Topic 5 - 5.5 Synthetic fuels from biomass and hydrogen

Decentralised ethanol reforming for on-demand low-carbon hydrogen production

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Introduction

Brazil is the second largest global ethanol producer, only after the United States. In the 2020/21 season, around 30 million cubic meters were produced. The Brazilian system is mostly based on sugarcane biorefineries, responsible for 90% of national ethanol production (Conab, 2022) and for delivering 35 million tons of sugar, of which three quarters were exported – making Brazil responsible for 38% of the commodity's global trade (USDA, 2022). An additional product from the biorefineries is surplus electricity generated in combined heat and power units using sugarcane bagasse as fuel, delivering 23 TWh to the grid (EPE, 2021). Regarding the remaining 10% of national ethanol production, it is originated from corn-based biorefineries, a recent but rapidly expanding industry in the country. Corn production is growing in Brazil's Centre-West region in a double-cropping system, in land previously with a single soybean harvest per year (Moreira et al., 2020).

Ethanol is currently used as fuel for light vehicles in Brazil. A dominant flex-fuel fleet allows the use, in any combination, of both hydrated ethanol (E100) and ethanol-blended gasoline (E27) – as the fuels are commercialised in the country. Considering Brazil has banned diesel in vehicles with under 1,000 kg of capacity since the 1970's (Dallmann & Façanha, 2016), and that natural gas covers only a small share (2%) of road transport energy demand, ethanol and gasoline are basically responsible for fuelling light vehicles in Brazil. In 2020, pure gasoline covered 57% of this dual-fuel mix, while ethanol supplied the additional 43% – around two thirds as E100 (EPE, 2021). Although more competitive and consumed in producing regions and in states with tax differentiation, ethanol as E100 is widely available throughout Brazil. This arises from an established distribution system relying on ethanol pipelines, railways, and road-based transport, through to fuel stations willing to provide a choice to the consumer.

Besides corn ethanol ongoing expansion, other factors indicate there is space for growth in ethanol production in Brazil. Sugarcane could expand into marginal lands and degraded pastures, minimising land use impacts especially if combined with livestock intensification (Bordonal et al., 2018). The increase in soil carbon stocks is a potential co-benefit of this strategy (Alkimin & Clarke, 2018). Moreover, second-generation (2G) ethanol is again gaining momentum as the leading group in Brazil announces several new facilities after their first experience (Raízen, 2022). The additional ethanol output would come from lignocellulosic residues of sugarcane processing and harvesting, bagasse and straw respectively, although it might reduce electricity exports.

In terms of its climate benefits, studies already assess ethanol to deliver around 75% greenhouse gas emissions reductions compared to gasoline (Canabarro et al., 2022). To improve these figures, a wide variety of options for low-carbon investment is available for the sugarcane sector, besides 2G ethanol.

A key technology is anaerobic digestion of vinasse and other processing residues, producing biogas, with the first industrial-scale projects already in place. Upgraded to natural gas-equivalent biomethane, it can be used as fuel within the sugarcane system, replacing diesel in the industry's trucks and machinery. Biomethane can also supply fertiliser factories to reduce emissions embedded in agricultural inputs, with positive impacts on ethanol's carbon intensity. In addition, near-pure CO_2 is co-produced in sugar fermentation for ethanol production, providing a unique opportunity for carbon capture utilisation and/or storage (CCUS). One option is the hydrogenation of CO_2 to produce methanol, a fuel favoured by the shipping industry as a decarbonisation solution. On the other hand, geological storage could deliver negative emissions, making ethanol a desirable carbon dioxide removal (CDR) solution.

However, as a low-carbon fuel for the transport sector, ethanol is facing challenges from other solutions. Particularly for light vehicles, electrification is growing rapidly, consolidating as a global pathway for decarbonisation as electric vehicles scale and their costs decrease.

On the other hand, other subsectors within the transport sector are considered hard-to-abate, as electrification is more challenging. This is the case of heavy vehicles in road transport, aviation, and shipping. In these sectors, one of the options is hydrogen. For these and other potential roles in decarbonisation and due to the variety of production pathways, including renewables-based, hydrogen is considered a key vector in a low-carbon energy system.

Objective and preliminary results

In this context, this study aims to present and assess a proposed model for decentralised hydrogen production from ethanol reforming. In this system, ethanol would be used as a hydrogen carrier, and distributed to fuel stations or other locations with demand for hydrogen, where on-site reforming would take place. It is important to note that in Brazil all fuel stations already offer ethanol (E100). Within the fuel station, a hydrogen storage facility and a hydrogen dispenser would then be used to supply hydrogen to the tanks of trucks or other transport modes, for conversion in electricity (traction energy) by fuel cells.

A pilot project of this model was recently announced to be implemented at University of São Paulo, Brazil, to provide fuel for four hydrogen fuel cell buses running on the campus. Two ethanol reformers are proposed to be constructed, with a capacity of 5 kg/h of hydrogen (Hydrogen Central, 2022) from 38.5 litres of ethanol/h each, intended for future scale-up. The project is a partnership of the University with the companies Shell, Raízen, and Hytron, and Senai's innovation institute.

As a preliminary analysis, the advantages of the model can be outlined.

Most benefits are linked to relying on ethanol as the transported energy vector, or a dense energy carrier to low-carbon hydrogen. First, it makes use of existing liquid fuel distribution, avoiding the large sunk costs of pipelines or liquified hydrogen delivery. It also escapes the deadlocks around building new infrastructure regarding interdependency risks, planning, permitting, and construction delays. Still on distribution infrastructure, hydrogen pipelines remain challenging in terms of leakage, which is a climate and cost-related issue.

Second, ethanol reforming can provide on-demand hydrogen production, based on low-cost ethanol storage. This reduces the requirements for costlier and riskier bulk hydrogen storage. In comparison, a stand-alone green hydrogen (electrolysis-based) system – based on solar or wind energy without grid connection – would have a higher requirement for hydrogen storage to secure supply from intermittent production.

Third, compared to the production of hydrogen directly in sugarcane biorefineries, this model allows for sharing the production costs with partners or third parties. In this case, the sugarcane industry can focus its limited capital investment capacity on other important technologies, such as biogas, CCUS, or 2G ethanol, directly implemented at their facilities.

Finally, the model allows the expansion of ethanol to decarbonise other hard-to-abate transportation subsectors besides light vehicles, mainly heavy vehicles. Besides the potential for emissions reductions, it creates new prospects for a key industry in Brazil, supporting its expansion.

However, a main challenge remains and should be further explored, which is the communication of the Brazilian scenario specificities, in order to improve the understanding of these processes and benefits by stakeholders in the national and international spectrum.

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