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**TECHNO-ECONOMIC INDICATORS FOR THE THERMOCHEMICAL  
AND BIOCHEMICAL ROUTES FOR BIOFUELS PRODUCTION  
USING SUGARCANE BAGASSE AS FEEDSTOCK**

By

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**Abstract**

THE MAIN GOAL of the paper is to compare the biochemical and thermochemical routes for second generation biofuels production performance, using efficiency and economic indicators. In both cases, the feedstock used is bagasse. Calculations are carried out for a biofuel plant having a bagasse consumption of 1772 t/day of dry matter, equivalent to 400 MW of thermal energy. By-products utilisation, such as lignin in the biochemical route, and bagasse for steam and electricity self sufficiency through cogeneration were considered also. The high production cost of bioethanol obtained through the biochemical route (21.32 to 22.7 US\$/GJ<sub>ETOH</sub>) is strongly influenced by the enzyme costs. The biomethanol production cost by the thermochemical route (15.82 US\$/GJ<sub>MeOH</sub>) is mainly influenced by the high equipment cost.

**Introduction**

Biofuels derived from lignocellulosic biomass can be produced through two conversion routes: the biochemical and thermochemical ones, and are classified as second generation biofuels to differentiate them from the conventional first generation ones.

The production of ethanol through pre-treatment, hydrolysis and fermentation from the sugars resulting from lignocellulosic materials conversion corresponds to the biochemical conversion route. On the other side, the obtainment of biofuels derived from biomass gasification synthesis gas conversion (Fischer-Tropsch liquids, methanol synthetic natural gas – SNG, and other hydrocarbons) corresponds to the thermochemical conversion route Schwietzke *et al.* (2008).

Presently, the bioethanol production cost from lignocellulose is high, and this is the main reason it has not reached the market commercialisation stage. Sassner *et al.* (2008) presented the results of the technoeconomic evaluation of bioethanol production from three types of lignocellulosic materials, and showed production costs in the range from 0.66 to 0.87 US\$/L, depending of the feedstock used. Finally, according to a study carried out by the United States Energy Department (DOE, 2008), the bioethanol cost can be reduced to the range 0.3–0.4 US\$/L in the future.

Regarding methanol, although great environmental restrictions exist regarding its utilisation due to the mainly fossil origin, a considerable number of techno-economic evaluations based on its production through renewable non-commercial technologies have been reported. The use of the renewable methanol could increase the sustainability of biodiesel production considerably, raising the output/input relation (renewable to fossil energy relation) of this process from 5 to 8, reaching the same value as for conventional ethanol, as reported by Angarita *et al.* (2009).

According to Hamelick and Faaij (2001), the average biomethanol production cost varies between US\$9 – 12/GJ for a plant with a processing capacity of 400 MW (biomass feedstock cost is 2 US\$/GJ).

Lower production costs, of about 8.04 US\$/GJ also for a 400 MW plant (biomass feedstock cost of 2 US\$/GJ), can be reached when the technology LPMeOH<sup>TM</sup> (Liquid Phase Methanol) is used, as work of Sørensen (2005).

In this paper, the biochemical and thermochemical routes for the production of second generation biofuels (bioethanol and biomethanol respectively), using sugarcane bagasse as feedstock are compared using different techno-economic indicators.

### Feedstock

Lignocellulosic biomass is composed mainly of carbohydrates (cellulose and hemicelluloses), lignin and a small fraction of extractives, acids, salts and minerals, as reported by Hamelinck *et al.* (2005) and Mosier *et al.* (2005).

Sugarcane bagasse and trash are co-products of the sugar and ethanol industry. In the harvest 2007/2008, the Brazilian sugar and alcohol agro-industry, having approximately 300 mills, processed  $4.32 \times 10^8$  tonnes of cane for the production of  $2.0 \times 10^7$  m<sup>3</sup> of ethanol. The quantity of sugarcane processed generated about  $1.2 \times 10^8$  tonnes of bagasse (UDOP, 2009).

Therefore, a wide recognition exists that the annual production of cane bagasse reaches huge figures and that the efficient use of this residue is an urgent necessity, with wide potential for the development of more profitable activities than direct combustion or gasification for electricity generation, and biofuels production, as discussed by Pitarelo (2007). It is assumed that both the bioethanol and biomethanol plants are located in Brazil, are autonomous, and have a processing capacity of 400 MWth (1772 t/day of dry biomass). Bagasse is acquired from nearby sugar and alcohol mills at market prices.

### Biochemical platform

#### Process description

The process of bioethanol production starting from lignocellulosic materials has the following stages: pre-treatment of the raw material, hydrolysis, fermentation and distillation (Figure 1). Also, a stage of steam and power generation by using the solid residues of the process as fuel should be considered.

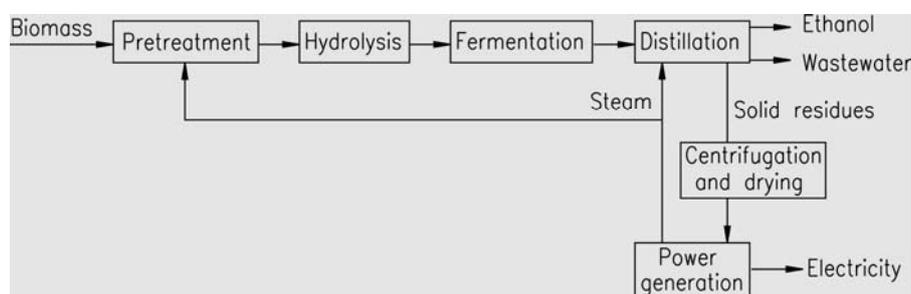


Fig. 1—Flowchart of bioethanol from biomass production (Hamelinck *et al.*, 2005).

In the bioethanol plant, bagasse does not require previous grinding due to its small size distribution, and it is assumed to have 50% moisture. The bagasse is imbued with gaseous SO<sub>2</sub> that functions as a catalyst for the pre-treatment process (Sendelius, 2005). The bagasse pre-treatment is carried out in a reactor, where steam with a pressure of 400 kPa is injected. A sudden system decompression is carried out and the slurry is collected in an expansion tank.

After this, comes the proper hydrolysis process using enzymes, where two types of sugar are produced: C6 (glucose) and C5 (non glucose-xylose). It must be taken into account that conventional yeast can not ferment C5 sugars. Before the hydrolysis, the pH of the pretreated bagasse should be adjusted by the addition of sodium hydroxide.

For sugars fermentation, two technologies are considered: the simultaneous saccharification and fermentation (SSF) and the simultaneous saccharification and co-fermentation (SSCF). In the case of the SSF hydrolysis (Table 1), only the fermentation of C6 sugars is considered. It is assumed that conventional *Saccharomyces cerevisiae* yeasts are used and that these are produced *in situ*, while enzymes are acquired from specialised suppliers.

In the case of SSCF hydrolysis, it is assumed that the yeasts used are genetically modified and they are capable of fermenting both C6 and C5 sugars (Table 1). However, presently, these yeasts do not reach yields shown in Table 1, and they are being used only in laboratory scale (Öhgren, *et al.*, 2006).

**Table 1**—Main parameters and stages yields assumed for the modelling of the two selected systems for ethanol production from lignocellulose.

Technology	SSF	SSCF
Biomass input	400 MW <sub>th</sub>	400 MW <sub>th</sub>
	1772 t <sub>dry</sub> /day	1772 t <sub>dry</sub> /day
<i>Pre-treatment</i>	Catalysed steam explosion	
Biomass moisture (%) <sup>a</sup>	50	50
Catalysis (kg SO <sub>2</sub> /kg based on wet bagasse) <sup>b</sup>	0.02	0.02
Cellulose recuperation (%) <sup>b</sup>	96.3	96.3
Hemicellulose recuperation (%) <sup>b</sup>	51.9	51.9
<i>Hydrolysis and Fermentation</i>		
Enzymatic load (FPU/g cellulose) <sup>b</sup>	10	10
Cellulose hydrolysis (kg glucose/kg cellulose) <sup>b</sup>	0.85	0.85
<i>Fermenting</i>		
Glucose (%) <sup>b</sup>	90 – 95	90 – 95
Xylose (%) <sup>c</sup>	80 – 92	80 – 90
Required power (MWe) <sup>d</sup>	3.76	3.52
Required steam <sup>c</sup>		
Pre-treatment (kg/kg bagasse <sub>dry</sub> )	0.2 (400 kPa)	0.2 (400 kPa)
Drying of the centrifugated lignin (t/twe)	1.01 (1100 kPa)	1.01 (1100 kPa)
Distillation (kg/kg produced ethanol)	2.57 (400 kPa)	1.03 (400 kPa)

<sup>a</sup> Macedo, 2008.

<sup>b</sup> Sendelius, 2005. FPU (Filter Paper Units)

<sup>c</sup> Hamelinck *et al.*, 2005.

<sup>d</sup> The required power for different process stages was estimated according to Wooley *et al.* (1999).

In the hydrolysis stage, 96.3% of the cellulose is recovered. A performance of bioethanol production of 76.89% of the theoretical value is assumed to be achieved starting from glucose (Sendelius, 2005).

The bioethanol is concentrated up to 92.5% on a distillation stage that consists of two columns, the first being an exhaustion column, and the second a rectification one, and operating on different pressures. After this, the bioethanol is concentrated up to 99.5% of purity through a molecular sieve process. A scrubber is used to minimise the bioethanol losses with the CO<sub>2</sub> vent from fermentation.

From the bottom of the rectification column, the co-products of the distillation stage mixed with the residual lignin are recovered. Lignin is separated by centrifugation and dried in a steam dryer up-to moisture of 48%, before being supplied to the boiler, to be used as fuel for cogeneration.

The recovered lignin is burned in a boiler that produces 127.08 t/h of steam for electricity production in steam turbines. The isentropic efficiency of the turbine was assumed to be 0.85, while the generator efficiency was 0.925. The lignin low heating value (LHV) in dry basis was considered to be 17.5 MJ/kg (Bensen *et al.*, 2006).

## Thermochemical platform

### Process description

In Figure 2, the general outline of the evaluated process is shown. For this case study, a pressurised bubbling fluidised bed gasifier, that uses a mixture of oxygen and steam as the gasification agent, was chosen. In Table 2, the main gasifier parameters are shown (Tijmens, 2000).

Once the cane bagasse arrives at the plant with moisture of 50%, it is necessary to dry it until it reaches the specifications requested by the gasification process, about 20% (Tijmens, 2000).

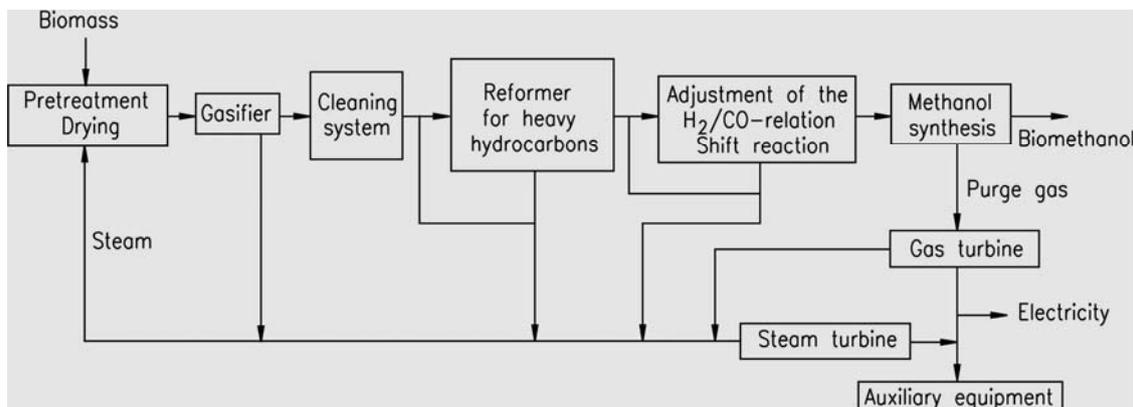


Fig. 2—Flowchart of biomethanol from biomass production (Hamelinck and Faaij, 2001).

**Table 2**—Main parameters of the gasification process.

Gasification parameters	
Relation [(steam+oxygen)/biomass] (kg/kg) <sup>a</sup>	0.6
Bed temperature (K) <sup>a</sup>	1173
Pressure (Pa) <sup>a</sup>	3039.75
Biomass moisture (%)	20
Gas yield (kmol/dry tonne)	82

<sup>a</sup>Hamelinck and Faaij, 2001

The gas produced contains tar, dust, alkalis and halogens that can affect the catalysts used in downstream processes. Particles removal from the gas is carried out using cyclones, fabric filters and scrubbers. A HRSG (heat recovery steam generator) is used for gas cooling.

The gas produced has a considerable amount of methane and other light hydrocarbons. A steam reforming stage is included to maximise the concentration of CO and H<sub>2</sub> by the conversion of CH<sub>4</sub> and C<sub>2</sub>H<sub>6</sub>. The H<sub>2</sub>/CO relation of the syngas is adjusted through the gas-water shift reaction (WGS). The synthesis gas passes through a CO<sub>2</sub> removal stage and enters the reactor of methanol synthesis. Finally, the raw gas obtained from the synthesis goes through a purification stage to obtain the biomethanol with the necessary purity (Ohlström, *et al.*, 2001).

## Economic analysis

Relevant parameters assumed during ethanol production cost calculations are given in Table 3.

**Table 3**—Parameters for the economic evaluation.

Parameters		Reference
The economical lifetime ( $t_e$ )	15 years	Assumed
The technical lifetime ( $t_t$ )	25 years	Assumed
Interest rate ( $i/R$ )	10%	Assumed
Exchange rate	1 US\$ = 2.2972 R\$	14/10/2008
Bagasse price	10.9 US\$/t <sub>(wet base)</sub>	Market price
Enzymes cost	0.32 US\$/L <sub>ETOH</sub>	Ministério de Relações Exteriores do Brasil, 2008
Electricity commercialisation price	50 US\$/MWh	Aneel, 2008.

The total capital investment, or TCI, is calculated using an estimated scale factor based on known costs for major equipment as found in literature and/or given by experts (Tables 4 and 5). Operational costs (maintenance, labour, consumables, residual streams disposal) are taken as a single overall percentage (4%) of the total investment

**Table 4**—Costs of the bioethanol system components in MUS\$<sub>2008</sub>.

Component	Base investment costs	Scaling Factor	Base Scale
<i>Handling and feeding</i>			
Conveyors <sup>a</sup>	0.19	0.76	160 t <sub>(wet base)</sub> /h
Feeding system <sup>a</sup>	0.0081	0.76	160 t <sub>(wet base)</sub> /h
<i>Pre-treatment</i>			
Steam Explosion <sup>b</sup>	1.48		83,3 t <sub>(dry base)</sub> /h
<i>Hydrolysis and Fermentation</i>			
Reactors SSF <sup>a</sup>	3.02	0.8	17.65 t ethanol/h
Reactors SSFC <sup>a</sup>	3.02	0.8	17.65 t ethanol/h
Seed unit production <sup>a</sup>	0.79	0.6	17.65 t ethanol/h
<i>Distillation and purification</i>			
Column distillation 1 <sup>b</sup>	1.04	0.7	18.47 t ethanol/h
Column distillation 2 <sup>b</sup>	0.90	0.7	18.47 t ethanol/h
Molecular sieve <sup>b</sup>	2.80	0.7	18.47 t ethanol/h
<i>Lignin recuperation</i>			
Dryer <sup>c</sup>	0.074	0.76	184 m <sup>3</sup>
<i>Power and steam generation</i>			
Boiler <sup>c</sup>	2.79	0.76	187 200 kg steam/h
Steam turbine system <sup>b</sup>	5.36	0.7	10.3 MWe

<sup>a</sup> Wooley *et al.*, 1999

<sup>b</sup> Hamelinck *et al.*, 2005

<sup>c</sup> Eijsberg, 2006

**Table 5**—Costs of the biomethanol system components in MUS\$<sub>2008</sub>.

Component	Base investment costs	Scaling factor	Base scale
<i>Pre-treatment</i>			
Conveyors <sup>a</sup>	0.085	0.76	54.5 t <sub>(dry base)</sub> /h
Dryer <sup>b</sup>	0.074	0.76	184 m <sup>3</sup>
Feeding system <sup>c</sup>	0.44	1.00	33.5 t <sub>(wet base)</sub> /h
<i>Gasification system</i>			
IGT <sup>c</sup>	38.1	0.7	68.8 t <sub>(dry base)</sub> /h
Oxygen plant (installed) <sup>c</sup>	47.51	0.85	41.7 t O <sub>2</sub> /h
<i>Gas Cleaning System</i>			
Cyclone <sup>c</sup>	2.79	0.7	34.2 m <sup>3</sup> /s
High Temperature Heat Exchanger <sup>c</sup>	7.50	0.6	39.2 kg steam/s
Bag Filter <sup>c</sup>	1.72	0.65	12.1 m <sup>3</sup> /s
Scrubber <sup>c</sup>	2.79	0.7	12.1 m <sup>3</sup> /s
<i>Syngas Conditioning</i>			
Compressor	11.92	0.85	13.2 MWe
Steam Reformer <sup>c</sup>	10.09	0.6	1390 kmol total/h
Shift Reactor (installed) <sup>c</sup>	39.61	0.85	15.6 Mmol CO+H <sub>2</sub> /h
CO <sub>2</sub> Selexol Remover (installed) <sup>c</sup>	58.08	0.7	9909 kmol CO <sub>2</sub> /h
<i>Methanol Production</i>			
Methanol Synthesis (Gaseous phase) <sup>c</sup>	7.51	0.6	87.5 t MeOH/h
Refining <sup>c</sup>	16.21	0.7	87.5 t MeOH/h
<i>Power generation</i>			
Steam Turbine System <sup>c</sup>	5.36	0.7	10.3 MWe

<sup>a</sup> Wooley et al., 1999

<sup>b</sup> Eijsberg, 2006

<sup>c</sup> Hamelinck and Faaij, 2001

### Techno-economic performance

For the ethanol production plant using SSF and SSCF enzymatic hydrolysis, the enzyme costs represent 66 and 70% of the total biofuel production costs, respectively. The costs of the cane bagasse, investment, M&O (maintenance and operation) and electricity commercialisation revenues, represented 21 and 17%; 17 and 15%; 3 and 3%; -7 and -6%, respectively. The electricity generated in co-generation systems has negative revenue, which results in biofuels production cost decrease.

Out of the sensitivity analysis, when varying the enzyme costs  $\pm 55\%$ , a sharp reduction is observed in the production cost of bioethanol down to 0.48 US\$/L. Other parameter variations do not affect the production costs significantly (Figure 3).

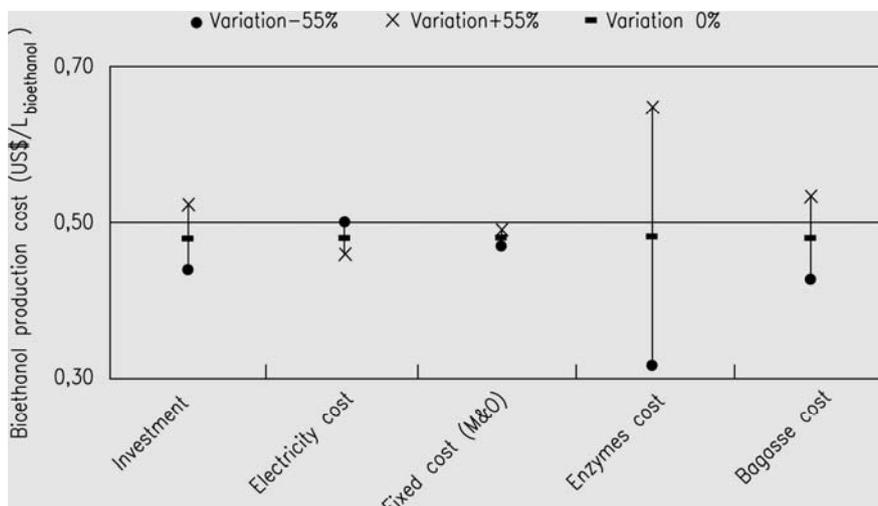


Fig. 3—Sensitivity analysis of the bioethanol SSF enzymatic hydrolysis.

The behaviour of the production costs for the SSCF case is very similar to SSF. A reduction of 55% in the cost of the enzymes results in an ethanol production cost of 0.314 US\$/L. Significant changes in the production costs are not observed for variations in the other economical parameters.

Although the bioethanol production cost through SSF technology is larger than the production cost by the SSCF method (0.48 and 0.45 US\$/L of bioethanol, respectively), these costs are still very high when compared with the costs of ethanol starting from sugarcane juice and from corn, as shown in Figure 4.

The cost of the enzymes used in this work was taken from information published in the news section of the Ministry of External Relations of Brazil related to Novoenzymes data (0.32 US\$/L bioethanol). The enzyme manufacturing companies are focused on reducing these prices by several times, which would make the process profitable (Ministry of External Relations of Brazil, 2008).

The biofuel production cost was calculated for different scenarios, as presented in Figure 5. Scenario 2 corresponds to the more optimistic one, with an enzyme cost of 0.05 US\$ per litre of produced bioethanol (Novozymes, 2008; Bon, 2007). Scenario 1 is more pessimistic with a cost of 2 US\$/L bioethanol (Bon, 2007). Scenario 3 was the one considered in this research.

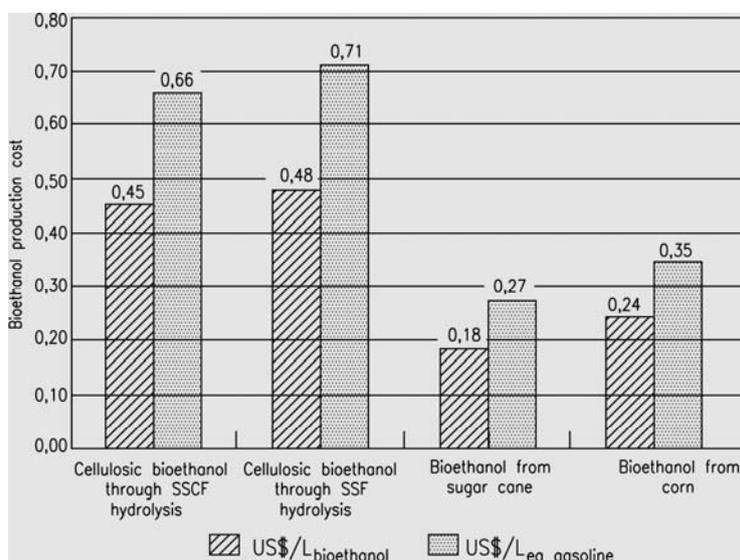


Fig. 4—Comparison of ethanol production costs from bioethanol starting from enzymatic hydrolysis (SSCF and SSF) and the conventional processes from sugarcane and corn.

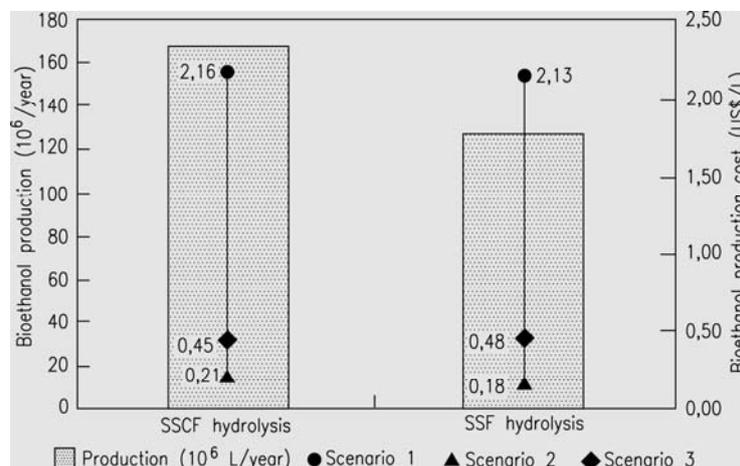


Fig. 5—Comparison of the costs of the bioethanol produced from enzymatic hydrolysis for different scenarios.

Different from the case of the biochemical platform, in the thermochemical one the largest percentage of the biofuel production cost corresponds to investment with 65%, followed by the fixed costs of M&O, cost of sugarcane bagasse and electricity commercialisation revenues with 22%, 18% and -4%, respectively.

Making a sensitivity analysis, varying the costs  $\pm 55\%$ , it is observed that the production cost is strongly influenced by the investment and, consequently, for the fixed costs of M&O. The fluctuation of the bagasse costs between -55 and +55% leads to biomethanol costs of 0.23 and 0.27 US\$/L<sub>MeOH</sub>, respectively, as shown in Figure 6.

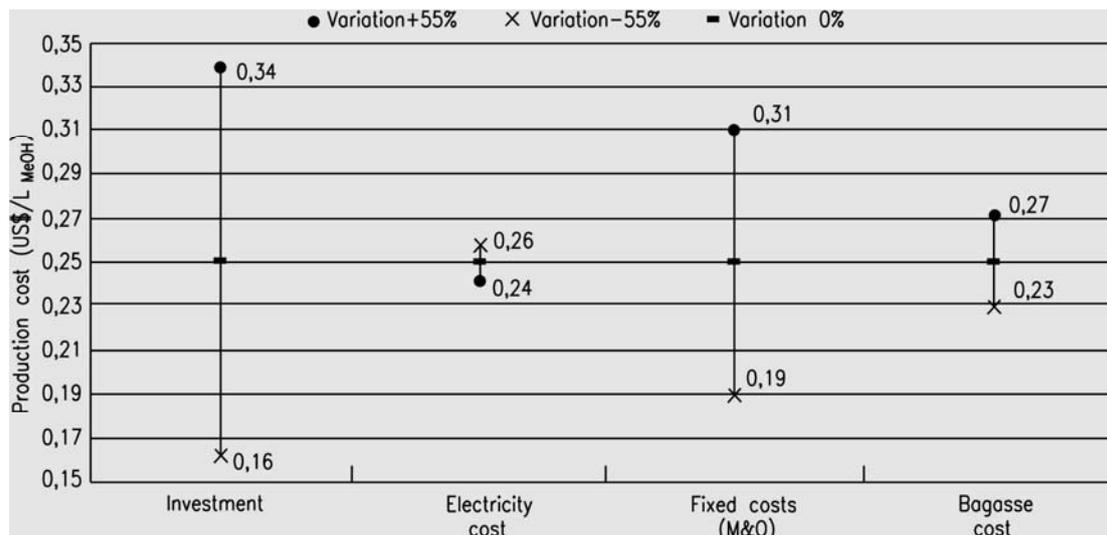


Fig. 6—Sensitivity analysis of the biomethanol production costs starting from biomass gasification.

In Figure 7, the cost of production of the methanol obtained from biomass is shown compared with the production cost starting from natural gas. It is observed that the production cost of methanol obtained through the first technology is greater than the second one with 0.25 US\$/L and 0.11 US\$/L, respectively.

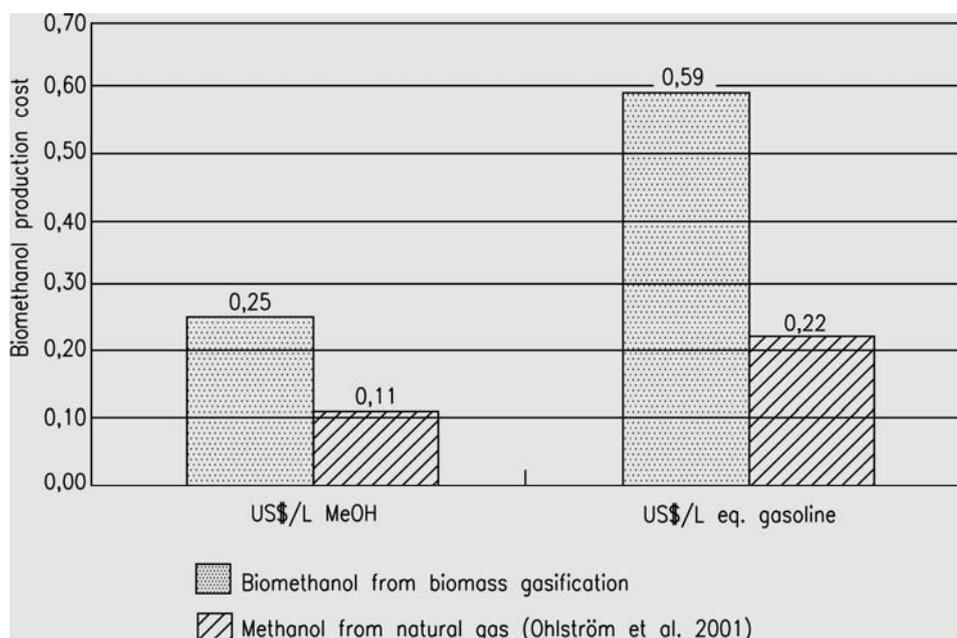


Fig. 7—Methanol production costs when using biomass and natural gas as feedstock.

Seeking the comparison of the biochemical and thermochemical routes, as is shown in Figure 8, the biofuel production cost in US\$/GJ<sub>HHV</sub>. It is observed that, in spite of the total investment cost of the biomethanol plant being much higher than for the bioethanol plants, the cost of production of the bioethanol starting from the enzymatic hydrolysis is higher than the cost of production of the biomethanol. This is due mainly to the high annual total costs involved in the biochemical platform.

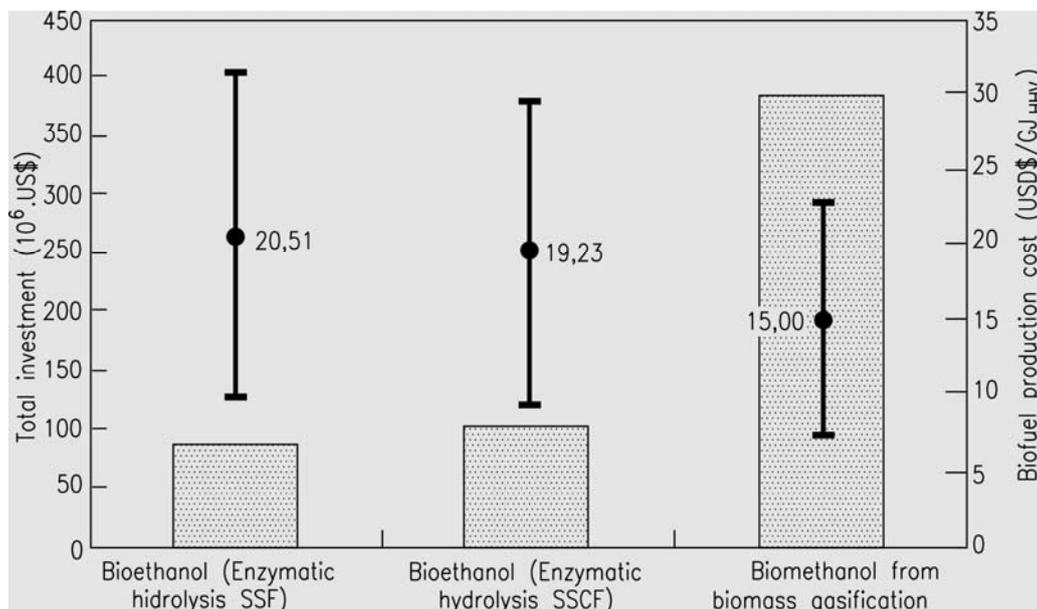


Fig. 8—Total investment costs (bars, left axis) and biofuels production cost (points, right axis) for the biochemical and thermochemical platforms for obtaining second generation biofuels.

A similar behaviour is observed when the biofuel production for plant capacity of 400 MW<sub>th</sub> and the production costs are compared (Figure 9).

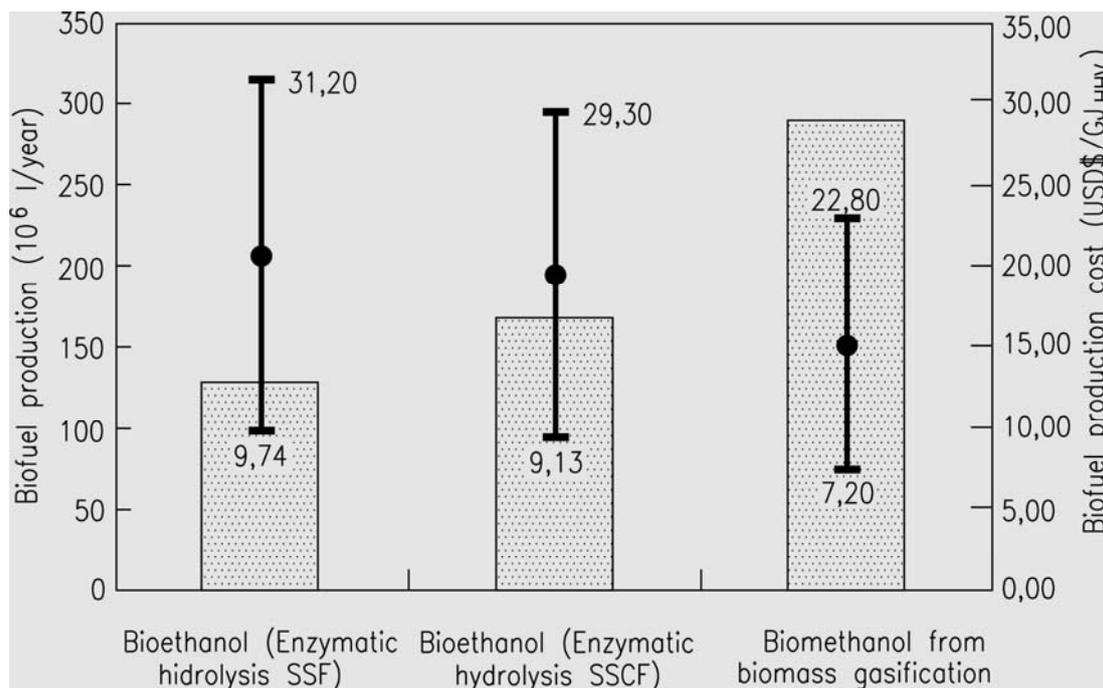


Fig. 9—Annual total production (bars, left axis) and second generation biofuels production cost (points, right axis) for the biochemical and thermochemical platforms.

Another scenario comes when the most optimistic case for the biochemical platform is considered. In this case, it is possible to reach ethanol production costs greater than biomethanol ones, that are 13.68 and 11.73 US\$/GJ respectively, as shown in Figure 10.

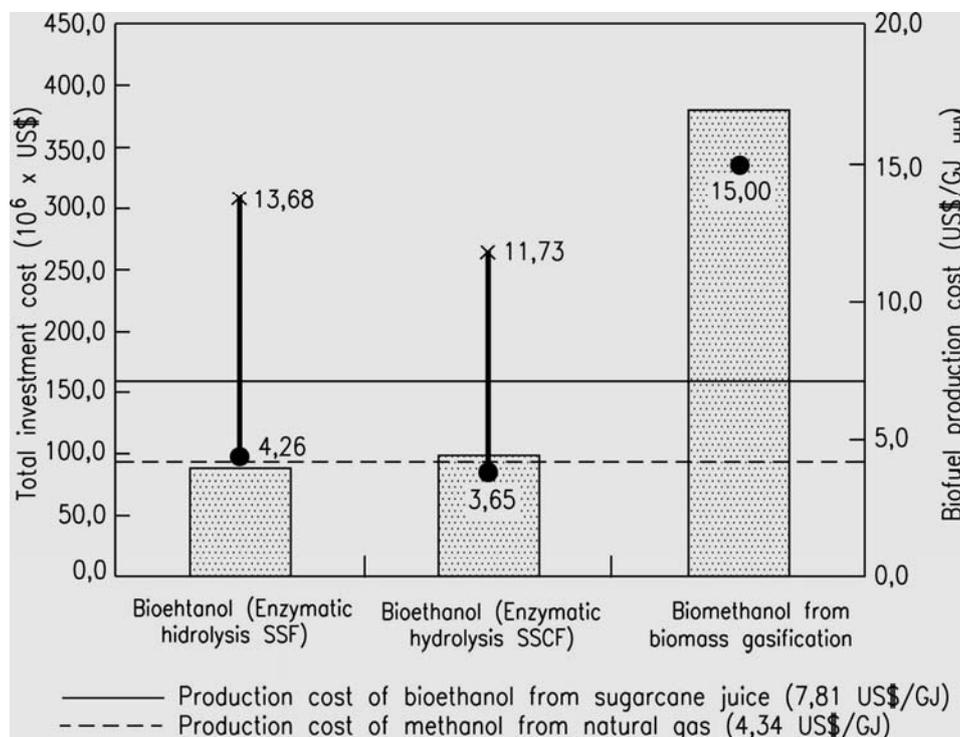


Fig. 10—Platforms comparison when the most optimistic scenario for the biochemical platform is considered (Enzymes cost  $\approx 0.05$  USD\$/L<sub>ETOH</sub>).

It is also observed that, for the more optimistic scenario of the biochemical platform, the ethanol production cost becomes competitive when compared with the production costs of the sugarcane juice ethanol.

Considering the process energy efficiency (GJ product / GJ required), the biomethanol production starting from biomass presents a greater value, of 45.3%, than ethanol production through enzymatic hydrolysis types, both SSCF and SSF, that have an efficiency of 34.08 and 25.78%, respectively. It should be pointed out that energy efficiencies were calculated taking into account only the energy content of biofuel.

The estimated efficiencies in this study don't differ too much from efficiencies found in the literature. According to Hamelinck *et al.* (2005), for the process of ethanol production starting from enzymatic hydrolysis, the efficiency varies in the range from 30 to 40%. For the biomethanol process starting from biomass gasification, they are around 50% (Hamelinck and Faaij, 2001; Cardenas, 2006).

### Discussion and conclusions

Production costs of 22.7 and 21.32 US\$/GJ<sub>ETOH</sub> were obtained from the economic analysis of the processes of ethanol production through SSF and SSCF enzymatic hydrolysis, respectively. These costs are not competitive when compared with the costs of the conventional processes for ethanol production starting from sugarcane juice and corn.

The high current production costs that characterise the biochemical route are strongly influenced by the costs of the enzymes (0.32US\$/L<sub>ETOH</sub>), that represent from 66 to 70% of the annual total costs. The implementation of the enzymes production '*in situ*' could reduce costs, and lead to the economical feasibility of the process.

A reduction of the enzyme costs down to 0.05 US\$/L<sub>ETOH</sub> would make the lignocellulosic ethanol production process competitive when compared with the conventional routes of ethanol production. Besides, it would lead to lower production costs than in the case of the thermochemical platform.

For the thermochemical platform, the estimated methanol production cost is 15.82 US\$/GJ<sub>MeOH</sub>, significantly less than for the biochemical platform. However, the cost of production of the methanol from biomass is higher than from natural gas (6.96 US\$/GJ<sub>MeOH</sub>).

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## INDICATEURS TECHNO-ÉCONOMIQUES POUR LA PRODUCTION DE BIOCARBURANTS A PARTIR DE LA BAGASSE DE CANNE A SUCRE PAR DES PROCEDES THERMO-CHIMIQUE ET BIOCHIMIQUE

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**MOTS-CLÉS: Biocarburants de Deuxième Génération,  
Bagasse de Anne à Sucre, Procédé Biochimique, Procédé Thermochemique.**

### Résumé

L'OBJECTIF PRINCIPAL de cette communication est de comparer les itinéraires biochimique et thermochemique pour la production de biocarburants de deuxième génération à l'aide des indicateurs deficiencies et d'ordre économique. Dans les deux cas, la matière première utilisée est la bagasse de canne à sucre. Les previsions ont été effectuées pour une usine de biocarburants ayant une consommation de bagasse de canne à sucre de 1772 tonnes jour<sup>-1</sup> en matière sèche, équivalent à 400 MW d'énergie thermique. L'utilisation de sous-produits, comme la lignine dans la voie biochimique et de la bagasse de canne à sucre pour attendre l'auto suffisance en vapeur et en électricité par cogénération ont été également prise en considération. Le coût élevé de production de bioéthanol obtenu par le procédé biochimique (US \$ 21.32 à 22,7/GJETOH) est fortement influencé par le coût élevé de l'enzyme. Le coût de production de biométhanol par la procédé thermochemique (15.82 \$ US/GJMeOH) est principalement influencé par le coût élevé des équipements.

## **INDICADORES TÉCNICO-ECONÓMICOS PARA LAS VÍAS TERMOQUÍMICA Y BIOQUÍMICA PARA LA PRODUCCIÓN DE BIOCOMBUSTIBLES, EMPLEANDO BAGAZO DE LA CANA DE AZÚCAR COMO MATERIA PRIMA**

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**PALABRAS CLAVE: Biocombustibles de Segunda Generación, Bagazo de Caña de Azúcar, Vía Bioquímica, Vía Termoquímica.**

### **Resumen**

EL PRINCIPAL OBJETIVO de este trabajo es comparar las vías bioquímica y termoquímica en el comportamiento de la producción de biocombustibles de segunda generación, empleando indicadores económicos y de eficiencia. En ambos casos a partir de bagazo. Los cálculos se realizaron para una planta de biocombustible con un consumo de bagazo de 1772 t/día base seca, equivalente a 400 MW de energía térmica. Se consideró, así mismo, el empleo de subproductos tales como la lignina en la vía bioquímica y el bagazo para la autosuficiencia de vapor y electricidad a través de la cogeneración. El alto costo de producción del etanol obtenido por la vía bioquímica (21.32 a 22.7 US\$/GJ etoh) está influido por el costo de la enzima. El costo de producción del biometanol por la vía termoquímica (15.82 US\$/GJ meoh) está influido por el elevado costo del equipamiento.