Promoting Bioethanol Production through Clean Development Mechanism:

Findings and Lessons Learnt from ASIATIC Project

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Global climate change mitigation policies call for increasing use of biomass fuels as renewable substitutes to fossil energy resources. Quantified targets for biofuels introduction in to the market exist in the United States, the European Union, and a number of developing countries. In this context, mixing biologically produced ethanol with conventional gasoline represents an attractive technical option allowing for reducing emissions of greenhouse gases and lessening the dependence on non-renewable petrol in the transportation sector. This paper investigates technological and socio-economic aspects of ethanol production in developing countries, particularly in China, with special focus on determining eligibility of bioethanol projects for Clean Development Mechanism. Basing on the findings of the ASIATIC study (Agriculture and Small to Medium Scale Industries in Peri-urban Areas through Ethanol Production for Transport In China), we analyse how alcohol fuels can be produced in a sustainable way with mutual benefits between rural and urban people. The bioethanol production cost and life cycle CO_2*eq emissions were calculated for six different types of feedstock: sugarcane, sugarcane molasses, sweet sorghum juice, cassava, corn, and sorghum bagasse. Implications of the CDM rules and procedures for bioethanol industry were examined under the angles of environmental and economical additionality, and conformity with the principles of sustainable development. It is found that the starch-based (cassava) ethanol production path has the greatest potential for market penetration in China, followed by the conversion route using sugar-based feedstock (sorghum juice, sugarcane molasses). Meanwhile, the lignocelluloses biomass - to - ethanol technology may represent the highest interest for implementation as Clean Development Mechanism project.*

Keywords: Ethanol, Biomass, Renewable Energy, Clean Development Mechanism, China

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1. INTRODUCTION

Unconstrained and reasonably cheap access to energy resources is the pledge for ensuring sustained economic growth and enhancing the quality of life in developing countries. The global consumption of fossil fuels augments rapidly over past decades, and the prices of most well-liked energy agents (oil and natural gas) follow the same logic. That raises several problems which may hinder future economic development around the world. The first issue is how to insure the security of energy supply. Because of unequal distribution of primary energy resources, especially in the case of oil and natural gas, the energy deficient countries tend to be vulnerable in the face of eventual market disruptions and price hikes. The second obstacle is the exhaustion of crude oil reserves that necessitates finding adequate substitutes to the conventional petroleum products among fossil and renewable alternatives. Finally, the carbon emissions due to combustion of fossil fuels also should not be neglected, because of their contribution to the global warming.

There is a strong empirical evidence of direct impact of crude oil prices on the pace of economic development. According to the recent OECD study a sustained 15 $ / bbl increase in the price of oil is capable to reduce the GDP by 0.25–0.40 % per year in countries like the USA, Japan and those of the Euro area (OECD, 2004). With the current oil price approaching 60 US$ / bbl we can likewise expect a deceleration of the global GDP growth because of induced inflation and increased spending on energy imports and risk premiums. The loss of welfare can be much higher if long-drawn price escalations occur due to physical disruptions in energy supply infrastructure and the exhaustion of existing oil fields. In a long – to – very long term perspective the socio-economic costs associated with atmospheric pollution and climate change may even overwhelm the incremental benefits of fossil energy use. Thus, there is strong need for diversifying energy supply and developing the production of alternative, preferably renewable, fuels that could alleviate the dependence on fossil energy resources and reduce the emissions of greenhouse gases.

Biologically produced ethanol represents such a renewable fuel with various environmental and socio-economic merits, which is already being used in significant quantities in different countries. According to “F.O. Licht” data, in 2004 total world production of ethanol was about 40’700 million litres, of which 73% were used as vehicles fuel, 17% for production of beverages and 10% for other industry needs (RFA, 2005). Brazil and the United States are by far the largest producers of fuel alcohol. In Brazil, bioethanol, mostly from sugar cane, is produced as either anhydrous ethanol that contains 99.6% (vol.) ethanol and 0.4% (vol.) water for use in 20–25% blends with gasoline or as hydrous ethanol containing 95.5% ethanol and 4.5% water that is burned directly as a pure fuel in dedicated ethanol-fuelled vehicles. In 2004 total Brazilian ethanol production was about 15’100 million litres. In the United States, fuel ethanol supply grew from virtually negligible quantities in 1980 to about 12’700 million litres by 2004 (Murray, 2005). Almost all of this ethanol is produced from corn starch and it is used in 10% ethanol blends. Special flexible fuel vehicles (FFV) are also available in the United States that can run on any fuel containing up to 85% of ethanol in mixture with fossil gasoline.

While Brazil and the USA occupy about 70% of the global ethanol market, the production of alcohol fuels in other world countries also grows steadily. Canada had ambitious plan for expanding bioethanol production with the current output of 230 million litres in 2004. In the Green Paper on the security of energy supply, the European Commission envisages replacing 8 % of conventional fuels in the transport sector with biofuels, including ethanol and biodiesel, by 2020 (EC, 2000). Meeting this target requires continuous increase of bioethanol production capacities in the European Union from present 460’000 tons (575 million litres) in 2003 to 10’700’000 tons (13’375 million litres) in 2010 (Corre, 2004). China also promotes use of bioethanol fuels in several provinces. In 2004 China projected the production of 2’800 million litres of ethanol, mainly from corn and cassava (Mingsong, 2004). India and Thailand are also implementing significant plans for set up and expansion of bioethanol production facilities (Wyman, 2004).

Considering that up to now the cost of bioethanol was considerably higher than the cost of fossil gasoline supply, national governments had to enact special policies in order to encourage production and use of bioethanol in the transportation sector. In general, the following three main approaches can be distinguished in the implementation of biofuels supporting policies and regulation: (1) Taxation-based policies; (2) Agriculture-based policies / subsidies; and (3) Fuel mandates (IEA Bioenergy, 2004). The first two types of policies allow for keeping the price of biofuels paid by the consumers at the same level as the retail price of their fossil analogues. The main drawback of this regulation approach is that government revenues are likely to be reduced. The third approach assumes that motor fuel should contain minimum percentages of biofuels prescribed by national standards, and the burden of excess cost of the ethanol-gasoline mixture is transferred to the fuel end-user.

Although the fuel ethanol industry is expanding rapidly around the world, there exist certain technical and economical barriers that prevent bioethanol from taking a larger market share. First of all, there is a potential competition for land and raw materials between ethanol and food / feed production. Indeed, the structure in agricultural production is very sensitive to the governmental policies and the market prices of final products. In this situation, reasonable compromises should be found how to distribute the tax breaks and subsidies across the bioethanol production and distribution chain without undermining the security of alimentary supplies. The second group of market barriers relates to the technical standards that prescribe certain rates of ethanol incorporation in gasoline blends and determine the possibility of using the fuels with high ethanol concentration in the internal combustion engines. In the absence of compulsory norms and economic incentives that favour massive use of alcohol fuel, the market penetration of bioethanol may be significantly hindered.

The prospects for bioethanol production and use as a transportation fuel are very optimistic. According to Berg (2004) the world ethanol production will continue to grow dynamically at least up to 2012, reaching about 65'000 million litres. A strong political support exist in many countries for promoting fuel ethanol projects, and the industry, including major oil suppliers and car manufactures, also seem to be interested in this new type of motor fuel. While certain countries (USA, Brazil, EU) already possess important ethanol production capacities and commit to their further expansion, a significant increase of bioethanol supply is expected to occur in China and India. Due to rapid economic growth and lack of indigenous resources of crude oil, these world biggest developing nations are ought to import considerable amounts of petroleum products. Hence, the use of ethanol fuel is seen in these countries as one of the possible ways to reduce their dependence on imports of non-renewable fossil fuels and to create an additional revenue source for local agricultural producers.

The objective pursued in the present study consists in analysing the state-of-the-art and perspectives for development of the biomass-to-ethanol technology, determining the key success factors for implementation of alcohol fuel projects, and searching for promotion strategies that can lead to a sustainable and significant production of bioethanol in the developing countries, with special focus on China. This paper is structured as follows. Next section will give an overview of the policy framework and current situation of bioethanol fuel supply in China. Main findings of the ASIATIC project will be presented herein describing different production chains, respective costs and life cycle CO_2eq emissions, and explaining the specifics of bioethanol and alimentary products competition for agricultural land and raw materials. Section 3 will analyse possible strategies to promote bioethanol production in developing countries. Then optimal strategies having less impact on the land use and lower competition with food and feed will be proposed, taking into account the cost reduction opportunities created by the free market trade and the Clean Development Mechanism. Section 4 will describe in more details the case of bioethanol production from sugarcane molasses in the particular circumstances of Guangxi province in China. Finally, main findings and policy recommendations will be presented.

2. CHINESE POLICY IN BIOETHANOL PROMOTION

2.1 Government programme and policy incentives

Starting from 2001 two major fuel ethanol programmes have been implemented in China with the objective to promote renewable energy sources, enhance national energy security and improve domestic environment (Hu et al, 2004). Within the framework of these programmes China adopted the quality standards for denatured fuel ethanol and ethanol-blended gasoline that pave the way for large scale use of alcohol fuels in transport. As regards the industrial production of bioethanol in today's China, it is still in experimental phase in nine provinces, where the central government gives incentives to support the conversion of corn to ethanol and its blending with gasoline. According to the Chinese law, ethanol plants were exempted from tax during 2001 - 2003, the experimental period for introduction of bioethanol fuel and ethanol-gasoline blend. This tax exemption is likely to remain in near term perspective. For a number of exemplary bioethanol production facilities, the central government accorded subsidies to cover the gap between the production cost and ethanol's selling price. Furthermore, in several cities, distribution of E10 fuel (a 10% ethanol blend with gasoline) in every fuelling station is imposed by the local regulation.

Although the Chinese authorities already have put in place significant efforts to support production and use of bioethanol fuel, an optimal design of the bioethanol promotion strategy remains to be elaborated. As a matter of fact, the actual policy of central government is driven mainly by the willingness to stabilize the income of the farmers in the corn production basin in Central and North China. Considering that this situation can not hold for a long time and taking into account the lack of financial resources for providing direct subsidies to ethanol plants, different mechanisms must be enacted that favour free market competition and exploit the opportunities of non-discriminative worldwide trade in agricultural products and CO_2 emission reductions. The resulting bioethanol encouragement policies should reach a consensus or at least a compromise between different stakeholders (farmers, oil companies, car manufacturers, municipalities, end users…). Moreover, this compromise should be based on a multi-criteria approach including technical, economic, environmental and social background.

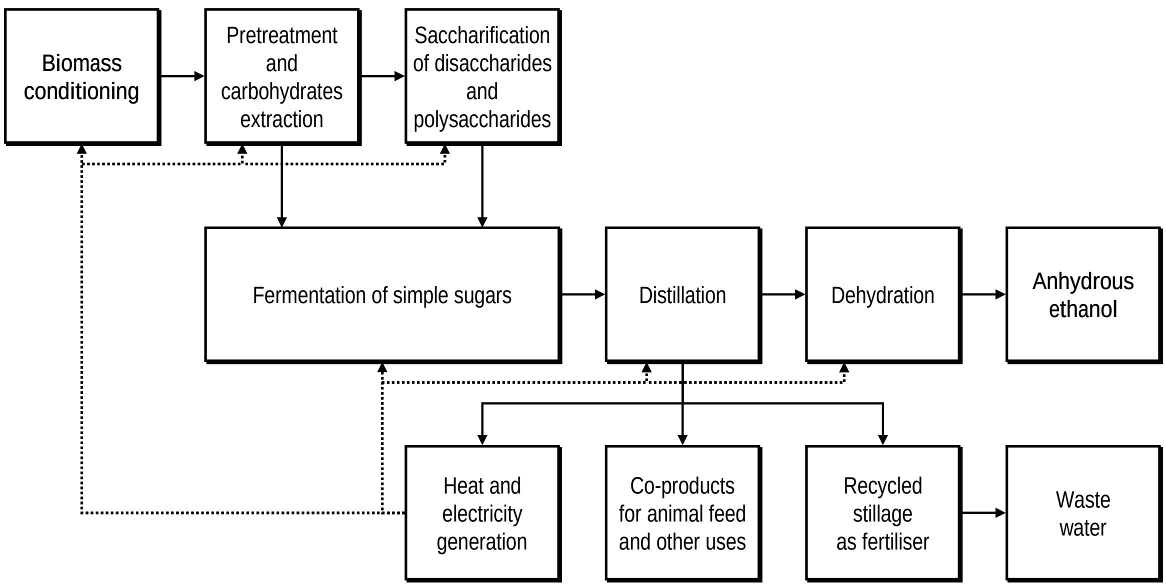
The ASIATIC study (Agriculture and Small to Medium Scale Industries in Peri-urban Areas through Ethanol Production for Transport In China) was carried out in this context with the objective to deliver such multi-criteria background and method to monitor the dialog between all the stakeholders that might be interested in the successful implementation of bioethanol projects in China. While performing comprehensive analysis of biomass-to-ethanol technology and its underlying socio-economic patterns, the ASIATIC study aims to propose a roadmap allowing for sustainable production and use of bioethanol in the transportation sector with mutual benefits between rural and urban partners. The following tasks were accomplished in particular work packages of the ASIATIC study: (1) Modelling and forecasting of the long-term evolution of the demand of gasoline and oxygenated additives in China; (2) Analysis of the current availability and the possibility for future sustainable production of agricultural raw materials, which may be used for producing fuel ethanol; evaluation of the competition and/or synergy between food, feed and fuel production in the case of bioethanol, (3) Specification of the technology, determination the scale and sites of the industries depending on the biomass feedstock, their location, the economy of scale and the mode of ethanol blending with gasoline; (4) Comparative analysis of bioethanol and gasoline production and E10 use in the Chinese context (environmental impact, energy balance, economic and social profitability); (5) Identification of the bottlenecks and barriers to implementation and market penetration of the biomass-to-ethanol technology (6) Detailed case studies of Liaoning and Guangxi provinces; knowledge transfer to the end-users through training courses, exchange of scientist, website and workshops. Next sections will provide a deeper insight into biomass-to-ethanol technology and will present main findings of the ASIATIC project.

2.2 Comparative analyses of main bioethanol production paths

Large scale bioethanol industry mostly uses the following feedstocks: sugarcane or sugar beet juice, corn or wheat. Ethanol is also commercially produced in the pulp and paper industry as a by-product. Lignocellulosic biomass is also envisaged to provide a significant portion of the raw materials for bio-ethanol production in the medium and long term due to its low cost and high availability. For a given production line, the comparison of the feedstocks includes several issues: chemical composition of the biomass; cultivation practices; availability of land and land use practices; use of resources; energy balance; emission of greenhouse gases, acidifying gases, ozone depletion gases; absorption of minerals to water and soil; injection of pesticides; soil erosion; contribution to biodiversity and landscape value losses; farm-gate price of the biomass; logistic cost (transport and storage of the biomass); direct economic value of the feedstocks taking into account the co-products; creation or maintain of employment.

Figure 1 presents an outline of the biomass-to-ethanol processing. One or more steps can be omitted and several may be combined depending on the feedstock and the conversion technology. Once the biomass is delivered to the ethanol plant, it is stored in the warehouse and conditioned to prevent from early fermentation and bacterial contamination. Through pre-treatment, carbohydrates are extracted or made more accessible for further extraction. During this step, simple sugars may be made available in proportions depending on the biomass and the pre-treatment process. A large portion of fibres may remain for saccharification through hydrolysis reactions or other techniques, in order to obtain simple sugars which are then fermented.

Figure 1. Schematic outline of biomass-to-ethanol process



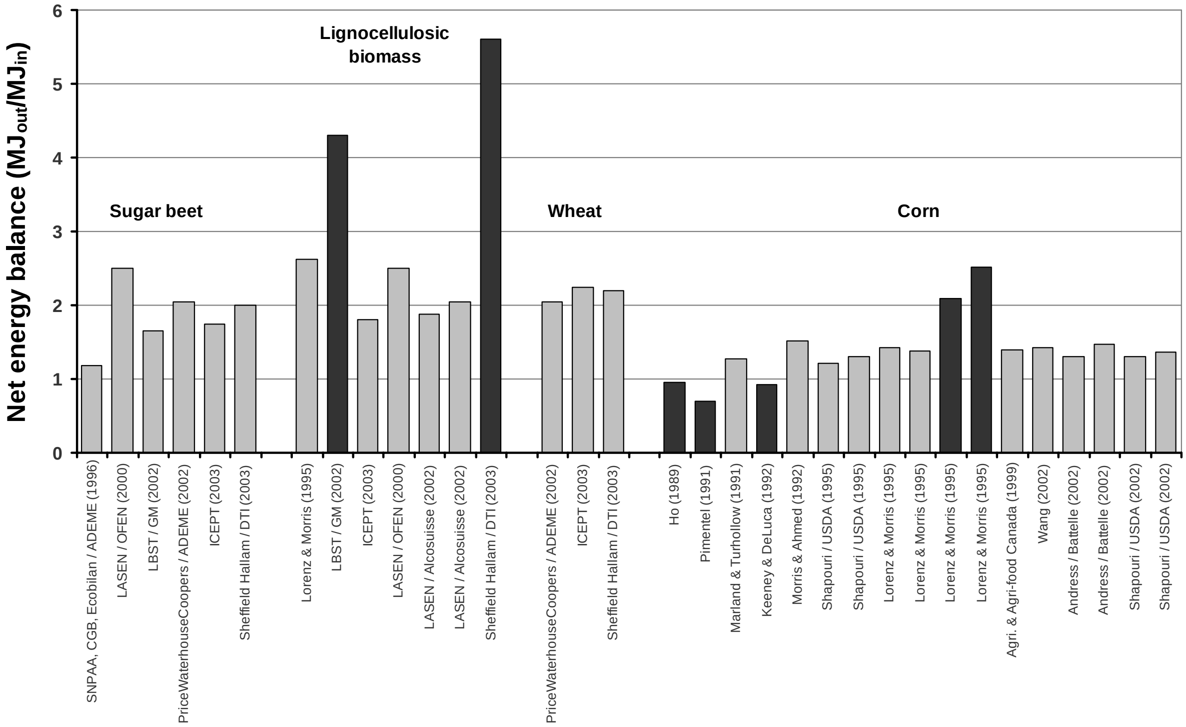
Source: Gnansounou & Dauriat, 2005

In the fermentation step, batch operations may be used in which the hydrolysate, the yeasts, nutriments and other ingredients are added from the beginning of the step. In case of a fed batch process, one or more inputs are added as fermentation progresses. Continuous process in which ingredients are constantly input and products removed from the fermentation vessels are also used (Wyman, 2004). In efficient processes, the cell densities are made high by recycling or immobilising the yeasts in order to improve their activity and increase the fermentation productivity. The fermentation reactions occur at a temperature between 25 °C and 30 °C and last between 6 hours and 72 hours depending on the composition of the hydrolysate, the type, the density and activity of the yeasts. The broth typically contains 8 to 14 % of ethanol on a volume basis. Above this latter concentration, inhibition of yeasts may occur that reduces their activity. The distillation step yields an azeotropic mixture of 95.5% alcohol and 4.5% water that is the "hydrous" or “hydrated” ethanol which is then dehydrated to obtain an "anhydrous" ethanol with 99.6% alcohol and 0.4% water.

The remaining flow from the distillation column, known as vinasse or stillage, can be valorised to produce co-products that largely contribute to reducing the net production cost of the alcohol. The nature, composition and use of the various by-products depend on the nature and composition of the feedstock from which bioethanol is produced. By-products such as DDGS (distillers dried grains with solubles) or concentrated stillage are often used as a substrate for animal feed or fertiliser. By-products may also be used for heat and power generation within the ethanol plant itself.

The net energy balance of biomass-to-ethanol conversion is the key parameter that explains the interest in using bioethanol fuel instead of fossil gasoline. From a life cycle assessment (LCA) viewpoint, the net energy balance corresponds to the ratio of the energy content of bioethanol to the net non renewable primary energy (allocated to ethanol) consumed in the whole production process from biomass production to its conversion into ethanol. As the approach is LCA oriented, the energy input must be estimated in terms of primary energy. On average, the ratio (output/input) between the produced ethanol and the input of non renewable energy varies from 1.2 to 3.0 or more (Gnansounou & Dauriat, 2005). These values depend on the following factors: allocation between ethanol and the co-products; the use of renewable energy for fuelling the process, the agricultural practices for producing the feedstock, the energy integration within the production plant, the size of the plant, transport distances between the plant and the area of biomass collection. Intensive agriculture needs more fertilisers and leads to a larger energy consumption. Recycling the residues to produce process steam and electricity, as it is often the case for sugarcane, improves the net energy balance. The graph on Figure 2 depicts the results of a literature survey for various feedstocks (incl. sugarbeet, lignocellulosic biomass, wheat and corn).

Figure 2. Results of a literature survey on the net energy balance of ethanol production



Source: Gnansounou & Dauriat, 2005

The data corresponding to the dark boxes represent the extreme values that are mostly incoherent with the other reference sources. Ho (1989) gives too old data (in terms of energy use in both agricultural and ethanol production phases), leading even to a net energy balance less than one. The much debated Pimentel (1991) indicated an excessively high energy use for corn supply and high outdated doses of fertilizers. Keeney & DeLucca (1992) is also an old reference which above all did not consider any allocation procedure in the life cycle analysis. Two values from Lorentz & Morris (1995) correspond to futuristic cases for 2010 (best of industry) and 2015 (state of the art), which is not the case for the other references. LBST (2002) based on the 1999 study from NREL (Wooley et al., 1999) considered wood chips as wastes and therefore did not include any energy use for biomass supply (only transport). Also, the allocation was applied according to the replacement value, which often leads to inconsistent results when it deals with alternative electricity production. Finally, ICEPT (Woods & Bauen, 2003) also considered the feedstock (straw) as a waste and uses mere suppositions concerning the consumption of energy within the ethanol plant. The energy balance of Brazilian ethanol from sugarcane (8.3-10.2 MJ_{out}/MJ_{in}) as indicated by Macedo (2004) was not included in Figure 2 as it evaluates the ratio of the energy produced in the form of ethanol to the net final energy (as opposed to primary energy) consumed along the process of ethanol production.

Another important issue to be considered while analysing the energy and economic efficiency of bioethanol is the necessity to refer to functional performance of the fuel rather than to simple energy content units. The problem is that ethanol has a significantly lower heat value (21.3 MJ/l) compared to gasoline (31.5 MJ/l). Meanwhile, when used in a mixture of 5% (vol.) bioethanol and 95% (vol.) gasoline, 1 GJ of ethanol has a significantly better performance than 1 GJ of gasoline due to the higher oxygen content of ethanol. In fact, a vehicle running with the gasoline-ethanol blend will even drive little more kilometres than the same vehicle running with conventional gasoline. It means that, ethanol and gasoline having significantly different heat values, the two fuels must be compared on volume and performance (km) basis, rather than on an energy basis.

As regards estimation of the production cost of bioethanol, it depends on many technical and economic factors, i.e. biomass-to ethanol conversion pathway, plant size and location, feedstock and co-products markets etc. These factors may vary from one country to the other, and in the same country various projects may have different production costs. From the short review of typical bioethanol production costs given in (Gnansounou & Dauriat, 2005) and summarised in Table 1 many remarks can result: ethanol derived from sweet juice is commonly cheaper than the others; production in North America (Brazil and USA) is less expensive than that in Europe due to learning curve and other differences in expenditures; Brazil offers the cheapest ethanol worldwide; economy of scale and learning curve are dominant explanation factors of difference in production costs; possibility to valorise co-products contributes to reduce the production cost of bio-ethanol; ethanol derived from lignocellulose is becoming competitive with ethanol from corn and although its production cost is based on engineering estimates as no commercial plant exists, research progress has already decreased significantly the production cost of enzyme and the investment, two major components of the expenditures in case of lignocellulose-to-ethanol.

Table 1. Synthesis on typical bioethanol fuel production cost

Reference	Feedstock	Country or Region	Range of sizes Million litres per year	Production cost US$ (2000) / litre
	Sweet juice			
Walker (2005)	Sugarcane	Brazil	-	0.17 – 0.19
ASIATIC (Gnansounou, 2005)	Molasses	China	125	0.30
ASIATIC	Sweet sorghum	China	125	0.27
F.O. Lichts (2003)	Sugar beet	Germany	50	0.88
F.O.Lichts	Sugar beet	Germany	200	0.77
	Starch			
F.O. Lichts	Corn	USA	53	0.32
ASIATIC	Corn	China	125	0.31
ASIATIC	Cassava	China	125	0.23
F.O. Lichts	Wheat	Germany	50	0.55
F.O. Lichts	Wheat	Germany	200	0.48
	Lignocellulose			
NREL (Wooley, 1999)	Yellow poplar	USA	197	0.38
NREL (Aden, 2002)	Corn stover	USA	262	0.28
ASIATIC	Bagasse of sweet sorghum	China	125	0.30

Breakdown of the production cost for two types of starch-based feedstock (corn and cassava chips) which are being actually used for producing fuel ethanol in China is given in Table 2. All calculations were made basing on the reference plant capacity of 100'000 tons (or 125 million litres) of anhydrous ethanol and correspond to the specific technological process, conditions and hypotheses as described in the final report on ASIATIC project (Gnansounou et al., 2005).

Table 2. Details of bioethanol production cost in China

Components of the production cost	Ethanol from corn	Ethanol from cassava chips
Feedstock costs (CNY/yr)	321’620’000	212’400’000
Variable operating costs (CNY/yr)	77’830’000	77’590’000
Fixed operating costs (CNY/yr)	18’590’000	19’040’000
Investment costs (CNY/yr)	29’720’000	31’600’000
Sales of by-products (CNY/yr)	-114’850’000	-98’500’000
Ethanol production (l/yr)	125’000’000	125’000’000
Gross production cost (CNY/l)	3.56	2.73
Credit due to by-products (CNY/l)	-0.91	-0.79
Net production cost (CNY/l)	2.65	1.94

The net production cost of anhydrous ethanol from corn amounts to 0.26 $€_{2005}$ / l (2.65 CNY/l) and from cassava chips it is about 0.19 $€_{2005}$ / l (1.94 CNY/l). The net production cost is strongly dependent upon the biomass feedstock cost and upon the price at which by-products can be sold on the market. One has to bear in mind, however, that the production of 125 million litres of ethanol (as envisaged in the present case) is associated with the production of about 100’000 tons of by-products (DDGS), and the development of a large-scale ethanol industry might overwhelm the market of animal feed (which may result in a significant drop of the price of DDGS unless export to other provinces is envisaged). Such a phenomenon would require a more detailed local economic analysis.

2.3 Main bottlenecks

Concerning the plantation of crops which supply biomass feedstock for ethanol production, two cases are to be distinguished: multipurpose crops that are also devoted to food markets and dedicated ethanol crops. The latter are cultivated especially for ethanol production on non agricultural lands (i.e. fallow or undeveloped lands). The former provide almost all the feedstocks used to date for ethanol production (i.e. sugarcane in Brazil and corn in the United States). In most industrialized countries, the development of biomass-to-ethanol conversion emerged as alternative markets for sugar and grain surpluses. As the feedstock cost often represents more than three fourth of the ethanol production, in these cases the economic viability of multipurpose crops-to-ethanol depends on the food markets situations (i.e. sugar and grain markets). This correlation between food and ethanol markets may generate a volatility of the ethanol prices. In developing countries, the possible competition with food is one of the risks when using agricultural crops for ethanol production. Thus this option should be limited to cases where actual and sustainable surplus of crops occurred. Finally, ethanol production cost is scale sensitive. Feedstock and investment cost affect economy of scale in different ways. Marginal costs of feedstock collection and transport increase with the size of the ethanol plant whereas marginal investment cost decreases. Optimal sizes of ethanol plants depend on the particular context under study (availability of feedstocks, demand of ethanol, cost of transport and storage). It may vary between 50 Ml and 500 Ml of annual ethanol production.

Speaking about particular case of corn-to-ethanol production in China, it was found that the cost of supplying required feedstock represents about 72% of the production cost and the potential for reduction of other expenditures is low. Hence the price of corn is a key variable of the evolution of the production cost of ethanol from maize. Incentives to corn may encourage corn production and maintain the corn surplus at an artificially high price. Another big problem is the China’s WTO membership and the pressure for opening the Chinese market to international trade. Concerning corn in particular, China has no comparative advantage. The Nominal protection rates (NPR)[1] of corn in 2001 was 32%. Therefore, according to the common practice in WTO, China will likely moderate her policy and import more corn. The domestic price and production of corn will then decrease. As a consequence, using corn at a price close to the international price for producing bioethanol in China means that China will increase in long term her deficit in corn, unless she improves very significantly her productivity. Such an improvement means additional capital and natural resources like land use and water. Therefore, corn may be only an option for the transition period.

As regards, the production of bioethanol from cassava chips, from the point of view of process economics it seems a bit more advantageous than corn-to-ethanol conversion path. However, the problem with cassava is that because of its low economic value there are not enough incentives for farmers to produce it in sufficient quantities. Up to now cassava crops mostly have been planted on hillsides without proper cultural

[1] The Nominal protection rates (NPR) of an imported product compares the domestic price with the international price on CIF basis: NPR= (domestic price –CIF)/CIF*100. A high NPR indicates low competitiveness.

practices, and that causes serious erosion problems (Yinong et al., 2000). Furthermore, the currently available cassava species have relatively low yields and spreading of high-yield varieties is vitally needed to motivate the farmers and increase the production of cassava in order to meet the demand from ethanol industry.

3. ALTERNATIVE STRATEGIES FOR BIOETHANOL PROMOTION THROUGH CLEAN DEVELOPMENT MECHANISM

3.1 Main criteria for sustainable strategies

In the present situation, considering the limitations regarding supply of biomass feedstock and lack of public financial resources to support bioethanol production chain, the increase of alcohol fuel supply in China requires elaboration of alternative strategies that conform better to the principles of sustainable development and rely to a greater extent on the free market mechanisms. China's approval of the Kyoto Protocol and its entrance into force up on Russia's ratification have open the way for implementation of large scale international projects with the participation of industrialised and developing countries which result in measurable reductions of greenhouse gases emission within the framework of the Clean Development Mechanism (CDM). Due to its renewable nature and positive energy balance the production and use of bioethanol in China potentially can qualify for CDM under the condition that certain CDM requirements are met.

The sustainable development aspect should be seen as a major driver for a developing country to participate in CDM projects, since the projects have beneficial local economical, social and environmental impacts (UNEP, 2004a). As a matter of sovereignty, each host country is responsible for defining the sustainable development criteria. While no general definition exists, typically a three-dimensional approach is used to illustrate the main objectives; environmental, economical and social sustainability. Sometimes additional dimensions such as technological or cultural sustainability are also suggested, although one could argue that those can be included in the three first ones (UNEP, 2004b; Pembina Institute, 2002; Torn & LaRovere, 1999).

Indicators suggested for assessing the sustainable development impact of a CDM project illustrate well the wide scale of possibilities to contribute to the improvement of the host country's standard of living. As these indicators are concrete and measurable, they serve for verifying and monitoring purposes. Detailed lists present indicators for each dimension, including for example:

- Environmental: contribution to GHG and other harmful emission reductions globally / locally, diminution of non-renewable natural resource use, preservation of specific species
- Economic: impact on GDP, foreign exchange requirement, net employment generation, energy efficiency and security, cost effectiveness, expenditure on technology change
- Social: legal framework regulations, number of institutional units participating, local stakeholders participation, gender aspects, change of number of people living below poverty limit, energy services provided to poor people, changes in duration of education, different health measures.

As the suggested lists are very comprehensive, different projects use different sets of applicable indicators. Examples of the benefits of different kinds of CDM projects are presented e.g. in the studies by World Bank (World Bank, 2004) and Asian Development Bank (ADB, 2005). The pilot projects indicated important pollution reduction, increased employment and improvement of the living standards of the poor rural areas.

3.2 Conditions of application and potential benefits of CDM for bioethanol industry

Many international studies confirmed that modern biofuel energy technologies possess all means to support the development of poor, rural areas dependent on agriculture providing them with additional revenues, creating new employment opportunities, and reducing local atmospheric pollution, hence promoting the sustainability (Coelho, 2005; Simms, 2003; Silveira, 2005). However, beyond contribution to sustainable development in order to qualify for CDM bioethanol projects have to demonstrate that they meet specific CDM criteria and follow the rules set up by the CDM Executive Board. First of all, potential CDM project has to demonstrate that it results in GHG emission reductions bellow those that would occur in the absence of the certified project activity. This is the so-called "environmental additionality" criterion. Measuring the emission reductions to be certified and attributed to a particular CDM project involves the following steps. First, the project boundary and potential leakage of GHG emission have to be defined. According to UNFCCC definition the project boundary shall encompass all anthropogenic emissions of greenhouse gases by sources and / or removals by sinks under the control of the project participants that are significant and reasonably attributable to the CDM project activity. The term leakage refers to net change of anthropogenic emissions by sources of greenhouse gases which occurs outside the project boundary, and which is measurable and attributable to the CDM project activity (World Bank, 2004).

Next step consists in determining the "Emission Baseline" which is a reference "business-as-usual" scenario that reasonably represents the anthropogenic emissions by sources of greenhouse gases that would occur in the absence of the proposed project activity. Different approaches exist for determining baseline emission scenarios, including: project-specific, sector-specific, technology-specific, country-specific, hybrid. Baseline methodologies can be also characterised as static or dynamic. In case of fuel bioethanol it seems most pertinent to adopt a technology specific emission baseline corresponding to the combustion of conventional fossil gasoline. Finally, in order to evaluate overall GHG emission reduction potential of a given bioethanol project, a technology specific emission reduction factor shall be calculated basing on the estimation of energy balances and life-cycle emissions of the chosen biomass-to-ethanol conversion path. In order to receive financial value actual GHG emission reductions shall be verified and certified by independent body in the process of bioethanol fuel or ethanol-gasoline blend consumption by the end-users. Necessary correction to the amount of GHG leakage also has to be made.

Besides the environmental additionality in terms of GHG emission reductions, potential CDM projects have to demonstrate their investment, technological and financial additionality. Responding the investment additionality condition consists in proving that implementation of potential CDM project will require additional investments compared to the existing technical options of the first choice and, hence, it is less economically attractive under the business-as-usual scenario. Practical approaches to define investment additionality were investigated by Greiner & Michaelowa (2002). Having reviewed the methodologies proposed in various studies, they have identified the following set of criteria (Table 3), which could be applied to verify if project activity meets the investment additionality requirement:

Table 3. Criteria for Investment Additionality

	The CDM project activity meets Investment Additionality if…
1.	… there are barriers to the CDM project that do not apply to the reference case
2.	… project developers can show that there are real barriers and name activities to overcome them
3.	… investment costs / total costs / social costs of the CDM project activity exceed those of the reference case
4.	… NPV reference case > NPV CDM project activity
5.	… IRR reference case > IRR CDM project activity
6.	… IRR CDM project activity < upper boundary
7.	… payback period CDM project activity > lower boundary
8.	… absolute value (FI2 CDM project activity incl. CER – FI CDM project activity excl. CER) significant compared to FI CDM project activity excl. CER

Source: Greiner & Michaelowa (2002)

It can be seen that abovementioned criteria considerably differ depending on the character of benchmark assessment. Some of them are purely qualitative, for example, the first two criteria focusing on existing barriers to project implementation. The other criteria are of quantitative nature comparing economic performance of CDM project either to the reference case, or to the certain threshold value. For a bioethanol project it may turn out somewhat difficult to find a reasonable quantitative benchmark due to high volatility of prices of conventional petrol fuels. Therefore, it is suggested to apply a combined quantitative and qualitative approach which will take into account the existing barriers to the implementation of bioethanol project as well as the cost differential between the fuel ethanol production and domestic supply of gasoline.

Another eligibility filter for potential CDM project is the technological additionality. According to Thorne & Raubenheimer (2000), in order to qualify for CDM, the proposed project activity must achieve a level of performance with respect to reductions in GHG emissions that is significantly better than average compared with recently undertaken and comparable activities or facilities within an appropriate geographical area. UNIDO (2003) describes the same criterion as checking whether the project components include elements of innovation beyond conventional practice and what is their impact on maintenance and / or supply chain. From the above definitions it can be concluded that practical implication of the technological additionality criterion for bioethanol industry will result in ensuring that potential CDM project leads to implementation of the state-of-the-art high performance biomass-to-ethanol conversion technology which otherwise, in the absence of CDM, is not accessible to the host country.

Finally, the financial additionality indicator assumes that international funding for the CDM project activities in host developing countries shall not result in a diversion of and shall not be counted towards the financial obligations of industrialised countries included in Annex II to the UNFCCC as well as to the official development assistance (ODA) flows. It means that funds from existing programs such as administered by GEF or other ODA activities shall not be used to finance bioethanol projects.

The price of Certified Emission Reduction (CERs) which is an official accounting unit of the Clean Development Mechanism will have a decisive impact on the feasibility and economic performance of potential bioethanol projects to be implemented under CDM regime. The study of Springer (2002) reviewing outcomes of

[2] Here FI stands for financial indicator, i.e. NPV or IRR

different models identifies average price of US$ 27 and median price of US$ 19 per ton of CO_2. According to Grütter (2002) a market price of US$ 7 – 17 per ton of carbon (equivalent to US$ 2 – 5 per ton of CO_2) is considered as most probable under current conditions. The study of Chen (2003) throughout broader scope of sensitivity analyses estimated carbon price within diapason US$ 3.26 – 27.73 / t C corresponding to US$ 0.89 - 7.56 per ton of CO_2. The similar price range is given in Point Carbon (2003) study: US$ 3 – 6.5 / t CO_2. On the other hand, the IETA survey of 116 carbon market participants predicted the median carbon price in the end – 2010 at US$ 10.5 / t CO_2 , the mean was US$ 14.3 / t CO_2, and the 75 per cent responses were in the range US$ 6 – 20 / t CO_2 (IETA, 2003). Furthermore, these CERs can be accrued throughout a certain crediting period that may last either 10 years firm without renewal, or 21 years (7 years with possibility of renewal maximum twice) which is approaching a typical lifespan of a bioethanol installation. Practical implications of the different levels of CERs price for economic viability of biomass-to-ethanol projects will be discussed in more details in the next chapter basing on the reference example of setting up a bioethanol production facility in the Chinese province of Guangxi.

3.3 Proposed strategies

Considering that sustainability criteria are the main driving factors that should underlie the decisions of governmental authorities in developing countries, like China, regarding the deployment of bioethanol production facilities, it seems reasonable to favour in near term two biomass-to-ethanol conversion paths, one based on sweet juice and another based on cassava. The first technological option uses sweet juice obtained from sugarcane and sweet sorghum and allows for ethanol production combined with cogeneration using bagasses. Both raw materials are planted on dry, hilly land and this alleviates the problem of competition for land resources with the plantations of food crops. Furthermore, the possibility to substitute each other in the production of ethanol increases flexibility and it may be beneficial for economic performance of the ethanol installation. The second option uses starch-based feedstock from cassava which is also planted in hilly arid areas in Southern China and its production is expected to grow (Yinong, 2000). In terms of economic performance as presented above in Table 1 the cassava-to-ethanol production path is the cheapest followed by the sweet sorghum and sugarcane molasses. Finally, if all the eligibility conditions for CDM project financing are met, it can further improve the economics of chosen technologies, thereby reducing the requirement for financial support from the government and facilitating their market penetration as it is confirmed by the example of Guangxi province.

4. CASE OF SUGARCANE MOLASSES TO ETHANOL IN GUANGXI PROVINCE

4.1 Context of Guangxi province

Lying in the South Western boundary of China, the Guangxi Province had a population of 44.89 million in year 2000, including 6.06 million living in poverty condition and 1.36 million in poverty stricken condition. The GDP/capita was 4’292 Yuan (€ 430) and the urban population rate was only 28%. Gungxi is the dominant sugar cane producer accounting for more than one half of China’s sugar cane output (GAIN, 2004).

4.2 Technical description of the process

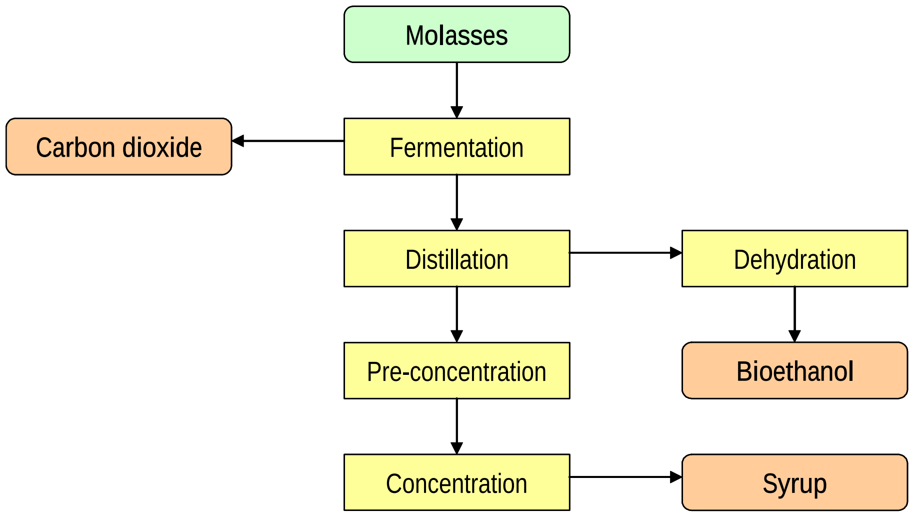
Figure 3 provides a global view of the process and organization of the various units in the sugarcane molassess-to-bioetanol production facility. The installation described here is supposed to be operating approximately 336 days per year. Molasses, for having a high sugar concentration (50% wt.) can indeed be stored easily, without a risk of degradation of the sugars.

The fermentation unit aims at producing a beer (or wine) at 9% (vol.) ethanol. Fermentation operates in a continuous mode and comprises two successive steps : (1) the pre-fermentation of a fraction of the molasses, to produce the required amount of yeasts for fermentation, and (2) the fermentation itself, aiming at converting the sugars into ethanol by means of the yeasts. The fermentation process lasts for 30-35 hours. Recycling of the stillage is not envisaged in the case of molasses. However, recycling of condensates (10%) is performed in order to reduce the consumption of fresh water and reduce the volume of liquid effluents.

The distillation unit aims at producing a hydrated ethanol at up to 93% (vol.). The unique distillation column operates at low temperature and in vacuum, in order to avoid possible clogging problems. As opposed to the corn process, the stillage is sent directly, as such, to the pre-concentration unit, without a clarification/separation stage. The distillation is coupled, in terms of energy use, to the pre-concentration unit, in order to reduce the global energy consumption. Hence, the distillation column is heated by direct injection of the steam produced in the first evaporator effect of the pre-concentration unit.

The pre-concentration unit aims at concentrating the produced stillage by evaporation. The evaporation is realized in a double-effect counter current unit, each effect comprising a group ‘evaporator-separator’ with forced recirculation. The second effect is heated by steam coming from the boiler, and the evaporation steam, in turn, heats the first effect. The evaporation steam of the first effect (as it was mentioned previously) provides the heat for the distillation stage by direct injection. The net consumption of plant steam in pre-concentration, and hence the concentration of dry matter at the exit, depends directly on the quantity of steam necessary at the distillation stage (therefore indirectly also on the ethanol concentration of the fermented mash). In the present case of molasses, the pre-concentration of the stillage by evaporation yields a dilute syrup with about 15-20% of dry matter (DM).

Figure 3. Diagram of the production process for the conversion of sugarcane molasses to ethanol



The concentration unit aims at concentrating further the dilute syrup (15-20% DM) in order to produce a concentrated syrup at about 55-60% DM. This by-product can be utilized as feed for cattle. Concentration is realized in a 4-effect counter current unit, each effect comprising a group ‘evaporator-separator’. Like in the pre-concentration stage, the 4th effect is heated with steam from the plant, while the evaporated vapour in turn heats the third effect and so on.

The dehydration of the hydrated ethanol (93% vol.) coming from the distillation unit is done by means of molecular sieves with regeneration by difference of pressure. The dehydration stage may not coupled with the distillation stage, in which case, the production of fuel-ethanol is not dependent upon the operating discontinuities of the distillation unit, themselves related to the availability of the feedstock. The hydrated ethanol is overheated prior to dehydration, in order to avoid any risk of condensation in the adsorbers. The dehydration stage is performed in vapour phase, in a cyclical and sequential way : adsorption, desorption. The alternation of cycles makes the production of anhydrous ethanol continuous.

4.3 Economic analysis

The economic analysis described in this paragraph aims essentially at evaluating the cost of production of fuel-bioethanol, in order to perform the allocation of environmental burdens between ethanol and the by-products, in the present case, concentrated syrup of sugarcane molasses stillage. The calculation of the production cost is based on an evaluation of annual expenses, composed of investment costs, fixed and variable operating costs. The following paragraphs describe each of these three cost areas and the assumptions to complete calculation of the production cost.

- ***Annual investment costs***

The total project investment as calculated in our model was based on the process design and the purchase cost of all the equipment required. The equipment costs were adapted from various quotes by manufacturers for European projects taking into account local conditions in China. Once the total equipment cost (TEC) has been determined, several other items must be added to obtain the total project investment (TPI), namely warehousing[3], site development[4], field expenses[5], home office and construction fees[6], project contingency[7], and yet other costs[8], amounting to an additional 56% of the TEC. It should be noted that the percentages applied have been reduced compared to normal practise to take into account the advantage of constructing the plant on the site of a sugar refinery.

To be able to assess the contribution of each process stage to the total project investment and then to the gross production cost of ethanol, these additional costs were distributed among the various stages, according to their respective specific equipment costs. In order to calculate the "shadow-price" of the stillage after distillation stage, the investments of the boiler were distributed amongst the other process units, according to their respective steam consumptions (Table 4). The investments for the water treatment unit (including biogas production) and for the water supply system were taken into account in calculating the cost of biogas and that of process and cooling water. The details of the total project investment (TPI) are presented in Table 4.

Table 4. Details of investment costs (Thousand CNY) per process stage

Process stages	Specific equipment costs	Equipment costs	Additional costs	Project investment
Fermentation	9'540	9'540	5'340	14'880
Distillation	7'150	23'280	13'040	36'320
Dehydration	11'130	15'240	8'530	23'770
Pre-concentration	16'690	33'810	18'930	52'740
Concentration	18'280	30'610	17'140	47'750
Boiler	49'680	-	-	-
Total (thousand CNY)	112'470	112'470	62'980	175'460

- ***Annual variable operating costs***

Variable operating costs include feedstock, raw materials (yeasts, enzymes, acid, soda, etc.), energy (coal, electricity, biogas), as well as by-products credits and are incurred only when the process is operating (i.e. when ethanol is being produced). All raw material quantities used and wastes produced were determined using the spreadsheet mass and energy balance model. The unit prices of the resources consumed within the process and of the by-products (in this case, concentrated syrup) are the result of various investigations carried out by the Chinese partners.

As opposed to other cases, the price of the feedstock was not decomposed into transport and non-transport costs. Given the fact that the bioethanol plant is built on the site of the sugar refinery, there is no need for transporting the molasses. However, given the capacity of the plant (100'000 t/yr), the quantities of sugarcane that should be processed into sugar to give rise to the corresponding quantities of molasses (i.e. 405'000 t/yr) is about 18.1 Mt. With a yield of sugarcane of 55 t/ha, this represents a surface area of 330'000 ha (or 3'300 km^2, i.e. a radius of about 32 km). By considering a factor of sugarcane availability of 20% (assuming that 50% of the land around the refinery is occupied by agricultural land and that 40% of this agricultural land is actually dedicated to sugarcane for sugar production), the actual surface area would be of the order of 16'500 km^2 (i.e. a radius of about 72 km). The map of the Province of Guangxi on Figure 4 gives an idea of the potential extent of the collection area. In this example, the installation is supposed to be located near Nanning. The larger outer circle represents the overall surface area of 16'500 km^2, (considering a 20% availability as described above), while the smaller inner circle would be the corresponding area with a 100% availability, i.e. 3'300 km^2.

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3 Warehousing was taken as 1% of the total equipment cost (TEC).

4 Site development was taken as 10% of the equipment cost of process equipment and includes fencing, curbing, parking, roads, well drainage, rail system, soil borings and general paving. The factor which is used allows for limited site development, assuming a fairly clear site, with non unusual problem such as right-of-way, difficult land clearing or unusual environmental problem.

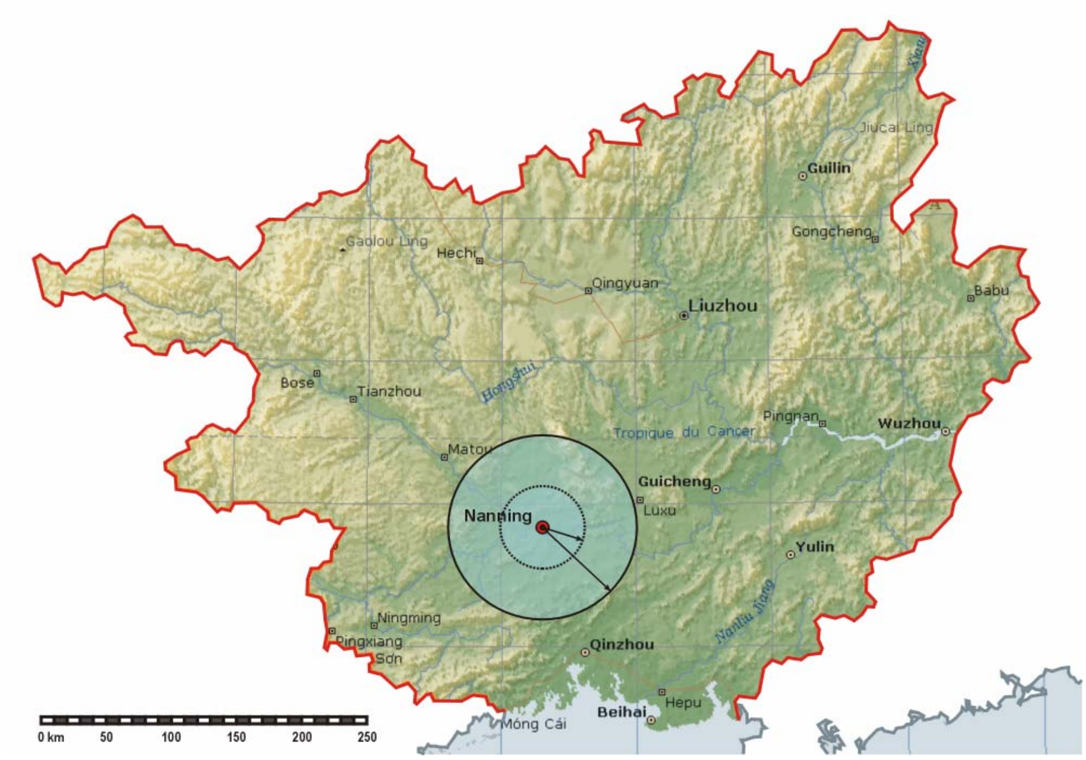
5 Field expenses were taken as 15% of the total equipment cost and include consumables, small tool equipment rental, field services, temporary construction facilities, construction supervision as well as prorateable costs such as fringe benefits, burdens and insurance of the construction contractor.

6 Home office and construction fees were taken as 15% of the TEC and include engineering plus incidentals, purchasing and construction.

7 Project contingency was taken as only 5% of the TEC.

8 Other costs were taken as 10% of the TEC and include startup and commissioning costs, land purchase, permits, surveys and fees, piling, soil compaction and/or dewatering, unusual foundations, freight, insurance in transit and import duties on equipment, piping, steel instrumentation, overtime pay during construction, field insurance, transportation equipment, bulk shipping containers, plant vehicles, escalation or inflation of costs over time, interest on construction loan and project team.

Figure 4. Representation of the collection area of sugarcane, Province of Guangxi, China



The price of molasses was considered to be 800 CNY/t. In this specific case where no transport is envisaged, the "farm-gate" price is equal to the price of the feedstock delivered at the plant.

The price for biogas is the result of a specific economic calculation and takes into account the treatment of all liquid effluents generated along the process. Therefore, the price of biogas reflects the cost of the entire processing of liquid effluents, including investments and operating costs for the water treatment plant (both anaerobic digestion and aerobic treatment), plus the elimination of the resulting mud. This is why, on a MWh basis, the price of biogas is very high and should not be compared to that of coal or electricity. The main reason behind the choice of such an approach was to make the distribution of these costs among the various stages more convenient. Similarly, the price of water takes into account the entire fresh water supply system (including investment, pumping, treatment and maintenance costs), in a situation where water is pumped directly from a nearby river or water body.

Table 5 summarizes the calculation of variable operating costs by indicating the contribution of the various components. Annual quantities as well as unit prices are given for all elements. Feedstock costs represent by far the most significant contribution to variable costs.

Table 5. Details of annual variable operating costs (CNY/yr)

Cost components	Quantities		Unit prices		Annual costs [CNY/yr]
Molasses	405’000	t/yr	800.00	CNY/t	324’000’000
Sulphuric acid	3’761	t/yr	550.00	CNY/t	2’070’000
Antifoam	63	t/yr	5’600.00	CNY/t	350’000
Process water	1’820’038	t/yr	2.50	CNY/t	4’550’000
Yeasts S. cerevisiae	150	t/yr	13’500.00	CNY/t	2’030’000
Phosphate	878	t/yr	3’100.00	CNY/t	2’720’000
Sulfate	627	t/yr	700.00	CNY/t	440’000
Electricity	22’579	MWh/yr	500.00	CNY/MWh	11’290’000
Coal	350’536	MWh/yr	30.00	CNY/MWh	11’290’000
Biogas	23’309	MWh/yr	1’100.00	CNY/MWh	25’650’000
Total without feedstocks	-		-		60’390’000
By-products credit	-		-		-99’510’000
Feedstock	405’000	t/yr	800.00	CNY/t	324’000’000
Total	-		-		284’880’000

- ***Annual fixed operating costs***

Fixed operating costs comprise salaries, but also general overheads, maintenance costs as well as all costs related to insurances and taxes. The number of employees for the whole ethanol production plant was estimated to 270. With salaries ranging from 120'000 CNY/yr for the general manager to 10'000 CNY/yr for yard employees, the resulting average salary is about 16'800 CNY/yr. General overheads are calculated as a percentage (in the present case, 60%) of the salaries and include elements such as security, salary bonuses, general engineering, telephone, light, heating, etc. Based on experience, plant maintenance is taken into account as a percentage (in this case, 2%) of the total project investment (TPI). Similarly, taxes and insurances are taken as 1.5% of the total project investment. The distribution of fixed operating costs amongst the various stages of the process is done according to their respective contributions to the total project investment. The details of annual fixed operating costs are given in Table 6.

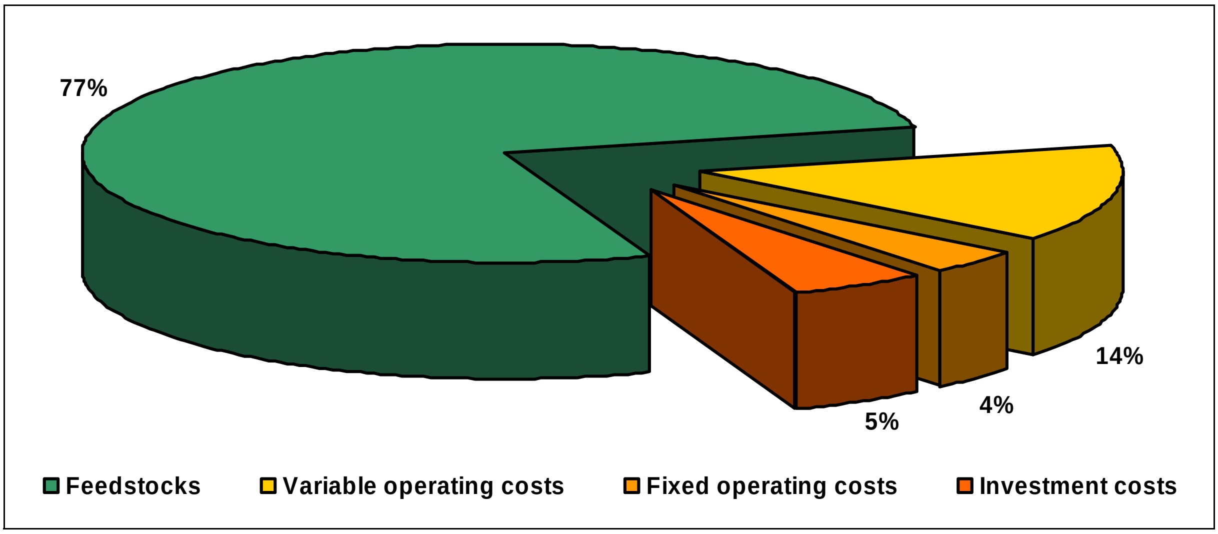
Table 6. Details of annual fixed operating costs (CNY/yr)

Cost components		Annual costs [CNY/yr]
Salaries		4'530'000
General overheads	(60% of salaries)	2'720'000
Maintenance	(2.0% of total project investment)	3'510'000
Taxes and insurances	(1.5% of total project investment)	2'630'000
Total	-	13'390'000

- ***Bioethanol production cost***

The calculation of the three components of global annual costs makes it possible to determine the production cost of ethanol from molasses. The gross production cost per litre of bioethanol is obtained by dividing the sum of annual expenses (without the credit of by-products) by the total volume of ethanol produced. The structure of the production cost is illustrated in Figure 5. It comes out that in the present case of ethanol production from sugarcane molasses, the contribution of the feedstock is very large with 77% of the total. The price of the feedstock, therefore, seems to be the most significant determinant of the production cost of bioethanol from molasses. The relative contributions of the remaining components here vary from 4% (fixed operating costs) to 14% (variable operating costs) of the gross production cost.

Figure 5. Structure of the gross production cost of bioethanol from sugarcane molasses



The net production cost is obtained by subtracting to the gross production cost, the benefits of the sales of the by-products (in this case, the concentrated syrup) relative to the production of 1 litre of ethanol. All the results of the economic analysis are presented in Table 7, on an annual basis and relatively to the production of one litre of ethanol.

Table 7. Details of bioethanol production cost on annual basis and a "per litre" basis

Components of the production cost	Ethanol from molasses
Feedstock costs (CNY/yr)	324'000'000
Variable operating costs (CNY/yr)	60'390'000
Fixed operating costs (CNY/yr)	13'390'000
Investment costs (CNY/yr)	17'550'000
Sales of by-products (CNY/yr)	-99'510'000
Ethanol production (l/yr)	125'000'000
Gross production cost (CNY/l)	3.31
Credit due to by-products (CNY/l)	-0.79
Net production cost (CNY/l)	2.52

The net production cost of anhydrous ethanol from molasses amounts to about 0.25 $€_{2005}$/l (2.52 CNY/l). This result is strongly dependent upon the cost the feedstock and upon the price at which the concentrated syrup can be sold on the market. One has to bear in mind, however, that the production of 125 Ml of ethanol (as envisaged here) is associated with the production of about 250'000 tons of concentrated syrup, and the development of a large-scale ethanol industry might overwhelm the market of animal feed (which may result in a significant drop of the price of the syrup unless export to other provinces is envisaged).

4.4 Potential role of CDM

In order to estimate potential impact of the clean development mechanism on the economics of biomass-to-ethanol projects it is important to evaluate two parameters: the unit reduction of CO_2eq emissions of one litre of fuel ethanol produced from given type of feedstock according to a specific technology, and the price of one ton of certified emission reductions at which it can be sold on the international market. The life-cycle rate of CO_2 emission reduction for bioethanol made from sugarcane molasses is about 1.92 kg CO_2eq / litre. For this estimate it is assumed that the baseline is unleaded gasoline. With the projected CERs price of 5 € / t CO_2 and annual production of 125'000'000 l the project can obtain an additional revenue of € 1'200'000 per annum. Meanwhile, at this level of CERs price its impact on the bioethanol production cost is practically negligible (€ 0.01).

Basing on the evaluations made in the ASIATIC study for other types of biomass feedstock, we have compared the competitiveness of different bioethanol production paths and derived the required subsidies and the corresponding cost of CO_2eq emission abatement at a gasoline gate cost of 25 €/barrel in 2010 (see Table 8). This relatively low gasoline price was chosen in accordance with the reference scenario projection of the "World Energy Outlook" (IEA, 2004).

Table 8. Bioethanol competitiveness in 2010

Biomass	Ethanol production cost	Equivalent of gasoline gate cost	Required subsidies for a gasoline gate cost of 25 €/bbl	CO2eq emissions abattement per litre of ethanol	Corresponding cost of CO2eq emission reduction
	€/l	€/bbl	€/l	kg/l	€/t CO2eq
Cassava	0.194	30.8	0.038	2.32	16
Sorghum juice	0.235	37.4	0.078	1.90	41
Sugarcane	0.308	48.9	0.150	2.61	58
Sugarcane molasses	0.253	40.2	0.095	1.92	49
Corn	0.266	42.3	0.109	2.51	43
Sorghum bagasse	0.338	53.7	0.181	2.88	63

It is found that at a gasoline gate cost of 25 € / barrel in 2010, no biomass to ethanol route could be considered competitive with gasoline. The least expensive is cassava followed by sweet sorghum juice and sugar cane molasses. In terms of CO2 abatement cost, conversion route of lignocelluloses feedstock (sweet sorghum bagasse) is by far the most expensive. On the other hand, looking at this situation from the perspective of clean development mechanism we can conclude that at the assumed level of gasoline price practically all bioethanol production paths can be eligible for CDM. Hence at high CERs price on the international market certain project could become economically viable. This supposition probably will not hold for all types of feedstock if we consider a higher level of gasoline price, close to its actual value in 2005 of 50 € / bbl. In this case it will be difficult to justify conformity with the CDM investment additionality criterion. Anyhow, even at this high gasoline price the lignocelluloses biomass – to – ethanol production path have luring perspectives to be implemented as CDM project.

5. CONCLUSIONS AND RECOMMENDATIONS

At the world level, the use of liquid fossil fuel in the car transportation sector is facing a very crucial challenge i) this sector is increasing very rapidly and ii) it's a source of oil depletion, greenhouse gases emissions and air pollution especially in urban area. Asian countries and China are now also facing this crucial question; increase in fuel consumption in China is among the highest in the world, not only for industry needs, but also for transportation. Regarding car consumption, no solution other than carbonated liquid or gaseous fuels will be available for large consumption before 2020, among these, biogas and liquid biofuels are the only ones to reduce the greenhouse gases emissions. Among existing liquid biofuels, bioethanol is the one with the highest productivity per area unit.

Even if the bioethanol production in China is presently based on maize raw material, the results gained in the ASIATIC study indicate that other chains (sweet sorghum juice and bagasse, bagasse and molasses from sugar cane, cassava) are promising in terms of land use, environmental impacts, rural development and economy. Regarding production costs, biofuel production in China is not yet competitive vs fossil fuels or even vs fuel from sugar cane in Brazil, but the gap is not that high since biofuel from maize reaches net production cost about 2.65 yuans per liter (0.265€/l), sweet sorghum juice 2.34 yuans per liter (0.234 €/l) and cassava 1.94 yuans per liter (0.194 €/l). In addition, the sale of certified emission reductions obtained through Clean Development Mechanism could improve the economic performance of bioethanol industry.

The economic and environmental performances of the bioethanol production and use will depend on many factors: technical performances of the whole production chain, gate price of gasoline, environmental performances of the whole chain, technological and operational learning etc. The behaviours of the actors will also impact the market price of bioethanol. As the cheaper production routes of ethanol are sensitive to the price of feedstocks, production costs of biomass are not robust enough for assessing their value. Therefore, opportunity costs approach must be considered.

Regarding emission of greenhouse gases, all analyses show that bioethanol is better than gasoline. Thus the replacement of one liter of pure gasoline with one liter of pure bio-ethanol in a vehicle could potentially offset 90% of the greenhouse gas emissions. Such results can be improved with the use of the whole part of the plant (bagasse, molasses, sweet juice). Different feedstocks exist (sweet sorghum, cassava, corn, sugar cane,…) that allow for a better use of the cultivated land.

Regarding rural development and social aspect, the ASIATIC project shows that different socioeconomic and pedo-climatic contexts allow the implantation of bioethanol industry in a sustainable way. It is found that an ethanol plant of 100’000 tons annual production will provide around 1000 full time jobs in the whole supply chain.

Technologies applied to the bioethanol production from sweet juice and starch are available and sufficiently mastered in China. Concerning the next generation of bioethanol process, i.e. from lignocellulose, R&D in such technology is being presently achieved abroad (USA, Europe, Brasil), as well as in China. It can be expected that the use of Clean Development Mechanism will help this technology to penetrate the market as well.

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