Scoping technology options for India's oil security: Part I – ethanol for petrol

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Crude oil prices recently crossed US$ 75/bbl, fuelling serious concerns whether India's rapidly expanding economy can sustain a high and growing level of crude imports. There are also serious concerns of global warming from burning of fossil fuels. It may be time for India to explore options which can substitute petrol and diesel and are climate-friendly. In a series of two articles, we examine a few such technology and policy options. Part I focus on options for substituting petrol by ethanol from sugarcane: molasses, sugarcane juice and cellulose (bagasse). Part II analyses options for diesel substitution: Fischer–Tropsch liquids from coal, and bio-diesel from oil-bearing plants like jatropha.

Keywords: Ethanol for petrol, India's oil security, scoping technology.

THE last few years have been critical for global oil consumers. After about 150 years of growth, the world started consuming more crude oil than it could discover. About 944 billion barrels of oil has so far been extracted, and about 1200 billion barrels remain underground[1]. With the present rate of production, about 81 million barrels a day[1], the reserves would last for only 40 years, though the numbers vary depending on whose data we trust. Oil-producing countries like Saudi Arabia inflate their data on reserves and talk of almost unlimited oil, with no end in sight for at least 60 more years. Even the US government data include all oil lying under the Arctic tundra and possibly under Antarctica, without worrying either about the cost of production or the environmental price. Even with all these reserves, the peak in oil production is expected anytime between 2006 and 2020. The fear of depletion is already seen with nations scrambling at each other to sign long-term supply contracts with oil-producers. US$ 100 a barrel, unthinkable just a few years ago, appears to be a distinct possibility.

Predicting the exact year when the world will 'run out of oil' is not going to be easy or even necessary. However, based on available statistics and experience in predicting the discovery and drying of oil wells, the end of oil as an abundant and cheap energy resource is near. Even if supplies of oil were to continue for several more decades, there is increasing pressure to look for alternate fuels in response to the potential threat of global warming. It is time for consumers and the global economy to move away from the crude oil-based economy to other fuels.

This scarcity comes at an inconvenient time for rapidly growing economies like India or China, whose elasticity of energy consumption to GDP is more than 1. The Indian economy is showing robust growth of around 8%. By 2040, one in five Indians is expected to own a car as against one in 100 now[2]. India is likely to account for 15% of the world's oil demand[2] by 2040. India's domestic production of crude has almost stagnated at around 11 million tonnes per annum. Crude imports touched 90 million tonnes in 2003–04 and will only increase further[3]. Unlike developed countries, India is a diesel-based economy. Diesel consumption is about five times that of petrol. Diesel is the fuel for trucks, agricultural machinery, water pump-sets and stand-by generators[4].

Given India's ambitious growth targets, volatility of crude oil prices and concerns of climate change, this may be the time for India to explore substitutes for diesel and petrol. Technology analysis in and of itself is not meaningful without the context of economics, policy and overall sustainability (including environmental). In this analysis, we examine these aspects for:

- Ethanol from sugarcane substituting petrol;
- Diesel from coal using Fischer–Tropsch synthesis;
- Bio-diesel from oil-producing seeds such as jatropha.

We have not examined hydrogen as a transportation fuel here. Hydrogen technology is many years away from even modest adoption, especially if envisaged with alternative prime mover technologies such as fuel cells. It also involves a radical change in the supply-chain. Hydrogen is not a primary fuel but a carrier; it requires primary fuels for production, which remains an energy supply concern. Much of the hydrogen used today comes from

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methane (natural gas), which itself is a good energy source, though in short supply. In this article, we have also not studied in detail other innovations such as hybrid or plug-in vehicles that in part use electric power for fuel or development of energy-efficient (e.g. lighter) vehicles. These are attractive innovations and should be pursued with vigour. These change the amount of liquid fuel required, but not their source per se. This analysis focuses on fuels that can substitute petrol and diesel.

Ethanol for petrol

Ethanol is a promising substitute for petrol. It is produced by fermentation of sugars, which can be derived from a variety of sources; the alcoholic beverage industry has known this technique for centuries. Sugars can be derived from a variety of feedstock such as sugarcane molasses, cane juice and starch-containing crops such as corn. An enticing option would be to produce ethanol from cellulose in agricultural and forest residues. Some claims have been made in this direction[5,6]. However, no large-scale commercial production has yet been established.

Most petrol engines can operate on a petrol–ethanol blend of up to 10% with minor or zero modification, and the modifications for greater blending are modest. The heating value of ethanol (29 MJ/kg) is about a third lower than that of petrol (42 MJ/kg). Blending ethanol therefore would lead to a decrease in the engine mileage per unit volume fuel. However, unlike petrol and diesel, ethanol contains oxygen resulting in improved combustion and lower emissions of unburnt hydrocarbons, CO and particulate matter. Already ethanol is blended as an additive to boost the octane number in some states of the US, especially since the previous additive, methyl tert-butyl ether, is being phased out due to groundwater pollution concerns.

International experience: Brazil and the US

Brazil leads the world in successfully harvesting ethanol for automotive applications. At about 14 billion litres, it is the world's largest ethanol producer, manufacturing 36% of the global production[7]. Sugarcane is the primary feedstock and ethanol is made both from molasses and cane juice; about 50% of Brazil's sugarcane harvest is used for making ethanol from juice[7]. To utilize (and pushing) the large supply of ethanol, there has been a dramatic rise in manufacture and sales of Fuel Flexible Vehicles (FFV) that can run on petrol, ethanol or any combination of these fuels[8]. FFV accounted for almost 20% of all cars and light commercial vehicles sold in 2004, and this is expected to increase to 100% within a few years. The cost of producing ethanol is about US$ 1/gallon[9], which is competitive even at half of today's gasoline prices (Table 1).

At 12 billion litres, the US is the world's second largest ethanol producer. In North America, sugars are usually derived from enzymatic hydrolysis of starch-containing crops, mainly corn. However, it is not cheap; the present retail price is US$ 2.5–3/gallon[10]. There is a federal tax credit of 51 ¢/gallon. Thus, at present corn ethanol is almost as expensive as petrol and there are few direct economic incentives in the US to substitute it for petrol. The US government imposed a tariff of 54 ¢/gallon on ethanol imports from Brazil, to protect its domestic ethanol industry. However, there is growing pressure to revoke this tariff since the domestic ethanol production is not sufficient[11].

There are also questions in the US about the desirability of the corn–ethanol programme. Some have argued that on a life-cycle basis, it takes more fossil fuel energy to make one gallon of ethanol than the energy contained in it. In other words[12,13], energy output to input ratio is 0.8. These calculations are refuted by other workers[14,15], who have shown this ratio as 1.34. The corresponding ratio for making ethanol from sugarcane (juice and molasses) is 6–8. A few agricultural economists are concerned about large-scale diversion of corn for fuel. They argue that agricultural land use should follow the hierarchy of 'food first', then 'feed for livestock' and last 'fuel'[16].

Opportunities for an Indian ethanol programme

Can India emulate the success of the Brazilian programme? In India, ethanol is produced entirely from sugarcane molasses. India's ethanol production of 1.96 billion litres[17] is modest compared to the US and Brazil. Out of this, 628 million litres is available for fuel after accounting for potable, industrial and other uses (Table 2)[17]. This translates to a potential for 5% petrol blend today. About 60% of the cane is used for making sugar, 30% for jaggery and the balance for seeds.

In 2002, the government passed an order mandating the blending of 5% ethanol with petrol in nine States and four Union Territories[18]. However, there were difficulties in the supply and price of ethanol attributed to lower production of molasses and unfavourable economics[19]. Consequently, the order was modified to allow ethanol to be blended only when it is economical and the supply assured[19]. Recently, the government has reiterated its resolve to go ahead with 5% ethanol–petrol blends[20].

Clearly, India is struggling to meet a 5% blend with petrol. This is because India's sugarcane production is just enough to meet the domestic sugar demand and leaves little room for diverting sugarcane juice for ethanol, as is done in Brazil.

Sugar is an essential commodity and an important part of the 'food chain', and demands priority over other alternate uses of sugarcane. Any imbalance between domestic production and demand for sugar would lead to

Table 1. Ethanol production in Brazil, US and India

	Brazil	US	India
Production	16 billion litres	12 billion litres	2 billion litres
Main source (feedstock)	Sugarcane juice and molasses	Corn	Sugarcane molasses
Cost of production	US$ 1/gallon	US$ 2.5–3/gallon; includes federal tax credit 51 ¢/gallon	Rs 15/l; US$ 1.5/gallon
Energy output to input ratio	6–8	0.80–1.34	5–8

Table 2. Ethanol production and use from molasses in India[17] during 2004–05

Sugarcane production	~280 million tonnes
Molasses production	9.2 million tonnes
Ethanol production	1969 million litres
Potable use	693 million litres
Industrial use	578 million litres
Other uses	70 million litres
Balance	628 million litres

spiralling of prices and other antisocial activities such as hoarding. Even at the present stage of sugar production, there is a perceived scarcity of sugar and the government recently allowed private agencies to import sugar on a limited basis[21].

If sugarcane is to be the primary material for ethanol production, what options are there to ensure that the production of ethanol does not affect the production of sugar?

Increasing sugarcane yield: drip irrigation and fertigation

The Indian average sugarcane yield of 65 tonnes/ha is only a little lower than that of Brazil[22]. Tamil Nadu has the highest average yield of about 111 tonnes/ha[22]. Drip irrigation with fertigation (adding fertilizers during irrigation) is an attractive option to increase the cane yield to at least 150 tonnes/ha. According to agro-biological calculations considering 50% use of solar radiation and 30% transpiration losses, the theoretical yield potential is 600 tonnes/ha (R. K. Sivanappan, pers. commun.). A few farmers in Maharashtra have reported a yield of 350 tonnes/ha (R. K. Sivanappan, pers. commun.).

We estimate that deploying drip irrigation and fertigation in 25% of the present area under sugarcane (about 1 million ha), is expected to increase sugarcane production to 370 million tonnes (Table 3). Consequently, sugar production will increase to 25 million tonnes and ethanol to 2920 million litres. At this level, it is possible to realize a 10–15% petrol blend (Figure 1). Sugar production will be more than the present domestic consumption and consequently there may be room to divert some sugarcane for making ethanol. If 10% of the sugarcane is utilized for making only ethanol, then the likely sugar production is about 23 million tonnes and ethanol is 4450 million litres, sufficient for at least 20% petrol blend. In both the above cases, domestic demand for sugar is not compromised.

We now examine the two commercial options for producing ethanol from sugarcane: from molasses and cane juice. In the first case, the sugar mill uses sugarcane juice to produce sugar and makes ethanol from molasses, which is a by-product. In the second case, sugarcane juice is used to make ethanol and hence no sugar is produced. The relative economics thus depends on the prices of sugar and ethanol. Oil companies purchase ethanol from distilleries at a price fixed by the government; presently Rs 18.75/litre (Table 4; R. K. Sivanappan, pers. commun.; B. P. Dixit, pers. commun.). At present, a sugar mill benefits more if it makes ethanol from molasses than from sugarcane juice (Figure 2). Ethanol price should be at least Rs 22/litre for ethanol production from sugarcane juice to be attractive.

Actual utilization of cane for sugar and ethanol would depend on market forces and relative prices of the two (domestic and international). It is important to emphasize that irrespective of market forces, the government might have to formulate market intervention policies to ensure that sugarcane is utilized first for food and then for fuel. The one-time cost for building drip irrigation networks (about Rs 7000 crores) is not large when viewed against the petroleum imports. A detailed cost analysis, while not appropriate here, shows that implementing a drip irrigation programme is both economically and environmentally desirable. Sugarcane is a water-intensive crop; conventional water requirement is estimated to be about 1800–2000 mm. Drip irrigation reduces the water requirement by almost 50%.

Cellulosic ethanol: a challenge and opportunity

Cellulosic ethanol is attracting a great deal of attention[14,23–25], suggesting a possible energy payback as high as 14 : 1 (fossil-fuel displacement). Cellulosic biomass consists of cellulose, hemicellulose and lignin, with smaller amounts of proteins, lipids (fats, waxes and oils) and ash. It can be converted to ethanol through several technology pathways (Figure 3). One conversion process involves enzymatic hydrolysis of cellulose to sugars followed by fermentation to produce ethanol[5]. Another option is dilute acid hydrolysis followed by fermentation[6]. In each of these processes, lignin does not get converted

Table 3. Impact of drip irrigation and fertigation technologies

Sugarcane production		
Present area under cultivation	4.3 million ha	
Average yield	65 tonnes/ha	
Present sugarcane production	280 million tonnes	
Area proposed to be brought under drip irrigation and fertigation	1 million ha	@ 25% of present area under sugarcane cultivation
Yield under drip irrigation + fertigation	150 tonnes/ha	This is a conservative estimate
Estimated sugarcane production	370 million tonnes	~70% used for sugar production
Increase in annual cane production	90 million tonnes	
Cost		
Cost of drip irrigation and fertigation[22]	Rs 65,000–75,000 per ha	
Total cost	Rs 6500–7500 crores	

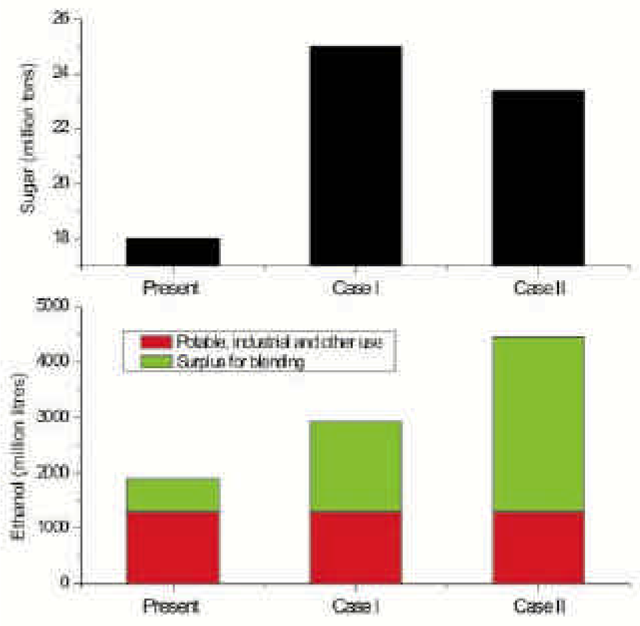

Figure 1. Present and future ethanol production with 25% of sugarcane cultivated area brought under drip irrigation and fertigation. Case I, Ethanol produced only from molasses; Case II, Ten per cent of sugarcane is used for making ethanol from juice.

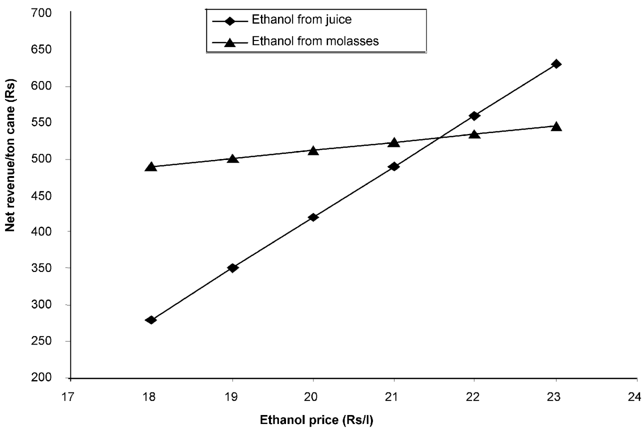

Figure 2. Relative economics of producing ethanol from molasses and cane juice.

as it is resistant to hydrolysis and the theoretical ethanol yield is about 110 gallons (415 l) per dry ton biomass[26]. In another process, biomass is gasified and the syngas can be converted to bio-fuels such as ethanol, methanol and higher hydrocarbons in a catalytic process[27,28]. This is a thermo-chemical process which converts lignin and therefore the theoretical ethanol yield is higher; about 170 gallons per dry ton bagasse. However, all these technology pathways are still in the experimental stage and initial experiments suggest an ethanol yield of about 60–80 gallons (227–302 l) per dry ton.

Cellulose ethanol presents a major opportunity since biomass feedstock is abundant and relatively inexpensive; India generates over 400 million tonnes of agro-forest residues such as wood chips, rice and wheat straw, coconut shells, sugarcane tops and leaves and bagasse. However, most of the biomass has well-defined applications in rural economy. For instance, straws are used for making roofs of huts and also as fodder for cattle, wood chips as fuel for cooking and many residues are burnt in the fields for their nutrient value. Moreover, most of the biomass is distributed in the villages and earlier work suggests that it is not economical to transport biomass over large distances to a central processing plant either for power generation or for making fuels[29]. Sugarcane bagasse and rice husk present a good opportunity because of the large availability at sugar/rice mill as a by-product and hence obviating the need for transport.

In this study, we assess the potential of making ethanol from sugarcane bagasse. We consider a sugar mill of crushing capacity of 5000 tonnes per day. Bagasse accounts for roughly 30% of the cane and contains almost 50% moisture. The theoretical yield of ethanol from cellulose is estimated to be ~415 l of ethanol per ton of dry bagasse[26,30,31]. The actual ethanol yield would probably be 60% of the theoretical yield.

Bagasse is used in sugar mills to generate process heat and electricity. It is burnt in boilers typically operating at 80 bar and 500°C to generate steam. This is expanded in back-pressure turbines to produce electricity and the low pressure steam exhaust is used for heating cane juice. In many sugar mills, surplus electricity is sold to the grid. It

Table 4. Assumptions and cost data

Sugar recovery	10%	This is the all-India average
Ethanol yield		
From molasses	11 l/tonne cane	
From cane juice	75 l/tonne cane	
Cost of sugar production	Rs 14–15/kg	
Cost of ethanol production from molasses	Rs 13–15/l	
Price of sugar		
Levy sugar (10%)	Rs 13.5/kg	Sugar mills have to sell 10% of the sugar to the government for stockpiling and for price support at levy price. The balance is sold in the market.
Market sugar (90%)	Rs 19/kg	
Price of ethanol	Rs 18.75/l	Fixed by the government for such uses.

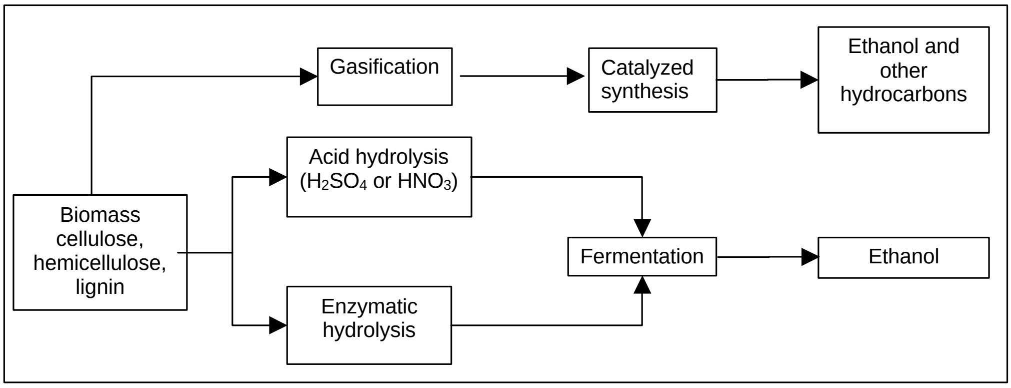

Figure 3. Conversion pathways for making ethanol from cellulosic biomass.

Table 5. Ethanol potential from bagasse in a sugar mill of 5000 tonnes per day and at a national level

Bagasse in sugarcane (by weight)	30%	
Moisture content	~50%	Bagasse is high in moisture
Theoretical ethanol yield	~415 l/ton dry bagasse	This is based on the assessment for a variety of bio-fuels[26,30,31]
Actual expected yield	260 l/ton dry bagasse	This is a conservative estimate. Actual yield is expected to be 60% of theoretical yield
Bagasse availability for ethanol	10%	Assumed to be 10% since bagasse is used for steam and electricity (cogeneration)
Mill capacity	5000 TPD	Tonnes per day
Ethanol production per annum	3.5 million litres	
India's sugarcane production	280 million tonnes	60% of this is used in sugar mills
Ethanol available for blending:		
From molasses	600 million litres	More than double the present ethanol available for blending. This can sustain a 15% petrol blend.
From bagasse	1120 million litres	
Total	1720 million litres	

is estimated that about 10% bagasse could be spared after utilizing for these processes (B. P. Dixit, pers. commun.). This could then generate about 3.5 million litres ethanol annually (Table 5).

Considering India's total sugarcane production of 280 million tonnes and assuming that 10% of bagasse is used for making ethanol, there is a potential for producing about 1220 million litres of ethanol, which is about double the present ethanol availability for blending and will meet 15% of India's demand for petrol (assuming other demands do not change, and all the incremental output is available for petrol blending).

This illustrates the potential of bagasse in augmenting ethanol production even under conservative estimates of yield and bagasse availability. Ethanol yield can be expected to increase with better technology. There is also scope to optimize bagasse utilization in sugar mills coupled with proper policy incentives to increase bagasse availability for making ethanol. One possible option is to dry bagasse before being introduced in the boiler so as to decrease the energy penalty associated with a high moisture fuel such as bagasse. Some of these options will be explored as future work. Ethanol production is expected to be 3000 million litres, if yield increases to 380 l/ton and 20% of bagasse is used. This is sufficient for 30% petrol blend.

Discussion

There are several options to augment ethanol production from sugarcane without interfering with the food chain (Figure 4). The present production of ethanol is just enough to support a 5% blend. By bringing 25% of sugarcane area under drip irrigation and fertigation, ethanol production (from molasses) can support about 15% petrol blend (case I). Cost of production is about Rs 15/l, since it is made from molasses.

If cellulosic ethanol technology is developed (case II), India can achieve 15% ethanol blend under conservative assumptions of yield (260 l/ton) and bagasse availability (10%). A blend of 20% ethanol can be realized by bringing 25% of the area under drip irrigation and using 10% bagasse for making ethanol (case III). With higher yield (380 l/ton) and bagasse availability (20%), ethanol availability is in excess of 4000 million litres; or 30% petrol blend (case IV). We have explored the possibilities from sugarcane bagasse. Cellulosic ethanol technology, if developed, can be used for other biomass feedstock such as rice husk, straw and even sugarcane leaves and tops. However, the process for producing ethanol from cellulose is still not commercially available and according to the US Department of Energy, cost of cellulosic ethanol is expected to be 50–100% more than that of corn ethanol, which itself is more expensive than ethanol from sugarcane. Claims of a few manufacturers in the West and also recent results in some Indian laboratories suggest that commercialization of cellulosic ethanol will soon be possible. Therein lies the opportunity for reducing the consumption of petrol.

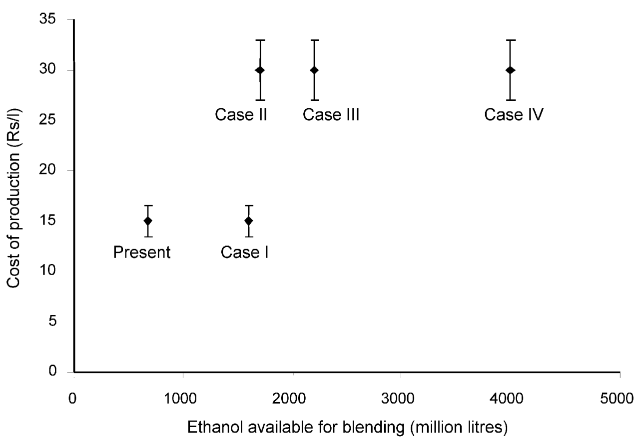

Figure 4. Comparison of options to increase surplus ethanol for blending: Case I, Increase sugarcane production by bringing 25% of sugarcane cultivated area under drip irrigation and fertigation technologies. Case II, Sugarcane bagasse (10%) is used for making ethanol with modest yield assumptions. Case III, Drip irrigation and fertigation technologies and using bagasse for ethanol production. Case IV, Using bagasse for ethanol assuming higher yield and availability.

Ethanol imports from Brazil

It will take a few years to commercially implement the above two options. In the interim period, it would be worthwhile for India to consider large-scale import of ethanol from Brazil. The present cost of production of ethanol in India compares well with the Brazilian cost. The US imports ethanol from Brazil because domestic production in the US is unable to meet the growing demand and Brazilian ethanol is cheaper despite an import tariff, which the US is now considering abolishing[11].

India also should encourage ethanol imports until her domestic production builds up. Ethanol import should not be a cause of alarm and the government should not impose prohibitive tariff. These imports will also give India the necessary opportunities for pursuing the development of cellulosic ethanol technologies and implementing drip irrigation. In a sense, this argument is similar to the one advanced in favour of importing light water reactor nuclear technology, so that India could focus on developing advanced fuel reactors based on thorium and plutonium[32].

Note added in proof

Since the submission of this article, international sugar prices, which crossed US$ 400 per ton in early 2006, crashed to about US$ 340 per ton in March 2007. This was due to expected record production in India (24 million tonnes) and Brazil (33 million tonnes). India now has a sugar surplus, leading the government to allow limited sugar exports. Present depressed sugar price provides an incentive to produce ethanol even from sugarcane juice. This may be an opportune time to introduce flexibility for sugar mills to make sugar or ethanol depending on market signals. Large-scale ethanol production however, will have to depend on the development of cellulosic biomass conversion technologies.

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