend it to other cellulosic material. Even you can use the 'mana' grass. It has much more potential. What you have done is with the straw.

Mr. Priyantha Wijewardena

Straw is always in the dry form and is readily available. It is ready for a market supply. If we go for grass, we have to find people to cut and so many other things as it is a new crop. In this process, we don't want to go for a new crop. We want to go for an existing crop or use the residues of that.

Prof. S A Kulasooriya

What I would suggest is you start with that, but leave room for extending to others. Because there is so much room with cellulosic material available, they are converting solar energy into chemical energy all the time. So don't confine, you start with that with possibilities of extension.

Mr. Priyantha Wijewardena

Compared to other countries, we have 2 paddy cultivation seasons. So we have quite a lot of material. The countries having one paddy season have to stock straw for production. For Sri Lanka there is no need for stocking

Dr. Saman Fernando

I am sure with this higher rate of IRR; you can convince any conservative bank. So funding won't be a problem for the \$ 10 million, they will fund

Mr. Priyantha Wijewardena

Already we have an investor for the first plant

Prof. Ajith de Alwis

You raised the question whether this type of thing can be done in Sri Lanka. The answer is you can. It is not expensive. It is just you should channel a little bit of research with money and then maintain consistent attitude towards having the facility to run it. Now even if you look at how many fermenters, pilot scale or small fermenters in the country and the productivity of these fermenters, you will find that we have a very poor productivity and some have been locked inside and not been used. Some countries have opted for a very small pilot scale facility, like in Malaysia where the companies can go and do pilot plant work, then once they are confident about operator training, the production, some quantities for market testing and so on, they move out and then convince the banks to get the money. So that kind of

a small facility perhaps is the way for Sri Lanka as well. Because all institutions having pilot facilities would probably be too expensive at this stage and you can put more specialists in running those things and that is something we should be having in Sri Lanka, and perhaps in some other countries. India is already having some of that. But you need consistency in the way you approach, focused, noting the data and really moving forward. So it is really possible in Sri Lanka and it should be done.

Dr. Muhammad Pervaz

Regarding the patenting internationally, if any international company buys the patent, then what would you have the right to manufacture and process in any country. So what will be if they do not start manufacturing and processing in Sri Lanka? In this case the benefits of Sri Lanka will be small.

Priyantha Wijewardena

The patent would not belong to me, to a company with a board. I think it will look after this issue. Part of the patent would belong to the University too.

Dr. Muhammad Pervaz

I think the bottom line should be that in the patent when you will sell it to some company, there should be an agreement that Sri Lanka should benefit.

Priyantha Wijewardena

Other thing is that this technology is only for Butanol, it can be used for the fermentation of other alcohol; as well land filled reactor, to enhance the microbial activities.

I. Open Discussion

Sustainable Biofuel Economy and Future of Biofuels in South Asia (Open Discussion)

Recently, the ASEAN countries developed guidelines (or road map) to promote biofuels in their region. Their context is different to ours. We can have guidelines to promote biofuels keeping the context of our countries & focused towards the region, also keeping the future prospects like Butanol.

There is going to be a SAARC energy ministers meeting in March 2009. This group can voluntarily prepare a discussion paper to present at this event, if the energy minister organising the event permits. What we plan to do is to develop some consensus here.

On biofuels policy matters, most countries do not have specific policies with regards to biofuels. Biofuels policy could be one area where intellectuals, professionals and academics can provide inputs to develop or formulate policy that is in consistent with the SAARC region.

Biofuels have become controversial subject and there are many schools of thoughts concerned with whether or not to push for biofuels and if so, towards what direction. The ministers can be requested to make a decision on scope of biofuels and what support structures should be touched. Some are contesting that some fuels should not be promoted as against the others. Therefore, if a comprehensive proposal or policy can be made for the region, even the SAARC or SACEP can support.

It was proposed and the participants agreed to convert the proposed discussion paper to be developed as the proceedings of this workshop learning from all the discussions and exchange of ideas into a position paper. This would explain the present background and then present status of biofuels with future directions in the form of a set of policy recommendations. Although the participants are not the ultimate authority to do it, a position paper can be presented by any forum. After some time, such position papers may gather some importance and such will be accepted as the base document as witnessed in the past.

Sri Lanka's ministry of Petroleum and Petroleum Resource Development has already prepared some guidelines, and this could be shared with the other countries.

Each country can develop guidelines or road maps for promotion of biofuels. But, regional policies cannot be agreed upon most of the time. The individual countries may view it as interference to their national development goals. The guidelines can be given and suggested as a position paper. This would help those member states who do not have a policy to prepare their national policies on promotion of biofuels.

We don't have a clear policy on whether we should shift from growing food crops into energy crops. We also do not have policies on what crops to grow (for bioethanol and biodiesel). We do not know exactly which land areas we have to allocate for these types of energy crops. Some countries have marginal lands, but some don't have. Should we use the existing agricultural lands replacing the biofuels is a question to be answered. Therefore, we must have some information based on surveys as to which kinds of lands and what extents of lands can be used for different crops.

In the discussion on Research & development, we did not develop any methodology for planting material and simple cost effective ways of mass scale production. An agronomic package has to be devised on how to grow or what to grow with other details such as the spacing, which cropping systems can be used etc. Currently, we lack this information. We need to have such information so that it would be easy to make accurate decisions on what capacities and what (ethanol / biodiesel) to produce.

To make effective time of the Energy Ministers, it would be better, if we could suggest them to design some protocol like Kyoto Protocol for the SAARC countries. This can include some time bound targets to be achieved. It also was suggested to recommend that the SAARC ministers strengthen one place where biobutanol research is being done at a good level and to upgrade the research stations as 'Centres of Excellence' for the SAARC region for the benefit of the entire region where the scientists can go and exchange experiences (like IIT Bangalore or Hyderabad). Further, to recommend the ministers to make a policy decision on land allocations for biofuels production and the different choices of crops for ethanol, diesel (Jatropha) or (Gliricidia) biomass energy.

Experiences gained by the SAARC countries should actively be shared on a regular basis through SAARC Forum so that the bottlenecks and solutions can be identified

Introduction of biofuels requires subsidies and incentives to all the producers and even to consumers and in order to adopt it, incentives and price structures should also be shared in order to formulate policies by governments of every country.

During the 2nd week on November 2008, there will be a Governing Board meeting of the SAARC Energy Centre where the policy level people related to the energy sector of member states are members from each country. The Governing Board consists of members at the Additional Secretary level persons. Therefore, they are senior government officials. If they are supportive, we can present the report of this workshop for discussions of the Governing Board. When the ministers make decisions, they shall feel more comfortable if the reports have been evaluated at this level (Governing Board), so that it will be easy for them (ministers) to make policies on promoting biofuels.

SAARC Energy Secretariat may like to consider during this workshop certain more than new ideas and concepts introduced such as Butanol that still needs a lot of work and home grown regional research to be done. In some areas, there is a relative convergence of views & meetings of minds, but some of the SAARC member states still have to form & fine tune their policies. The position paper may spell out clearly the resolutions or the extent to which different member states are in agreement, at-least in principle and extent to which they have done research & development of different sources of biofuels. In the position paper, we can include the research & development component highlighted, so that the respective energy ministers may allocate funds for research & development. Further, with the ministers' meeting, we must try to see some physical activities with regard to the 'SAARC Regional Centre of Excellence on Biofuels'

The guidelines for biofuels introduced by Sri Lanka don't include Butanol. It was suggested to include Butanol into the guidelines

There are no tax relieves with regards to bio-energy work at the moment. It is suggested to have a mechanism for the corporate sector to invest on research & development and obtain tax relieves or for the corporate sector and entrepre-

neurs to be provided with incentives for the research and development carried out on biofuels.

It was suggested to upload all the presentations and papers of this workshop on the Sri Lanka Sustainable Energy Authority web site (there were no objections for this suggestion or issues raised on copyrights) www.energy.gov.lk, so that it could be the starting point of exchange of ideas and sharing of knowledge.

It is decided that 'food' and 'fuel' should be kept apart. However, the decisions must be taken more on a logical manner rather than emotionally. They must be supported by scientific facts and each aspect to be considered on a case by case basis.

The resource assessments of other renewable sources of energy are at an advanced stage (wind, hydro energy). They are very much well documented and available throughout the world, but, biomass resource assessments are not that fine tuned and we are working on this aspect learning from Europeans. In Europe, they start with assessing land resources availability and other factors such as soil nutrients, rainfall etc and arrive at biofuel yield, and whether they are up for cultivation. Food crops can be a subsequent decision after this initial assessment of land resources.

At the concluding remarks, Mr. Ananda Gunasekera, Chairman of the Sri Lanka sustainable Energy Authority stressed that the participants agreed to present a position paper and do what ever we can do to influence the SAARC Energy Ministers meeting that is scheduled to be held in early 2009 in Sri Lanka.

J. Country Presentations

Country Presentations

Bangladesh

Md. Shafiqur Rahman and Mohammad Anwar Sadat

The sources of primary energy in Bangladesh are dominated by gas with a 45.5% stake followed by biomass which has a stake of 35%. Contribution by petroleum, coal and hydro are 18%, 1% and 0.5% respectively. Gas, petroleum, coal, renewable energies and electricity are the commercial energy sources with gas & petroleum contributing 73% & 25% respectively. Coal and hydro contribute 1.2 % and 0.8%.

As of 2007, the proven and probable gas reserves in Bangladesh was 28.62 Tcf while recoverable gas reserves being 20.63 Tcf. The cumulative production upto December 2007 was 7.42 Tcf while the proven, probable and possible being 7.89, 5.32 and 7.71 Tcf respectively. The average daily production was 1,785 MMcf, with public sector (Petrobangh) contributing 922 MMcf and private sector (IOCs/JVA) contributing 863 MMcf. The sector-wise gas consumption for year 2007 was CNG 11.90 (2.22%), Domestic 68.26 (11.80%), Power 221.14 (41.24), Tea 0.76 (0.14%), Commercial 6.66 (14%), Industry 77.48 (1.06), Captive 62.61 (11.66%) & Fertilizer 93.47 (17.48%) [Source: MIS Report, Petrobangla]

Compressed natural gas (CNG) has been used in vehicles since 1997 in Bangladesh. As of March 2008, the country had 229 filling stations and 116 conversion workshops of which the capital city Dhaka had 99 filling stations and 57 conversion workshops. 92,135 vehicles were locally converted to CNG of which 71,022 were in Dhaka. There were a total of 132,042 CNG vehicles and the gas use per day by CNG vehicles stands at 1.66 MMcm (~58.52 mmcf). [Source: RPGCL]

Bangladesh imports 3.6-3.8 million tons of Petroleum products of which 1.2-1.4 mill tons is Crude Oil & 2.4 mill tons is refined product. The total diesel requirement is about 2.3 mill tons which leads to a total import bill of more than US\$ 3.0 Billion. Petroleum products are highly subsidized and diesel is sold at Taka 55 (1US\$~Tk.70.00) per litre. For the year 2006/7, the sector-wise petroleum use was for power 9%, industry 4%, roads 36%, agriculture 20%, domestic 16%, air 7%, rail 1%, and river 7%.

By June 2007, Bangladesh had an installed electricity generation capacity of 5,269 MW, with Bangladesh Power Development Board having

3,872 MW and rest by Independent Power Producers and mixed sectors. The present generation capacity and the per capita electricity generation lie at 4,631 MW & 165 kWh respectively. The 230kV and 132 kV transmission lines extends to 7,044 circuit kms while the 33kV, 11kV & 0.4kV distribution lines extends to 271,142 km. Systems losses are recorded at 19.3%. 43% of the population has access to electricity. In the year 2007, power generation was contributed with a 88% stake by gas and coal, hydro, diesel and furnace oil contributing 5%, 2%, 1% and 4% respectively.

In the renewable energy sector, in the year 2004, 4 units of 225 kW capacity wind turbines were installed at Muhuri dam at Feni, and another 50 units of 20 kW capacity at Taboler Char, Kutubdia UZ by BPDB. Another 5 kW is installed at Saint Martins Islands by LGED. Further, there are 200,000 households with solar photovoltaic systems promoted by the agencies such as Rural Electrification Board, Infrastructure Development Company Ltd, Promotion of the Use of Renewable Energy and Grameen Shakthi. There were 26,400 biogas plants installed across the country promoted by the agencies such as Bangladesh Council for Scientific & Industrial Research, Infrastructure Development Company Ltd, Bangladesh Rural Advancement Committee, Environmental Pollution Control Department, Grameen Shakthi, DANIDA and other NGOs.

Bio Fuels are viewed from different perspectives in Bangladesh. Ministry of Energy sees them as an alternative source of energy. NGOs look from an employment generation and poverty alleviation perspective. Roads, railways and water development authorities view from a prevention of soil erosion angle.

Ministry of Energy has commenced working on biodiesel. Some of their plans include identification of appropriate species (like *Jatropha*), testing & cultivating biofuel plantations with a community forest concept throughout the country, assisting establishments of small crashing plants, collection of raw oil and refining them & blending with diesel. Further, 11 regional centres of Bangladesh Agricultural Research Institutes have been selected with government providing necessary funds to use molasses. As for cultivations, places like road sides, areas besides railway tracks, deforested hilly areas, embankments, coastal islands

and chars have been identified.

Despite the positive moves, Bangladesh also has some issues pertaining to promoting biofuels. Bangladesh is one of the most densely populated country in which agriculture contributes to a major share in the GDP & providing as a major source of employment. Food security is always a major concern and always gets top priority and the country is still a net importer of food, edible oils and fuel. Therefore, the land suitable for food crop cultivation can not be used for plantation of biofuels. Bangladesh is a country with lowest per capita energy consumption & one of the lowest levels Carbon emitting countries. So as to face the energy security issues, Bangladesh is also looking for renewable energy such as solar energy, wind mills & biofuels, coal power, nuclear power and regional energy trading through SAARC, BIM-STEAC and SASEC.

Bhutan
Lhabu Tshering

Bhutan is a country with a population of 632,000 people, of which 436,000 live in rural areas. Country has a land extend of 38,000 km². This country is blessed with ample of hydro power resources, and hydro power is a major foreign revenue earner. Government of India has been assisting Bhutan in hydro power resources.

Primary energy supply of Bhutan is dominated by biomass with an annual consumption of 1.2m³, which accounts to an annual per capita consumption of 1.9m³, which is supposed to be highest in the world. However, the country has to import petroleum fuels for heating and transportation applications. The import of fuels nearly nets out the revenue earned from export of hydropower. Fuel wood contributes by 72% to the national energy balance while electricity, diesel & coal contribute by 11%, 8% and 5% respectively. Kerosene, Petrol and LPG contribute marginally.

Government has a target of providing electricity to all by 2020. Currently, only 50% of the households are electrified and when it comes to rural areas, it is only 36% of the households. The grid extension costs are very high, sometimes as high as US\$ 2,000 per households. Providing electricity is estimated to cost US\$ 100 million, and it also can have the issues of deforestation and right of ways. The option of electrifying households using mini & micro hydro and solar PV systems is a costly. Producing a unit of electricity from solar PV and hydro costs about US\$ 0.20-0.40 and US\$ 0.03 – 0.08

The 9th 5 year plan has set certain programmes and targets. It has plans to develop micro hydel projects and extension of the grid to 6 districts. 15,000 households are planned to get access to electricity from renewable sources of energy. The Alternate Energy Programme encompasses the technical solutions such as solar, wind & biomass and development of major hydropower projects with an integrated energy plan which also considers energy efficiency and conservation aspects. The Private Sector Participatory Programme of Bhutan considers disinvestment of projects and training village electricians contributing to the overall energy sector. Some of the specific activities of the Department of Energy under the 9th Five Year Plan include resource assessment, updating of Power Sector Master Plan, Rural Electrification Master Plan of 2005 and Integrated Energy Management Master Plan of 2007.

Bhutan also has some emerging issues and challenges. Some of the main challenges are the lack of policy and regulatory framework for promoting other renewable sources of sustainable energy, capacity at local level, awareness amongst the players on the benefits of using clean energy, resources & financing and community participation & sense of ownership.

In order to face these challenges, the country also has devised some strategies for interventions on policy & technology, aspects of how to address the question of affordability for the rural poor who need subsidy & getting the involvement of local peoples participation, sense of ownership, introduction of investment excises, other tax credits and tradable renewable energy certificates. In addition to these, energy production payments & tax credits and public investment, strategic public-private partnerships, loans, Carbon trading mechanisms such as CDM (including bundling and sharing baselines) financing the energy sector are also considered.

Nepal

Amitabh Rajouria and Padam Raj Devkota

The energy consumption of Nepal accounts to 372 MGJ. From the consumption, the traditional sources dominate with an 87% stake and commercial energy with 13%. The renewable energy is only 0.57%. Traditional energy is dominated by fuelwood contributing to 89%, followed by cattle residues and agriculture residues contributing to 7% and 4% respectively. From commercial energy, petroleum products count to 64% followed by coal and electricity contributing 21% and 15% respectively.

Fuelwood is the predominant source of energy in Nepal. However, there are number of burdens confronted by this source, such as unsustainable use of forest resources leading to deforestation, high indoor air pollution due to heavy use of fuel wood for cooking resulting in serious health implications, the time wasted on collecting fuelwood and loss of forests leading to land slides and soil erosions and impacts on global warming. Petroleum is the predominantly used commercial energy in Nepal and it too has certain burdens such as it being completely imported, supply being disrupted frequently, fuel adulteration which leads to low quality fuel & engine problems, financial losses in billions of rupees due to subsidization of diesel and kerosene and environment degradation with transportation sector being the biggest emitter of PM10 and CO₂.

Biogas and solar home systems are major decentralized sources of energy providers in Nepal with country-wide programmes. Currently, over 150,000 biogas plants have been constructed covering 66 districts and, 2,617 Village Development Councils out of the total of 75 districts and about 4,000 Village Development Councils. Biogas also is significant becoming the first Clean Development Mechanism project of Nepal. When it comes to Solar Home Systems, they are being promoted in 73 districts and 1,850 Village Development Councils and there are around 70,000 Solar Home Systems in the country. The difficult terrain & remoteness, scattered & sparsely distributed population, lower load densities & utilization rates make the extension of grid-based electricity more expensive than the alternative energy technologies and makes Solar Home Systems more attractive. Nepal has a huge hydro-power potential with a theoretical generation capacity of 83 GW out of which only 44 GW is techno-economically feasible. However, only 1.2% of this is currently being harnessed.

Introducing biofuels brings new opportunities to both urban and rural Nepal. There is a scope for blending biodiesel and ethanol with fossil fuels (especially for urban areas) in the transportation sector bringing impacts such as reduction in urban air pollution, improving energy security with lesser disruptions, reduction in financial losses (lesser subsidy) and more stable fuel price. The rural energy sector could benefit from plant oil run cook stoves, irrigation pumps, electricity generators, agro-processing mills and tube well pumps.

Jatropha and sugarcane are two potential biofuel crops for Nepal. Jatropha is found recklessly growing all over Nepal in the terai (plains) and lower hills. Their application is currently limited to fencing and slope stabilization in most cases. This crop is suitable for cultivation in waste lands. Sugarcane is currently being used by sugar factories and the excess molasses from the sugar factories are adequate to produce ethanol for blending with petrol. The total diesel consumption in Nepal in 2004/5 was 315 ML. This means 10% blend of biodiesel with petro-diesel will require 32 ML of biodiesel for which only 30,000 ha of Jatropha plantation required. The country's petrol consumption during the same period was 76 ML and therefore, only about 8 ML of ethanol is required to have a 10% blends.

Nepal has gone ahead with national level initiatives to promote biofuels. The ministerial cabinet made a decision to blend 10% ethanol with Petrol in 2004 and Nepal Standard (NS 475) was developed for ethanol as a transportation fuel. The Latest budget has provision for promotion of bio-fuel production locally and the budget reiterates addition of 10% ethanol in Petrol. There are two mass plantations for Jatropha seeds. However, for the future, biofuel specific policies are necessary and government must identify a focal agency to mainstream biofuels as an alternative source of energy with strong promotional incentives and strategies to promote biofuels. There needs to be adequate research on feasible biofuel plants for various climatic conditions and quality seeds & species suitable for different ecological zones.

Pakistan

Sagheer Hussain Malik and Nadir Mumtaz Warraich

At present, the stake of biofuels in the Pakistan's energy mix is negligible. Pakistan's current energy consumption pattern by source include 41% gas, 30% oil, 15% electricity, 12% coal and 2% LPG. There are 7 oil refineries in operation in Pakistan with a total refining capacity of 12.8 million tons per year. Pakistan has a high consumption of diesel compared to gasoline. In 2007/8, 4.5 million tons of diesel was imported. Pakistan refined 2.33 million tons of gasoline and consumed 1.43 million tons. The rest was exported. Therefore, the country is deficient in diesel and has a surplus in gasoline. Any reduction in the throughput increases Pakistan's foreign exchange reserves. Due to this, the government is emphasizing and giving priority to the utilization of biodiesel.

In February 2008, the Economic Coordination Committee of the cabinet approved the policy for biofuels. The salient features of this policy are that the Ministry of Water & Power in collaboration with the Alternate Energy Development Board (AEDB) acting as the apex coordinating and facilitating body for the biofuels programme, the gradual introduction of biodiesel blends with petroleum diesel so as to achieve a minimum share of 5% by volume of the total demand and consumption of the country by 2015 and 10% by 2025, the oil marketing companies to purchase biodiesel (B100) from the biodiesel manufacturers and sell this biodiesel blended with petroleum diesel starting at B5 at their retail sales points and with the Ministry of Petroleum and Natural Resources to come up with a fuel quality standards for B100 and blends upto B20 with the Hydro Carbon Development Institute of Pakistan (HDIP) providing with technical support to the Ministry of Petroleum.

The Oil & Gas Regulating Authority will be regulating the pricing mechanism of various blends of biodiesel B5, B10 etc ensuring its competitiveness with the petroleum diesel. Fiscal and tax incentives for all imported plans and machinery equipment and selective raw material (for example *Jatropha*) for using in production of biodiesel shall be exempted from customs, sales tax and income taxes, duties and levies.

In the area of Research & Development, many institutions in the country are involved and engaged in carrying out R&D activities to evaluate the prospects of introducing biofuels in the coun-

try. These include the AEDB, HDIP, M/S Clean Power Ltd, universities & other academic institutions of the country. The studies carried out so far indicate that *Pongamia Pinnata* with the local name 'Sukhchain' is one of the good quality options with an oil yield of 25-30%. The AEDB has launched a pilot programme for the generation of electricity from biodiesel in the village called '*Goth Umar Din*' from the Sindh province.

Ethanol is produced from the molasses which is a bi-product of the sugar industry. Sugar industry is the second largest industry in Pakistan second only to the textiles industry. The total area under sugar cultivation is about 1 million hectare and Pakistan has an annual sugar cane production of around 4,200 million tons. There are 76 sugar mills operating. In 2006/7, 1.9 million tons of molasses were produced. Out of this, 18% (0.34 tons) were exported. There are 21 distilleries in Pakistan with an annual ethanol production capacity of 400,000 tons. In 2006/7, 280,000 tons of ethanol was exported.

Pakistan also has initiated an energy sector consultative process with the key stake holders, the line ministries and stakeholders are being consulted on sustainable supply, pricing mechanism, impacts on gasoline production, the development of infrastructure for the production of fuel grade ethanol and its blending with gasoline

Sri Lanka

Mr. M G A Goonetilleke and K L R C Wijayasinghe

Sri Lanka is a country with a land extent of about 65,000 km² and has a population of about 20 million people. The per capita GDP at market prices is US\$ 1,670 and the GDP growth rate was about 7.1%. The average annual per capita electricity consumption is 414 kWh. In the latest energy scenario, electricity accounts to only 7.8% while petroleum and biomass account for 36.6% and 55.6% respectively. Demand for energy grows at about 2.5% per year.

Ministry of Power & Energy is the organization responsible for the power & energy sector in Sri Lanka. The Public Utilities Commission is the regulatory body governing the electricity sector. The Sri Lanka Sustainable Energy Authority handles the alternative energy sector and the Ceylon Electricity Board (CEB) is the state utility responsible to generate and transmit electricity in the country. Electricity distribution in the western coastal of Sri Lanka is done by the Lanka Electricity Company (LECO) and Lanka Transformers Ltd is an establishment which is under the CEB, but functions similar to a private organization. There is also a recently formulated new company as a legislated statutory body to import future coal requirements. Therefore, the electricity industry in Sri Lanka is deregulated with separate functions undertaken by empowered bodies.

Sri Lanka has adopted a National Energy Policies and Strategies. Like in any other country, the energy policy of the government is to take the responsibility to provide the people with basic energy needs of all the people of the country, its energy security and promoting energy efficiency & conservation. Some other important areas include promotion of indigenous energy sources, capacity building, introducing fair and appropriate pricing structures, consumer protection & level playing field and protection of the public & the environment.

The states interventions during the past 15 years has recognized & encouraged cross border energy cooperation & trading. Currently, Sri Lanka is in the process of linking India with Sri Lanka through a 500 MVA cable. The feasibility studies & discussions are on the way. This is considered as a step forward in being whole SAARC region connected to a single network. Possible cross border investments within the region are seen with Indian and China taking a keen interest in investing in Sri Lanka.

No proven fossil fuel deposits are found in Sri Lanka. Certain exploration efforts are undertaken by several parties for oil related industries. Nuclear energy within the near future as a source of electricity is omitted in Sri Lanka. This is a small country and there are concerns as to where the people are to be evacuated rapidly in case of an accident of a nuclear plant however much small it is. The hydro resources are almost being fully utilized, although there is a potential for another 650 MW from hydro, which needs a high capital investment if we want to get additional benefits from hydro stations. When it comes to energy plantations, there have been various studies, but, it is hard to get a well defined quantity on the energy that can be produced from energy plantations.

The future of the electricity sector would have to rely on fossil fuels and the choice is between petroleum (diesel) or coal. After many deliberations, the government has decided to go for coal power which is considered to be cheaper with the possibility of importing coal from Indonesia, South Africa or Australia. After many negotiations and discussions etc, it has decided to put up 2 coal power stations. Therefore, the future electricity would be from coal. Sri Lanka however may not import coal from India due to the fact that the Sulphur content of the India coal is high. The government would welcome an effort on producing biofuels to replace even a fraction of the vast quantities of future oil or coal requirements.

The first phase of the 300 MW *Puttalam* coal power station is under construction. There are plans to put up another 300 MW here. Discussions are underway to put up another coal power station at '*Sampur*' in the '*Trincomalee*' district.

K. List of Participants

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