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Liquid Biofuels in South Asia: Resources and Technologies

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Abstract: South Asia with a geographical area of 5.1 million hectares is home to 1.5 billion people and is witnessing a sustained and rapid economic growth. As a result primary energy demand in this part of the globe has increased by 64 per cent since 1991 reaching 584 mtoe (million tons of oil equivalent) in 2003-04. All countries in this region are net importers of petroleum fuels. In this context, as an indigenous and renewable energy source, the use of biofuels can play a vital role in reducing the dependence on petroleum import and catalysing the rural economic development. In the last few years, interest in these green fuels has grown dramatically followed by the equivalent market responses.

This paper deals with the potential of biofuel production in South Asia in terms of availability of resources, existing processes and technologies. Biotechnological interventions to improve the economic competitiveness of biofuels have also been identified and scrutinized. It is concluded that a well-conceived biofuel programme with effectual cooperation among the countries has the potential to lead South Asia to high rates of energy sustainability.

Introduction

Energy Scenario in South Asia

Home to one fifth of the total world population, and having seen a rapid economic expansion in the last decade, South Asia's primary energy consumption witnessed an augmented growth of 64 per cent reaching 584 Million tons of oil equivalent (Mtoe) in 2003 – 04.[1] Against the backdrop of an enhanced oil import and growing apprehensions on sustainability, need for energy security has become a vital component of the economic sustainability of the region. This requires not only that existing fuel resources must be utilized as economically as possible but also that the energy sources used in this fuel system must be diversified.

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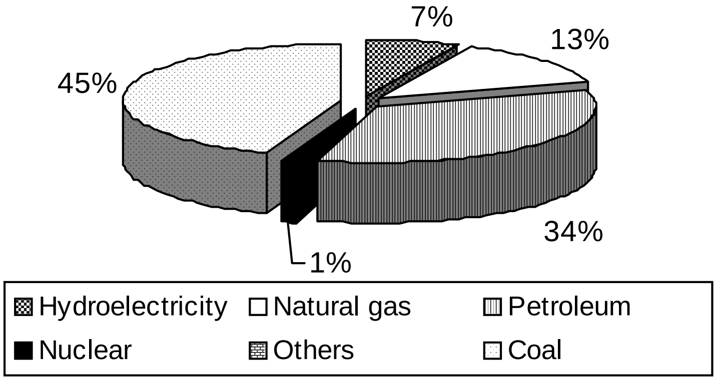
Figure 1: Sources of Energy in South Asia (2002)



Though there are significant variations among the countries in the composition of the energy mix, more than 90 per cent of the South Asian energy demand is from fossil fuels.[2] In this, petroleum accounts for more than 34 per cent (see Figure 1). More than 70 per cent of the oil demand is met through import and the quantum of imported petroleum is projected to be double by 2020. In this context, liquid biofuels as an alternative to petroleum can play a significant role in the energy scene of this region. Recent developments have made these fuels economically interesting in view of the resource potential and the possibility of improving environmental performance, along with employment generation and empowerment of the rural economy. However, development of this biomass-based energy sector would ensure the availability of adequate resources and efficient technologies to keep pace with society's need for these clean and viable alternatives. This paper looks into these aspects covering different resources, state of the art conversion technologies, research needs and technological innovations for timely implementation of a sustainable biofuels programme in South Asia.

Biofuel Options in South Asia

Biofuels can be defined as the renewable liquid fuels, derived from biological raw materials, which can be used as a substitute to petroleum fuels. On the basis of commercialization feasibility, mainly three liquid fuels could be considered in South Asia. These are straight vegetable oil, biodiesel, and bioethanol.

Vegetable oils have been used in the world as a fuel substitute since 1800 to run diesel engines.[3] The type of vegetable oil varies in different regions depending on the availability. As far as South Asian countries are concerned, non-edible oils are considered as a major resource for this purpose as edible oils are in short supply. Non-edible oils are being used in stationary engines in different parts of India. Pongamia oils have been used traditionally for lighting and for the pumping water in southern India. Currently a blend of pongamia oil with petrol is being experimented up on for use in vehicles.[4] Nepal is also going ahead with vegetable oil as a fuel substitute especially for simple blending with kerosene for use in the locally available stove. During the 90s, the Royal Nepal Academy of Science and Technology (RONAST) started exploring the potential of *Jatropha curcas* seeds, which contain 50-55 per cent fixed oil (Boswell, 2001). The Ministry has already planted some 40,000 *Jatropha* plants on marginal lands for Local Development and the Institute of Forestry in Tanuhun district that meet the target of the annual diesel requirements of fifteen agro-processing mills in the district. Research is going on in RECAST (Research Centre for Applied Science and Technology) and the GEM (Green Energy Mission) are doing research and development in this subject. In Sri Lanka, attempts are being made by private sector institutions to cultivate *Jatropha* for biodiesel production. The Ministry of Science and Technology of Sri Lanka is in the process of carrying out yield determination trials for *Jatropha*. Though vegetable oil has high calorific value, one of the major problems associated with its use in engines is its high viscosity. However, straight vegetable oil can be chemically processed to a less viscous form called esters or what is commonly known as biodiesel, which could be conveniently used to substitute diesel.

Biodiesel is relatively new term in the South Asian context. Exhaustive plans are being chalked out in different parts of the region especially in India for a comprehensive non-edible oil based biodiesel programme. India has taken the *Jatropha* plantation scheme to the highest level of national discussions with a large number and variety of institutions already involved in the pilot scale experimentations. With a view to blend diesel with biodiesel, the Government of India has launched the National Mission on Bio-diesel to address socio-economic and environmental concerns. The first phase of the programme intends to replace 5 per cent of diesel consumption by 2006 with 2.6 million tons of Jatropha biodiesel.[5]

Ethanol is produced in the range of a billion litres in South Asia. Much of the production comes from India and Pakistan and finds applications in the industrial and potable sector. Use of alcohol as a fuel became a significant option in these countries very recently. In Bangladesh, at present LPG is making inroads and biofuels are yet to make an impact. Private companies are making plans to manufacture fuel alcohol in the country. An investment of $4.5 million will be made for a 12000litres/day ethanol plant, which uses molasses as a feedstock (*Bangladesh Observer*, 2005). The major step forward in the Indian ethanol programme was the Government of India notification on EBP (Ethanol Blending Programme). This notification made five per cent ethanol doping in petrol mandatory in nine states and four territories, with effect from 1 January 2003.

Resources for Biofuel production

Biodiesel Resources

Land Resources for Energy Plantations

As stated earlier, channelising non-edible oils for biodiesel production may be a more feasible option in South Asia. Possible species such as *Jatropha curcas*, *Pongamia pinnata*, *Calophyllum inophyllum*, *Calotropis gigantia*, *Euphorbia tirucalli* and *Boswellia ovalifololata* are very hardy and are able to grow in adverse climatic conditions. Therefore, plantations of these non-edible oil crops can be targeted on underutilized, fallow barren or degraded or under stocked forests such as in drought prone areas. Over a period of ten years (1991 to 2000) although Asia recorded the largest growth (2.5 per cent) in the share of agricultural land to total area, minimal growth was noted in South Asia (see Table 1).

Table 1: Land Resources in South Asian Region

Country	Total land area (sq km)	Share of agriculture lands	Share of forest land
Bangladesh	146, 991	60.2	5.9
Bhutan	40,372	17.4	59.8
India	3.05 Million	60.0	17.4
Sri Lanka	65,610	32.5	29.6
Maldives	200, 000	——	——-
Nepal	274,620	25.3	36.7
Sri Lanka	65,610	32.5	29.6
Pakistan	770,880	22.2	2.4

Source: The Role of Wood Energy in Asia, FAO Corporate Document Repository, 2004.

The total degraded land in Nepal is around 5 million hectares (33 per cent of the total area of the country) with the largest area in middle mountains.[6] This area comprises non-cultivated inclusions, grasslands, shrub lands and degraded forests. The forests and forestlands cover 33 per cent of the total land area. With 75 per cent of the total cultivated area of 20.68 million hectares irrigated, Pakistan is among the countries with the most irrigated land in the world. Only 4 per cent of the country is classified as forestlands. The marginal and wastelands in Pakistan comes around 57 million hectares.[7] As per the recent waste land atlas of India,[8] about 63.85 million hectares are can be classified as wastelands. However, it may not be reasonable to assume that the entire classified wastelands are available for energy plantations.

Forest Resources for Biodiesel Production - Tree Born Oil Seeds

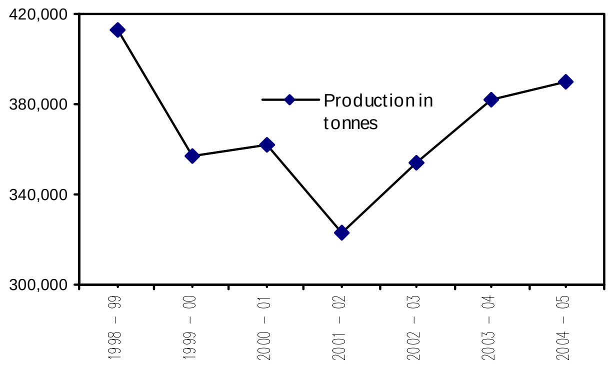
South Asia is home to abundant forests, bearing a variety of tree born oil seeds, which could be explored for biodiesel production. Nepal forests are reported to have vast quantities of non-edible oil seeds with over 100 plant species containing more than 30 per cent fixed oil. The annual potential fatty oil yield from seeds of *Pinus roxburghii* is estimated at 3 million tons in Nepal but it has not been commercially exploited until now. Apart from being a major source of building timber, Sal (*Shorea robusta*) is a prolific producer of seeds and has a high oil content. The actual authorized and unauthorized collection of Sal seeds in Nepal is only about 41,000 tons per year.[9] The pine oil (turpentine) is another source of bioenergy.

Bhutan has many trees and shrubs, which are potential sources of oil in both sub-tropical and sub temperate zones of the country. A few common species traditionally used by villagers in different parts of the country are *Gynocardia odorata, Aesandra butyracea, Symplocos paniculata*, and *Shorea robusta*.[10] But no systematic study has yet been carried out to survey Bhutan's potential for producing vegetable oil. In Pakistan, 20 thousand tons of walnuts are reported to be produced in forests.[11] Additional oil yielding crops of Pakistan are cotton and various cultivated varieties of crucifers like rape and mustard seeds. In the Maldives and Sri Lanka, coconut is a widely grown agricultural product with a production of 19,00,000 metric tons and 35,000 metric tons respectively.[12]

Methanol for Biodiesel Production

Alcohol is an essential reagent for the production of biodiesel. Generally, alcohol requirement is a minimum of 10 per cent by weight of biodiesel.

Figure 2: Yearwise Methanol Production Scenario in India since 1999



Source: India Infoline Sector Database, 2005.

The methanol based biodiesel sector is not fully reliable because of its import dependency and related price fluctuations. Further more it is significant to note that any fluctuation in the price of alcohol reagent can disturb the stability of the biodiesel price drastically. As a major methanol producing country in the South Asian region, the scenario in India is very critical and is represented in Figure 2.

It is clear from the table that the Indian methanol production capacity is half of the domestic requirement, which comes around 6,20,000 metric tons. In fact, the availability of raw material (natural gas) in India is very limited and it has multiple uses for which the government defines the priority. Also despite an exponential rise in demand, new methanol capacity is not being put up. Therefore if methanol is used for biodiesel production, the present resources will not be sufficient to meet the demand. In this context, ethanol can be foreseen as a sustainable chemical, and strategies need to be drawn out to enhance its production from alternate resources.

Resource for Ethanol

Different resources that can be utilized for ethanol production and their comparative production potential are given below in Table 2.

Sugarcane Molasses and Sugarcane Juice

Sugarcane is grown in both tropical and subtropical regions in South Asia. In 2003, India produced over 289 million tons of sugarcane, Pakistan 52 million tons and Bangladesh 6 million tons.[13] A majority

Table 2: Different Substrates for Ethanol Production and their Comparative Production Potential

Crop	Ethanol production potential (L/ton)
Sugar cane	70
Sugar beet	110
Sweet potato	125
Potato	110
Cassava	180
Maize	360
Rice	430
Barley	250
Wheat	340
Sweet sorghum	60
Bagasse and other cellulose biomass	280

Source: Nigam and Agarwal, 2004.

of molasses to ethanol plants are located in tropical and sub-tropical regions. In India, ethanol production is constrained because of its dependence on a single source. The maximum potential of ethanol production from molasses is estimated to be about 2.5 billion litres only. Enhancement in production to meet the huge demand at a reasonable price would only be possible by exploring alternate resources.

Utilization of cane juice directly for ethanol production is one of the major options to enhance ethanol production. In the context of the rising interest on fuel ethanol, it gives an opportunity to the sugar industry to diversify its factories as sugar ethanol and co product complexes. In a sugar factory attached with a distillery, if the sugar price is low, more sugars can be diverted to ethanol production in the form of cane juice or cane syrup. In the off-season, molasses can be used for ethanol production. Alternatively, primary juice can be used for sugar production and secondary juice can be utilized for ethanol production. It has also been projected that such a proposition might lead to additional benefits like stable sugar prices, export quality sugar production, adequate availability of ethanol, higher potential for export power and remunerative prices for sugar cane. In this context, the national sugar policy in India can be amended for facilitating the use of sugarcane juice for ethanol production.

Starch based Feedstocks and Fruits

Many wild fruits can be used as a good feedstock for ethanol production. For example, the fruit of the wild persimmon tree (*Diaspyrus lotus*) is rich in sugars and is found abundantly in Pakistan forests. An average tree yields 120 kg of dry fruit and a significant portion is not collected. Other commonly found wild fruits are gurgura (*Reptonic buxifolia*), deela (*Apparis aphlla*), Pelu (*Salvodara oleides*), jujube (*zizyphus spp*.), and Sumal. In 1998, 21.8 thousand tons of wild fruit production is reported in Pakistan. Being the fifth largest date producing country in the world, Pakistan is also experimenting with the option of bioconversion of date sugar to ethanol.[14] Cashew fruits (*Anacardium occidentale* L), available in the southern states of India, are other potential substrates for ethanol production. In Goa, these are trampled by foot to extract the juice for the locally famous distilled liquor, *feni*. Surplus cereals and starchy crops can also be used for ethanol production. For example, in Bangladesh 40 lakh tons of potato were harvested in 2005 while the annual demand is around 30 to 35 lakh tons[15] (FAO, 2004). On the other hand, Pakistan's rice production is likely to increase to 5.4 mt enabling it to achieve a $1 billion export target. Possible ways need to be looked into for apportioning these surplus starchy materials economically for ethanol production.

Sweet Sorghum

Sweet sorghum (*Sorghum Bicolor L)* is one of the most drought resistant agricultural crops as it has the capability to remain dormant during the driest periods.[16] Of the many crops being investigated for energy and industry, sweet sorghum is one of the most promising candidates, particularly for ethanol production principally in developing countries like India. It is the third major cereal in India. The possibility of year round cultivation and tolerance to acidity, alkalinity and salinity are other advantages. It requires less water and fertilizer compared to sugarcane. As molasses production is limited to around 4-7 months, based on the sugar cane crushing season, sweet sorghum can be cultivated and processed for ethanol during the non-crushing season. The crop can provide a cane yield of 30-40 tons/ha and 50-60 per cent juice recovery is possible under factory conditions.[17] Through a detailed analysis of the ethanol demand-supply scenario and resources assessment, suitable planting dates of sweet sorghum can be worked out. But this should be done very carefully so as to adjust with the sugarcane sector.

Sugar Beet

Two thirds of world sugar production is from sugar cane and one third from sugar beet. These crops are complementary as they are cultivated

Table 3. Comparison of Cane and Sugar Beet

Properties	Cane	Sugar beet
Cycle of crop	10 – 11 months	5 – 6 months
Yield per acre	25 – 30 tons	35 – 40 tons
Sugar content on weight	12 – 16 per cent	14 – 18 percent
Sugar yield	3.0 – 4.8 tons /acre year	4.9 - 7.2 tons/ acre year
Ethanol yield	1700 – 2700 litre/ acre /year	2800 – 4100 litre /acre / year

Source: Winrock International, 2004.

for specific requirements in two different climatic belts. In European countries, sugar beet is preferred. The advantages with sugar beet are a lower cycle of crop production, higher yield, and high tolerance of a wide range of climatic variations, low water and fertilizer requirement (see Table 3). Compared to sugar cane, sugar beet requires 35-40 per cent less water and fertilizer.[18]

Cellulosic Resources

Lignocellulosic biomass, for example agro-residues, appear to be one of the most attractive and low-cost future feedstock options for fuel ethanol production. As shown in Table 2, agro-residues have a higher theoretical ethanol yield compared to sugarcane. Further, agro-residues available in large quantities are cheaper compared to sugar crops, and do not require additional land resources for their cultivation. In India, the current production of agro-residues is about 800 million tons. Even if 10 per cent of the agro-residues are utilized for ethanol production, around 15 million kilolitres of ethanol can be produced.[19] Rice straw, wheat straw, sugarcane bagasse, and sugarcane tops are the main residues (see Table 4).

Table 4: Potential of Different Agro-residues for the Production of Ethanol

Agro-residue	Cellulose (% wt/wt)	Hemicellulose (% wt/wt)	Lignin (% wt/wt)	Theoretical ethanol yield (litres/ton)
Rice straw	41.36	20.36	12.06	346.00
Wheat straw	39.63	24.07	16.97	359 .00
Ground nut straw	36.55	13.94	31.28	319.96
Rice husk	44.06	17.85	17.20	392.33
Sugarcane bagasse	33.60	29.00	18.50	351.00

Source: Iyer, Rao, and Grover (2002); DoE (2005).

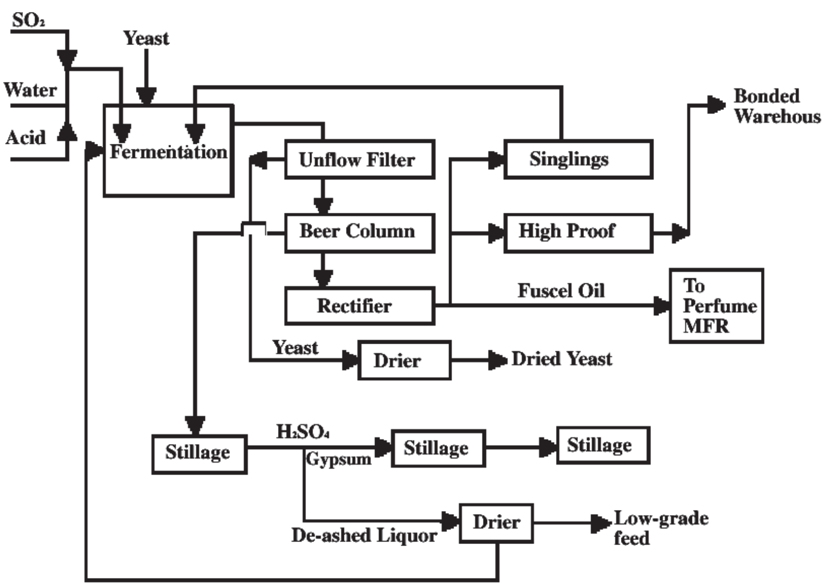
Processes and Technologies for the Production of Biofuels

Ethanol: State of Art

Conversion of Molasses to Ethanol

During the commercial fermentation process, molasses containing approximately 43 per cent fermentable sugars are diluted and fermented. Mash is diluted to the aqueous solution of sugar whose characteristics and composition are favourable for the fermenting organism in the efficient production of ethanol. Actively growing yeast ferments the sugar present in the solution to ethanol. Once the fermentation is complete, after settling of the suspended solids, the supernatant of the fermented mash is drawn off and pumped to the distillation house where ethanol is distilled out followed by dehydration for the production of anhydrous alcohol (see Figure 3). This is accomplished in two columns: the distillation and rectification columns, coupled with molecular sieves in which a mixture of nearly azeotropic water and ethanol are purified into pure ethanol. The stripping column

Figure 3: Different Process Stages for the Conversion of Molasses to Ethanol



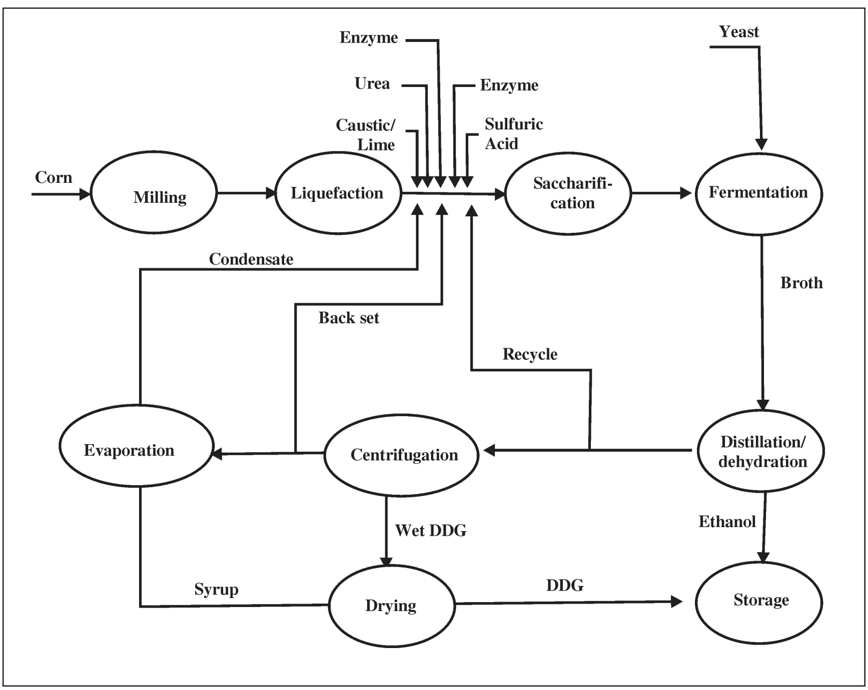
bottom liquid rich in BOD and COD is treated in biomethanation plant containing 5 per cent solids is concentrated to 40 per cent in evaporators. The concentrated mother liquor is dried as powder in a spray dryer. The CO_2 produced is collected and bottled.[20]

Conversion of Starch to Ethanol

Starch based feedstock need pre-treatment and hydrolysis of starch constituents for the preparation of starch molasses, which can then be fermented to ethanol. The first step of hydrolysis process consists of milling the grains to release starch from the raw materials. The step can be dry or wet.

In the dry milling process, the process is divided into three major stages: liquefaction, saccharification and fermentation. During liquefaction, the mash is mixed with hot water and μ amylase enzymes and consequently starch polymers are broken down to maltose and higher oligomers (see Figure 4). Continuous saccharification usually takes place in a CSTR where the enzymatic hydrolysis leads to the

Figure 4: Different Process Stages for the Conversion of Starch to Ethanol



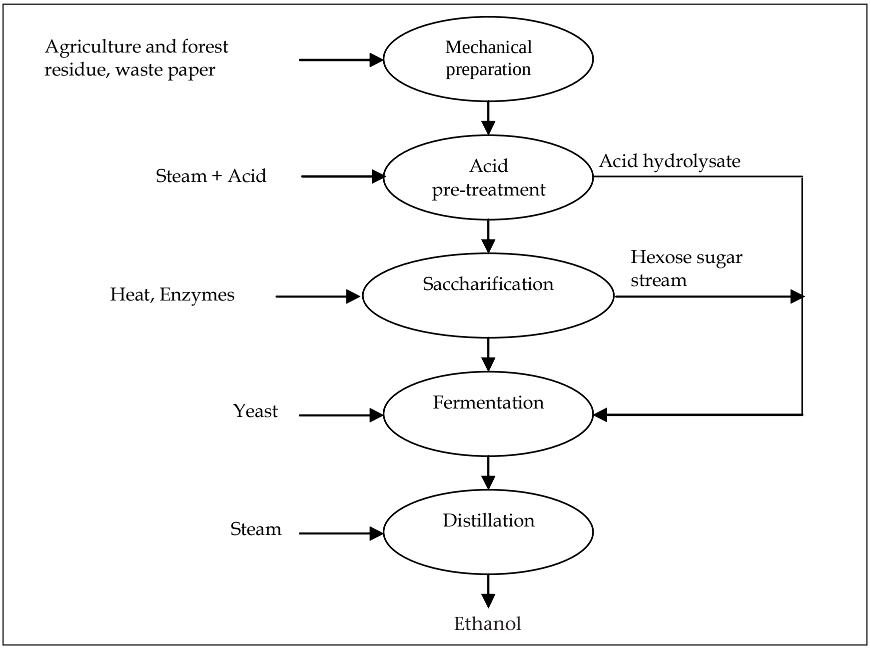
production of glucose sugars. The saccharified mash is then cooled to 32 °C and fed to the fermentors for production of ethanol.[21]

The wet milling process is used to obtain as many usable by-products as possible from different components of feedstocks. For example, in the case of corn it is first steeped in water to separate the kernel. Following this, the corn is ground and washed to further separate the kernel. When the corn is processed, the germ is removed to form corn oil and the starch is used for ethanol production.[22] The remaining solids, gluten meal and gluten feeds are sold as high protein livestock feed.

Cellulose-based Ethanol Production

For the conversion of cellulosic material to ethanol, two key steps are required. At first, cellulose and hemicellulose have to be hydrolyzed to simple monomers while in the second stage, the conversion of monomer sugars to ethanol is done. A large number of thermal, chemical and biological processes are under investigation for the saccharification of cellulose and hemicellulose. Till date, research primarily has focused on chemical pre-treatments such as dilute acids, alkaline, organic solvent

Figure 5: Different Process Stages for Biomass Conversion to Ethanol



treatment, ammonia, SO_2, CO_2, etc.[23] and also on enzymatic hydrolysis. The topic is subjected to intensive R&D in many developed countries though research on this subject is in its infant stage in South Asia. But it is important to note that South Asia has abundant ligno-cellulosic resource compared to any other region in this globe.

Internationally, there is an increased interest in commercialization of cellulose to ethanol technology. Research efforts have improved yield and reduced the time to complete the process. The National Renewable Energy Laboratory (NREL), USA, has modelled many potential process designs and estimated the economics of each process. The Department of Energy, USA, has chosen a target-selling price of 1.07 dollars per gallon by 2010. Presently, the technologies in competition include concentrated acid hydrolysis by Arkenol Inc., pentose and hexose fermentation process by BC International Corporation, and enzymatic hydrolysis process by logen.[24] The feedstocks include rice straw, sugarcane bagasse, wheat straw, and wood wastes.

Straight Vegetable Oil – Extraction from the Seeds

The extraction of oil from the seeds is generally mechanical for small-scale processes or it involves the use of solvent such as hexane or it can be the combination of both the processes. Depending upon the type of seeds, various types of grinding, cracking, flaking and rolling equipment is used to rupture oil cells to allow egress of the oil. Steaming is provided in order to increase the process efficiency. Softer oil seeds and nuts can be processed manually by means of ghanis. Further extraction of residual oil from the seed cake with the solvent can increase the oil recovery to a significant extent. There are several oil presses developed for extraction of oil from non-edible oil seeds especially for smaller scale extractions. Appro Tec's Mafuti Mali press, The Sundhara Press, Yenga hand press, the Komet Press, Caltech expellers and Bielenberg Ram Press are a few examples.[25]

In solvent extraction, oil is extracted using an organic solvent generally hexane. Residual cake is washed with solvent, under a counter current flow, producing an oil/solvent mixture (termed a miscella) and a residual meal containing solvent. The miscella is subjected to evaporation and steam stripping to recover hexane from the oil. The hexane is then separated from the water mixture by physical settlement and is recovered for re-use in the extraction operation. The solvent-laden meal is processed by steam distillation in a de-solventizer to recover most of the hexane content. The meal can find applications as animal feed, fertilizer and also for biogas production.

After the extraction oil, the next step is the refining process, which generally includes degumming, neutralization, bleaching, deodorization and further refining to get the final product.

Biodiesel Production

In simple terms, for the transesterification to take place, alcohol, catalyst and oil are made to react in a reactor and agitated for approximately one hour for 60°C. The reaction is sometimes done in a two-stage system. In the two stage system, 80 per cent of the alcohol and catalyst are agitated in the first phase. The reacted stream then undergoes a glycerol removal step before entering into a second reactor in which the remaining alcohol and catalyst are added.[26] The system has the potential of using a lesser amount of alcohol when compared to the single stage systems.

Both batch and continuous transesterification processes are being used commercially. While batch processes are used for small-scale systems, continuous processes are widely used for large-scale biodiesel manufacturing. In continuous processes, generally CSTRs (Continuous Stirred Tank Reactors) in series are used. In a plug flow reactor system, which behaves as it were a series of small CSTRs chained together, the reaction mixture moves in a continuous plug with little mixing in the axial direction. The result is a continuous system that requires rather very short residence times as low as 6 to 10 minutes for the completion of the reaction.[27] Following the completion of transesterification reaction, the glycerol is removed from the esters. Due to the very low solubility, separation between esters and glycerol occurs rather easily and can be accomplished with either settling tank or a centrifuge.

The maximum amount of free fatty acids acceptable in a base catalysed system is generally less than 2 per cent. Feedstocks having free fatty acids higher than this needs special treatments to eliminate the problems due to soap formation. The processes generally adopted to process the free fatty acids are given in the following sections.

Caustic Stripping: Caustic stripping is also referred to as catalytic refining. In this process, the free fatty acid content of the feedstocks is made to react with caustic soda and the resulting soaps are stripped out using a centrifuge. The refined oils are dried and sent to the trans-esterification unit for further processing. Instead of disposing off the soap mixture, it can be acidulated and esterified using acid catalysis in a separate reactor

Glycerolysis: Glycerolysis is done in a counter current reactor where sulphuric and/sulfonic acids and steam hydrolyse tri glycerides into free fatty acids and glycerol. After the separation of glycerol, pure free fatty acids are acid esterified in another reactor to transform them into esters. The esters are then neutralized and dried. Yield can exceed 99 per cent and the processes can uptake very high FFA and low cost feedstocks.[28]

Non-catalyzed Esterification Processes

Co-solvent process: One of the major problems associated with trans-esterification of tri-glyceride is the extremely low solubility of methanol in tri-glyceride. Utilization of a co-solvent, which facilitates the solubility of methanol can reduce the reaction time and the reaction temperature. Tetra hydro furan is used as the solvent, which has a boiling point close to that of methanol. The system operates at 30°C and reaction takes 5-10 minutes for its completion. In this process, the ester-glycerol phase separation is clean and the final products are catalyst and water free. But the equipment volume has to be larger because of the additional volume of co-solvent. At the end of the reaction, methanol and co-solvent are recovered in a single step.

Super Critical Process: In the processes based on super critical fluids also, the problems related to the phase separation are not encountered and a single phase is found due to increase in the dielectric constant of methanol in the super critical state. As a result the reaction was found to be completed in a very short time within 2-4 minutes when the oil to alcohol ratio is around 1:42 at pressures greater than 80 atm and at temperatures ranging from 350 to 400°C.[29]

Research Priorities – Role of Biotechnology

Biotechnology plays a vital role in encouraging the use of cleaner and environmentally friendly fuels. Regarding ethanol, biotechnology tools can help in developing genetically engineered enzymes and microorganisms for the efficient fermentation process. Development of an organism that can ferment all sugars found in biomass is a critical factor behind the success of the biomass to ethanol programme. The organism should have the properties of both desired substrate utilization and product formation. This can be accomplished by the production of a fermentation system, which allows a fast rate with high product selectivity and concentrations.

Another main challenge today is to increase the effectiveness of the enzyme converting the cellulose. Increasing the specific activity of the enzymes in the cellulase complex can reduce the cost of cellulases that act on pre-treated biomass used for bioethanol production.

For the production of biodiesel, enzyme catalysed transesterification reactions were found to be much more environment and user friendly. But this technology requires further R&D to increase the effectiveness of the enzymes for an efficient reaction so that the process becomes economical. Plant biotechnology can help in strain improvement; in the case of ethanol, it can produce crops with high sugar/starch content. With respect to biodiesel, varieties having higher seed yield with high oil content is preferred. Prospects do exist in identifying germplasms for developing improved varieties with better yield, better oil quantity and quality, early flowering, etc. using a variety of approaches like mutation breeding, tissue culture, and transgenics.

Conclusions

South Asian countries have enormous potential for liquid biofuels in terms of their diverse feedstocks with suitable edapho-climatic conditions besides having a complementary endowment on a contiguous land mass. However, there is a need for organised planning and systematic research mission to harness this potential for a sustainable biofuel programme.

As land requirement emerges as a major pre-requisite for the development of biodiesel sector, there should be proper identification programmes for wastelands and marginally productive lands. Moreover, plantation of oil-bearing species could be strictly targeted in these lands, with out compromising on food production.

Further more, respective governments may undertake identification of existing resources and site-specific feedstocks. National Mission on Biodiesel being launched by government of India is a major initiative in this direction. Choice of appropriate species also plays a significant role in such programmes. Selection of the species and provenance must aim at identification of the ones, which suit to the specific locations enhancing the economic viability of production and biological productivity of the land.

Technological challenges do exist in channelising many inexpensive alternate feedstocks for biofuel production. Typical example is cellulose based ethanol production. Therefore it is necessary to have extensive research efforts and technology development in these lines. Import of full-fledged technology from other countries is possible especially in biodiesel. But this could be coupled with indigenous technological interventions so as to fit those technologies in the regional context.

There is a definite need for policy and legislative framework for biofuels. The declaration of the agreement on South Asian Free Trade Area (SAFTA) gives hope and aspiration for added efficient cooperation in the promotion of biofuels too. It can help in promoting fair trade practices in biofuels based on efficient market mechanisms with the elimination of market distortion practices of implicit and explicit subsidies. In short, a well conceived biofuel programme with effectual cooperation among the countries has the potential to lead South Asia to high rates of energy sustainability.

Endnotes

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10 Chhetri, 2000.
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13 Godbole, 2002.
14 Noor, Hameed Bhatti and Tunio, 2003.
15 FAO, 2004.
16 Gnansounou, Duriat and Wyman, 2005.
17 Ratnavathi, 2004.
18 Gokhale, 2004.
19 Assumptions: (a) agro-residues contain, on an average, 50 per cent cellulose and hemicellulose sugars; (b) conversion efficiency is 60 per cent; and (c) average theoretical ethanol yield has been taken as 317 ml/kg (millilitres/kilogram) of dry residue.
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