INTEGRATED BIOREFINERY: FROM SUGAR CANE TO BIOJET FUELS

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ABSTRACT – *In a context of world awareness regarding the social and environmental impacts of fossil fuels it is essential to find a sustainable biojet fuel (BioATK). Our goal is to study the technical and economical feasibility of an integrated first (1G) and second generation (2G, ABE fermentation) biorefinery to produce a drop in BioATK from sugarcane and bagasse. Other products generated are: ethanol, sugar, butanol, acetone, aromatics (from lignin) and energy. The conversion of butanol to BioATK was simulated using ASPEN software. A financial study was conducted to calculate the initial investments (FCI) and economical parameters, such as Net Present Value (NPV). An in-depht analysis of several scenarios and a sensitivity analysis were conducted. The sugar cane flow rate considered was 500 tons/h and the project lifetime is 25 years. The FCI was estimated in R$ 600 million and the NPV is approximately R$ 650 million. The process is potentially profitable and technically feasible.*

1. BUSINESS OPPORTUNITY

Currently, oil is the main raw material in the production of fuels and products such as gasoline, kerosene, fuel oil, diesel, etc. Oil production follows, over time, an approximately normal curve, so after a maximum production phase, the supply crisis is imminent, and little can be done to mitigate its harmful effects for the world economy, in addition to environmental impacts notoriously recognized. (Rosa; Gomes, 2004)

The bioproducts market is constantly expanding and emerges as a solution to the crisis of supply of raw materials of fossil origin and its price fluctuation. In Brazil, the most widely used biofuel is ethanol, produced in sugar cane biorefinery, and biodiesel produced from vegetable oils or animal fats. One of the main farming that gives rise to the Brazilian biodiesel is soy, which carries the duality discussion of energy vs. food.

Another important factor is the aviation bio-kerosene production (bioATK) by conversion routes that fail to provide a product with competitive market value. The better use of renewable resources in the sugar cane industry generates benefits not only environmental, but also economic.

The trend in the aviation industry is gradually replace conventional kerosene (jet fuel) used today, by the one obtained in a sustainable way, bioATK. There is a worldwide goal of CO_2 emission reduction of 50% of the amount from 2005 until 2050.

Brazil is the protagonist in the production of biofuels in the world and holder of knowledge and technology. However, the 1G biorefinery in the country has reached its maturity and has no long-term growth forecast. Thus, the development of 2G plant capable of producing more biofuels and other products is innovative, and has high growth potential. In addition, other 2G advantages are: do not increase the planted area, deforestation and criticism of the competition for food and biofuel.

In this work we evaluate the implementation of an integrated first (1G) and second generation (2G) biorefinery that makes use of raw materials of renewable origin (sugar cane), and consequently, our fuels, reduce the emission of CO_2 and other greenhouse gases (GHGs). An integrated 2G plant, in addition to synthesize the products of a 1G plant, ethanol and sugar, uses the bagasse and sugar cane straw to produce other products, which would be **A**cetone, **B**utanol, **E**thanol (ABE fermentation) and aromatics. On the other hand, butanol would be the starting material for the production of aviation bio-kerosene (bioATK). The highlighted product of this project is the *drop in* bioATK, whose market demand and growth potential makes it a great deal.

2. MARKET ANALYSIS

The production of ethanol and sugar has technical and economic feasibility. In 2013, sugar production was 37.3 million tons, 3.1% below from the previous year, while ethanol production grew 17.6% and consumption grew 19.9%, according to the Ministry of Mines and Energy of Brazil. The marketing focus is to bioATK being an innovative and high value-added product, which is still being introduced to the market.

Brazil is the third largest market for domestic flights in the world and produces 75% of aviation fuel consumed. Still, its price corresponds to around 40% of costs for airlines in Brazil, and the world average is 30% (ABEAR). In terms of values, Brazilian companies have an annual expenditure of $400 million, according to statements by Carlos Ebner, IATA Director for Brazil. Furthermore, kerosene produced in the country, for this sector, is the world's second most expensive.

The projection of aviation fuel demand in 2024 is 1828 million liters more compared to 2015, according to the Ministry of Mines and Energy of Brazil. The annual growth of aviation fuel (2014-2024) is 3.4% per year. The factor that most affects the price of aviation fuel in the country, contrary to what is expected, it is not its constant high value, but the instability of the price in the market, as seen in Figure 1.

The technology that involves the production process of bioATK tends to reduce its price according to the ripening time and process optimization, generating product less susceptible to fluctuations, which is the main goal of the project.

Figure 1 – Fluctuation in the price of fuel.

3. PROCESS DESIGN

In our assumptions, ethanol, sugar and energy were produced in 1G, and butanol, acetone and ethanol in 2G. The difference is the chemical transformation of lignin (from the bagasse from sugar cane) in aromatics and production bioATK from butanol. Lignin, in addition to producing aromatics to meet the technical specifications of jet fuel, generates phenolic compounds which may be targeted to the market with a high added value compared to the lignin.

The great challenge of producing the bioATK is to meet all legal requirements for a competitive price in the market. However, for technology development and refinement of the process is required industrial scale production. To make this possible, a flexible portfolio would lead to the ability of adapting to market developments. The simplified flowchart of the process is presented in Figure 3.

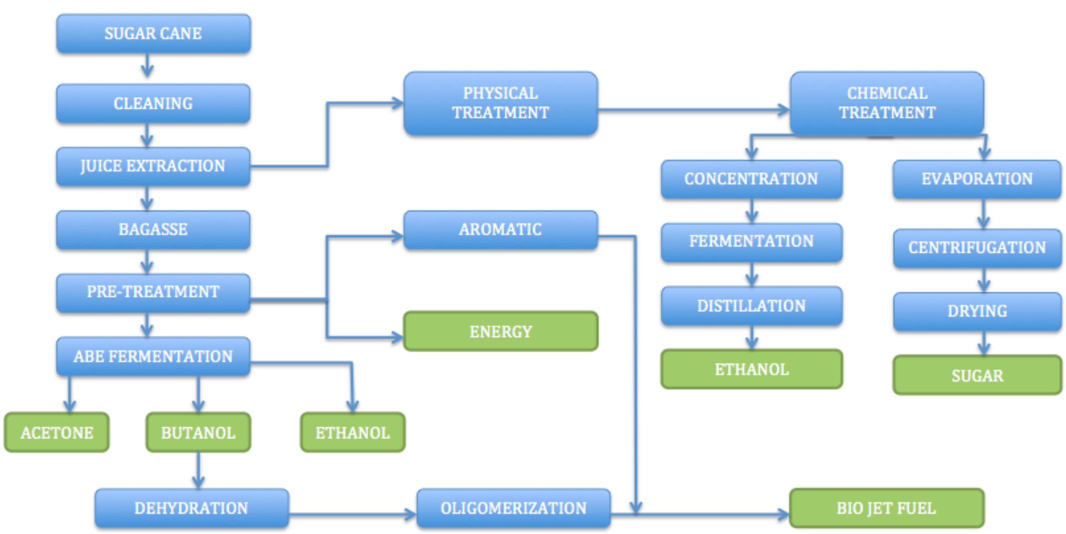


Figure 3 – Flowchart of process.

The processes and units in the first generation for the production of ethanol and sugar are well established. It starts with the sugar cane cleaning and preparation and a fraction of the sugarcane juice is diverted for sugar production and the remaining fraction along with the molasses (impure solution of sugars that remains after sucrose crystallization) is used for ethanol production.

The main idea of 2G process is to take full advantage of sugar cane, i.e., using bagasse and straw in the production of chemicals. Therefore, it is necessary for the lignocellulosic material to pass by prior treatment. For the ABE fermentation we were inspired by studies of Mansur et al. (2010), who performed the reaction by a novel strain of *Clostridium*.

Lignin generated in the treatment of bagasse is usually used for cogeneration. To convert lignin into aromatics, we have considered the same methodology used by Oliveira (2015). The proposal of this work is to pretreat with dilute acid, the lignocellulosic material, and to perform alkaline delignification in order to separate the lignin. After that, the lignin were subjected to oxidation using enzymatic, acidic and alkaline medium in order to obtain, in the liquid fraction, aromatics and also others lignin components and, in the solid fraction, the residual lignin.

The production of bioATK was based on oligomerization of alcohols in order build carbon chains (Figure 3).

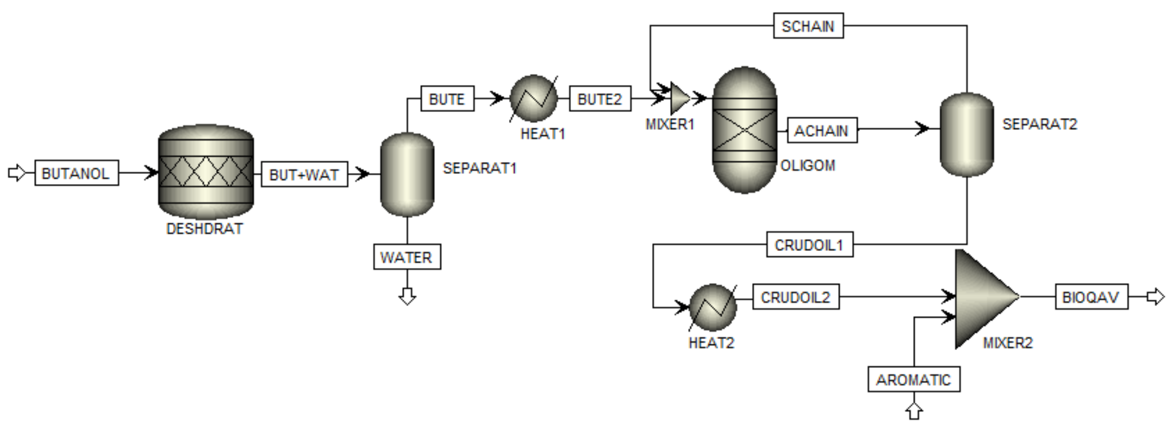


Figure 3 – ASPEN simulation from butanol to bioATK.

Butanol from the fermentation stage passes first through a process of dehydration (DESHDRAT) which is converted to butene in the presence of an acid catalyst with yield from 96 to 98% (US 2012/0271089 A1 and US 2008/0045754 A1). The water is separated from the butene in a fractionation stage in a distillation column. The alkene (top stream) is subjected to cooling and passes to the reactor for further oligomerization reaction.

In the oligomerization reactor (OLIGOM), butene is fed with the appropriate catalyst. At completion of the reaction roughly 90% of the butene oligomer mixture consists of C8 dimer and C12, C16, C20, and C24 oligomers (ACHAIN), and there are essentially no oligomers larger than C32 (US 2012/0209045 A1). The C8 dimers (SCHAIN) are removed and the heavier hydrocarbons are hydrogenated to a crude biofuel (CRUDOIL1 and CRUDOIL2) (bioATK) which is properly mixed to aromatics produced from conversion of lignin.

The process presented by Pereira et al. (2015a) is quite similar to the process we simulated except all the lignocelluloses residue is sent to cogeneration and in terms of environmental impacts per US$ of revenue, the second generation scenarios are the best positioned. Other study performed by Pereira et al. (2015b) showed that ABE fermentation with mutant strain (ABEM) was considered the best way to produce n-butanol in comparison with catalytic pathways from ethanol regarding environmental aspects.

The GHG emission of ATJ pathway is currently not available and it shows that it is time for innovation. A potential penalty expected for upgrading alcohols to jet fuels is roughly estimated based on the environmental impact of the refinery processes, including dehydration, oligomerization and hydrotreating by Wang and Tao (2016). All these results corroborate our choice regarding the production process in order to obtain green products in a sustainable way with low environmental impacts.

4. ECONOMICAL ANALISYS

General information about the project is show in Figure 4.

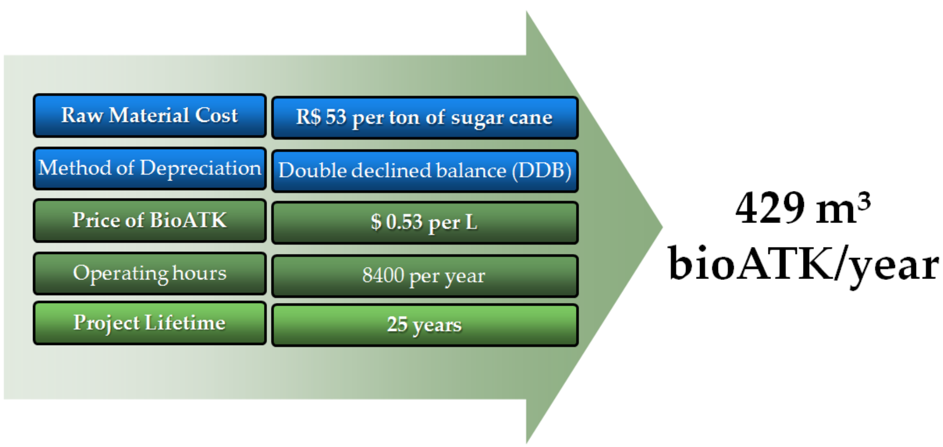
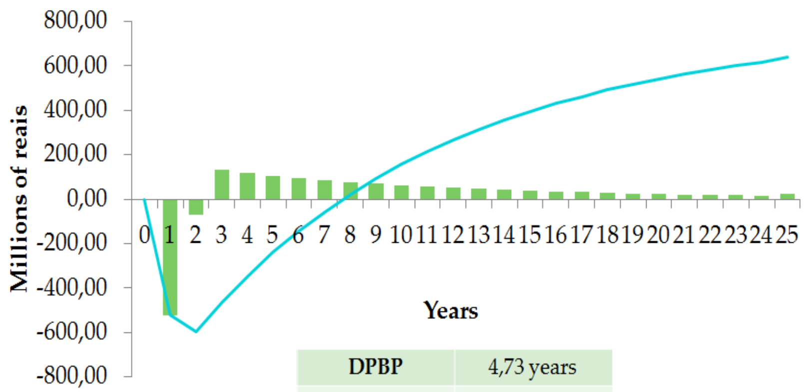


Figure 4 – General assumptions for the project.

In the discounted cumulative cash flow diagram, Figure 5, the construction phase takes two years to complete (time from project initiation to the start-up of the plant). Over the two years of the construction phase, there is a major capital outlay, this represents the fixed capital expenditures for purchasing and installing the equipment and auxiliary facilities required to run the plant. After that, a rising cumulative cash flow is observed over the operating years of the process, i.e., years 2 through 25. At the end of 25 years of operation, it is assumed that the plant is closed down and all the equipment and land is sold and the working capital is recovered.



DPBP	4,73 years
PB	3,32 years
IRR	21%
NPV	R$ 642 millions
CCR	5,89
PVR	2,08

Figure 5 – Discounted payback period.

The sensibility analysis provides the variability of NPV as dependent of the effect on the profitability of the change in the ethanol, sugar cane, bioATK and sugar prices. The effect of 140% change is considered (70% on either side of the base case) in each parameter on the NPV, Figure 6.

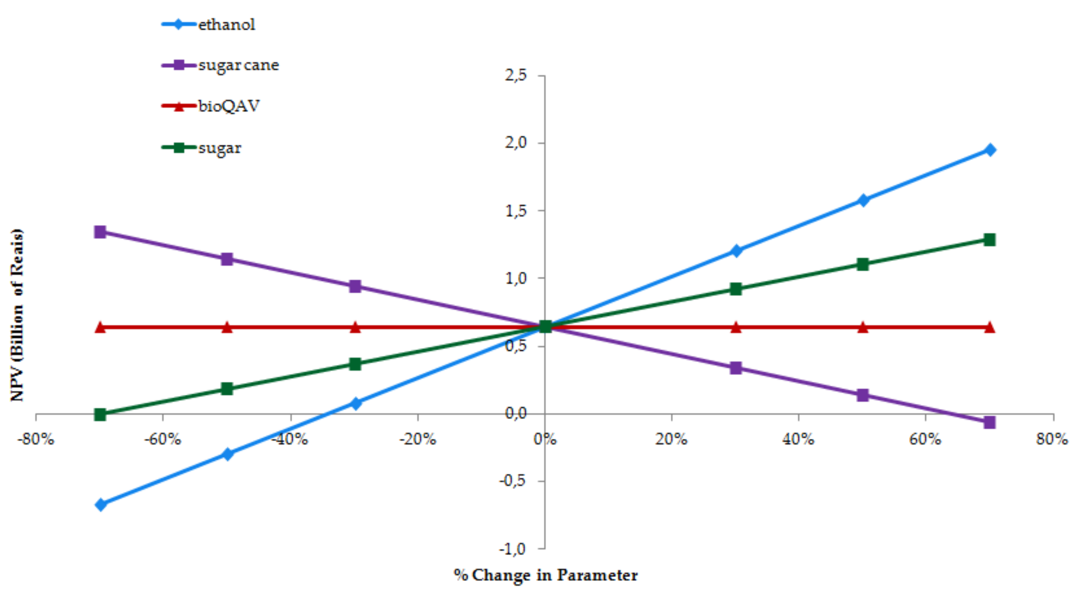
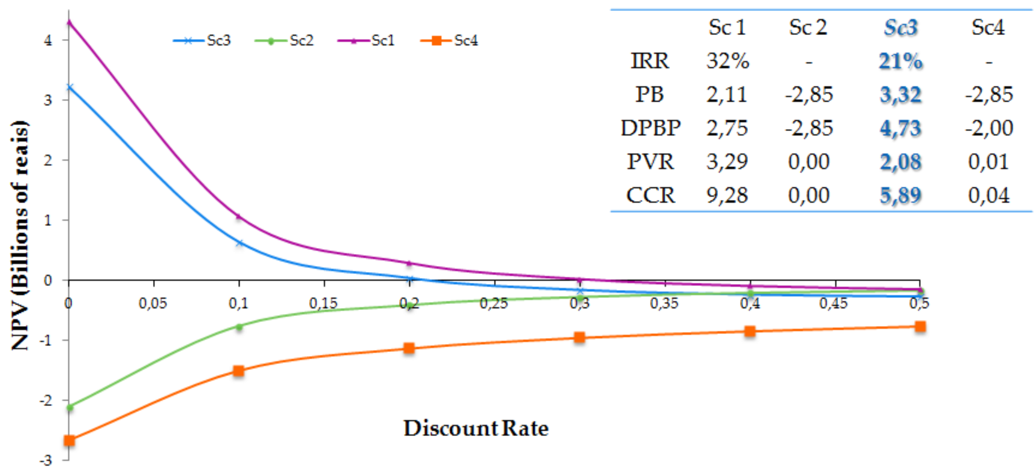


Figure 6 – Sensitivity analysis.

The variation on the price of bioATK does not affect the NPV, since it is produced in a very low rate. The product that provides the highest NPV is ethanol in a price 70% larger than it is today. Ethanol price from 2011 to 2015 increased 66%. Four scenarios were studied as seen in Figure 7.



	Sc 1	Sc 2	Sc3	Sc4
IRR	32%	-	**21%**	-
PB	2,11	-2,85	**3,32**	-2,85
DPBP	2,75	-2,85	**4,73**	-2,00
PVR	3,29	0,00	**2,08**	0,01
CCR	9,28	0,00	**5,89**	0,04

- Sc1 **(1G):** sugar and ethanol
- Sc2 **(2G):** ethanol, acetone and butanol converted to BioATK (ABE fermentation)
- Sc3 **(Integrated biorefinery):** sugar and ethanol (1G); and ethanol, acetone and butanol (2G, ABE fermentation) converted to bioATK
- SC4 **(1G):** sugar and ethanol converted to bioATK

Figura 7 – NPV versus Discount rate plot to scenarios 1 to 4.

Although the IRR and PVR are not as great as the Scenario 1, it is possible to produce bioATK, in a low rate, and still generate profit (Scenario 3). In the beginning of the 20th century, Brazil had their first experience with ethanol as a fuel (1925). During the PROALCOOL national program (1975), the process evolved and, in the beginning of 21th century, the ethanol market became competitive and strong, with 70% of reduction of the costs of production. We believe that the same development is possible to bioATK once the production is attempted in large scale and knowledge from experience is achieved.

5. NOMENCLATURA

CCR – Cumulative Cash Ratio

DPBP – Discounted Payback Period

IRR – Internal Rate of Return

NPV – Net Present Value

PB – Payback period

6. REFERÊNCIAS

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