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Potential and costs for the production of electrolytic hydrogen in alcohol and sugar cane plants in the central and south regions of Brazil

Maria Cristina Rodrigues Halmeman[a,*], *Samuel Nelson Melegari de Souza*[b], *Paulo Takashi Oyama*[b]

[a]*Department of Rural Engineering, UNESP, Botucatu, Brazil*
[b]*Agricultural Engineering Department, UNIOESTE, Cascavel, Brazil*

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ABSTRACT

This project verified the potential for the production of hydrogen via water electrolysis by using the exceeding electrical energy resultant from alcohol and sugar plants that use sugar cane bagasse as fuel. The studies were carried out in cogeneration plants authorized by the Electrical Energy National Agency (ANEEL). The processing history of sugar cane considered was based on the 2006/2007 harvests. The total bagasse produced, electrical energy generated and exceeding electrical energy in a year were calculated. It was obtained an average energy consumption value of 5.2 kWh Nm^{-3} and the hydrogen production costs regarding the amount of sugar cane processed that ranged from US$ 0.50 to US$ 0.75 Nm^{-3}. The results pointed that the costs for the production of hydrogen via the bagasse exceeding energy are close to the production costs that use other sources of energy. As the energy generated from the bagasse is a renewable one, this alternative for the production of hydrogen is economical and environmentally viable.

1. Introduction

The search for economic and environmentally viable energy sources has stimulated the growth of energetic plantations throughout the world and has put the biofuels (alcohol and biodiesel) in a privileged position.

The Brazilian government launched in 2006 the Agroenergy National Plan, the purpose is to stimulate the production of sugar cane, since the country is a great producer of biomass and the use of sugar cane bagasse on the plants provides the necessary energy for the industrial process and generates an amount of exceeding electric energy which can be used for other purposes. The hydrogen can be used in fuel cells for the production of energy, as well as stored in cylinders, commercialized or made available as an energetic vector [1].

One possible solution is to use an electrolyzer to convert this exceeding electric energy in hydrogen through water electrolysis, a process by which the water molecules are dissociated in order to obtain hydrogen and oxygen gases. There are several ways of obtaining hydrogen, but when considering its extraction from renewable sources, some stand out, the biomasses, solar energy, eolian, hydraulic and geothermal among others, allowing clean and abundant energy Garman [2].

* *Corresponding author*. Tel.: +55 14 81133233; fax: +55 14 38117194.
E-mail address: cristhalmeman@gmail.com (M.C. Rodrigues Halmeman).
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Nomenclature

C_e	electricity cost, US$ kWh^{-1}
C_g	investment total cost, US$ year^{-1}
E_g	total energy generated per year kWh year^{-1}
$C_{bagaço}$	bagasse cost, US$ kWh^{-1}
B_g	bagasse generated, kg h^{-1}
Qe	quantity of energy generated per kilogram of bagasse, kWh kg^{-1}
t	plant operation time, h year^{-1} = 4848
P_{ot}	power, kW
C_{Pcog}	cogeneration plant specific cost, US$ kW^{-1}
OM	operation and maintenance rate (%) = 4
F	capital recovery factor = 0.1339
d	discount annual rate (%) = 12
n	number of years for capital amortization invested on the plant, years = 20
C_p	production capacity in Nm^3
η_{el}	electrolyzer efficiency, (%) = 74
η_r	electrical equipment efficiency, (%) = 97

2. Biomass from sugar cane and cogeneration

One fifth of all energy in the world is generated from renewable resources, approximately 13–14% from biomass. The adequate use of biomass brings environmental and social benefits such as: better use of land, jobs creation, use of available agricultural areas, supply modern energy alternatives to rural communities and reduction of the CO_2 emission levels [2]. The energy resources from biomass may be classified in three main groups: the biofuels from wood; agrofuels (energetic plantations) and urban residues [3].

The sugar cane and alcohol agroindustry sector in Brazil stands out among the possibilities of distributed generation (DG), since the amount of biomass derived from this sector is larger than the needs of the alcohol and sugar production plants [4,5]. The energy matrix has 271 biomass enterprises in operation, from which 228 refer to enterprises that use sugar cane bagasse as fuel and a total of 18 cogeneration plants that use sugar cane bagasse as fuel, regulated by ANEEL [6].

The Brazilian production of sugar cane for the 2006/2007 crop reached a total of 425 million tons, that is, a quarter of the world production. The plants produce approximately 70% of sugar cane in their own land, rented or agricultural partnerships. The 30% left are supplied by nearly 45 thousand independent producers [7].

The production of sugar cane in large scale presents a great unexplored potential regarding the residuals [8]. Studies point that using only the bagasse, it is possible to generate about 3 GW of electric energy in the country. According to the National Energy Balance BEN [9], the thermal consumption of the sugar cane bagasse grew 4.6%, reaching 106.5 million tons. On most agroindustries the use of energetic residues contributes for the reduction of the dependency on purchased energy, by generating steam or electricity. The sugar cane bagasse is an example of energy resource used in sugar, alcohol, meat packing, paper and cellulose industries among others [4].

As an example, the cogeneration has become an attractive alternative, since it combines an efficient use of energy with technological, environmental and economic advantages [10]. The high productivity achieved by the sugar cane culture, along with the successive earnings resultant from the transformation processes of the biomass from alcohol and sugar industries has made available a huge amount of organic matter in the form of bagasse in sugar cane plants and distilleries, which, interconnected to the main electrical systems, attend large consumption centers from regions south and southeast of Brazil.

The creation of a governmental program called Program of Incentive for Alternative Sources of Energy (PROINFA) and the Law 10.848, regulated the DG in Brazil, boosted the generation of energy, awarding the undertakings based on biomass, qualified cogeneration, solar energy and wind power sources, with power under or equal to 30 MW ANEEL [11]. The plants that explore the commercialization of exceeding energy more intensively, plan the future expansion of the sugar cane and alcohol activity, increasing the offer of energy. As there is no feasible way of storing large quantities of electrical energy, it must be used immediately or transferred to the power lines [12].

3. Hydrogen

The electrolysis is the cleanest way of obtaining hydrogen, mainly if the electricity is obtained from a renewable source, as the energy derived from the biomass. The world production of hydrogen uses 15% of biomass resources and 85% of fossil fuels [28].

The production of hydrogen through water electrolysis is a technology known for over a century, it provides advantages such as the use of electrical energy available, reduction of CO_2 emissions and interaction with renewable sources [13], with widely spread technologies [29].

Brazil has a significant production of hydrogen for industrial consumption. In 2002, it has produced 425 thousand tons in order to supply oil companies, food, fertilizers and steel industries. In 2004, Petrobrás produced 180 thousand tons of hydrogen in its refineries, amount sufficient to generate over 2.4 TWh of electrical energy. The country is the biggest busses producer in the world, with approximately 19 thousand units per year. Only in metropolitan area of São Paulo there are nearly nine thousand busses that run on diesel. These vehicles contribute significantly to elevate the atmospheric pollution. In case those engines were replaced by hydrogen ones, there would be considerable environmental benefits [14].

The study of the exceeding electrical energy potential of the sugar cane bagasse to generate electrolytic hydrogen Souza showed that one plant with crushing capability of 4 thousand tons per day could produce 1351 kg day^{-1} of hydrogen, quantity that would be enough to fuel up 45 busses with autonomy of 200–300 km, same autonomy of conventional busses using an average of 2.7 l of diesel fuel in the city of São Paulo [15,32].

The Brazilian Hydrogen Bus Project, developed by the Brazilian Ministry of Mining and Energy since 2000 in