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Study of the energy potential of surplus green hydrogen produced in a sodium chlorate manufacturing plant

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Abstract. This paper addresses the inherent energy potential of hydrogen generated as a byproduct in a sodium chlorate production plant, emphasizing the existence of a significant surplus that is released into the atmosphere. Different technological options aimed at efficiently utilizing this surplus hydrogen are presented and discussed, covering areas such as energy storage, sustainable mobility, as well as Power-to-Gas and Power-to-Liquid technologies. With the objective of elucidating the potential economic and social impact of each approach, while taking into account the regional peculiarities inherent to the manufacturing plant. The results obtained indicate that the integration of hydrogen as a clean energy source can optimize operational efficiency and reduce the carbon footprint associated with sodium chlorate production. Consequently, this leads to increased energy autonomy for the facility and contributes to the principles of environmental sustainability. The study emphasizes the potential of hydrogen as a valuable and sustainable resource, promoting benefits for both the industrial sector and the environment. It is important to note that the production process generates a significant amount of waste, with an estimated annual volume of 750 tons. This highlights the need to implement efficient waste management practices and avoid unnecessary waste of this crucial energy carrier. By minimizing waste and maximizing the utilization of hydrogen, we can further enhance the economic and environmental benefits associated with its production and utilization.

Key words. Green Hydrogen, Energy Efficiency, Hydrogen Characteristics, Sodium Chlorate, Power-to-X.

1. Introduction

Hydrogen (H_2) occupies a prominent place in contemporary industry due to its versatility and potential as a clean and renewable energy source. It also plays a fundamental role in the chemical, oil and energy sectors and is used as a raw material in the synthesis of various chemical products, such as ammonia and methanol [1-3].

Despite its many applications, large-scale H_2 production faces significant challenges in terms of cost and greenhouse gas emissions. The main reason for this is that most of its global production is generated through processes that emit carbon dioxide (CO_2) into the atmosphere and can be classified as gray, brown or black, depending on how it is produced, whether from the reforming of natural gas, coal or oil, respectively [4].

A promising alternative that has been pointed out as an allied solution in the fight against climate change is the generation and use of green H_2, as it comes from renewable energy sources, such as solar or wind power, which do not generate emissions in the process of production. This possible approach presents an interesting path towards a low-carbon economy and less dependence on fossil fuels [5]. Furthermore, this approach is in line with the Sustainable Development Goals (SDGs) established by the United Nations (UN) for the year 2030, including SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), which aim to ensure access to affordable, reliable, sustainable, and modern energy for all, as well as take urgent action to combat climate change and its impacts. Incorporating green H_2 into energy systems can contribute to the achievement of these goals and foster sustainable development on a global scale [6].

In this context, this study was conducted to investigate the energy potential in the utilization of hydrogen generated as a by-product in a sodium chlorate production plant of the company Kemira Uruguay S.A., located in the city of Fray Bentos (Uruguay). Since part of the process that occurs in the aforementioned plant involves obtaining sodium chlorate through the electrolysis of sodium chloride, generating H_2 as a by-product, so that it goes mainly to the production of hydrogen peroxide and heat, while the surplus is released into the atmosphere.

It is also important to note that the energy used in this process is generated essentially from biomass, more precisely from the degraded lignin from the cellulose manufacturing cycle extracted from trees specifically grown for this purpose. This guarantees the sustainability cycle of the entire process, making it possible to classify the hydrogen as green.

In order to improve the operational efficiency of the company, especially in consideration of the high energy consumption associated with the electrolysis process, whose equipment has an installed power of 40 MW, the main objective was to identify and analyse possible applications from an environmental and economic perspective, as well as strategies for storage and effective conversion methods for the surplus H_2 generated.

2. Hydrogen Characteristics and Potential Applications

A. Vented Hydrogen Characterization

The sodium chlorate production process is a continuous and complex process involving several interconnected stages. In the course of the process, hydrogen is generated as a by-product, accompanied by minor amounts of chlorine and oxygen. In order to ensure the purity of the resulting H_2, four scrubbers are used, resulting in a final product with less than 3% oxygen and approximately 0.1 parts per million (ppm) of chlorine.
This point marks a bifurcation in the process, since a fraction of the hydrogen is directed towards a blower in order to be transported to a lime kiln for combustion by the pulp mill. The other fraction of the H_2 goes through an additional purification stage in which it undergoes filtration by activated carbon to remove any residual chlorine and then through a catalytic reaction using to form water with oxygen molecules.
Subsequently, the treated hydrogen is also channeled to two compressors before being used in the hydrogen peroxide plant. However, the surplus H_2 produced in this process, once the washing stage is completed, is released into the atmosphere. This means that a significant amount of hydrogen, which could represent a valuable resource, is dissipated in the form of emissions instead of being used efficiently.

B. Hydrogen Balance

The aforementioned company provided information regarding average monthly hydrogen production, together with the corresponding consumptions, all expressed in units of normal cubic meters of H_2 (see Table I). This data was sourced from records up to the year 2022.

Table I. Generation and Hydrogen Consumption. Source: Kemira Uruguay S.A.

	Average Generation (Nm^3)	H_2O_2 Plant (Nm^3)	Lime Kiln (Nm^3)	Venting (Nm^3)
January	3154745	1187173	377159	1590413
February	3149489	1213265	754319	1181906
March	2958255	1162168	667282	1128804
April	2294973	819373	551233	924367
May	2198364	823927	464196	910241
June	3219058	1252980	522221	1443857
July	3185589	1286006	116049	1783534
August	3328601	1289576	406172	1626653
September	3364640	1294556	377159	1718076
October	3394838	1259352	174074	1933744
November	2877501	1105500	638270	1130819
December	3179402	1222392	458921	1540693

To better understand this information and convert it into relevant quantitative terms, the ideal gas equation (1) was used. In this context, it is important to note that standard conditions were used, including a pressure of 1 atmosphere and a temperature of 273 K.

$$n = \frac{P*V}{R*T} \qquad (1)$$

Where:
n: Amount of substance in moles (in this case, moles of hydrogen).
P: Pressure in atmospheres.
V: Volume in liters.
R: Ideal gas constant (0.082 atm·L/mol·K).
T: Temperature in Kelvin.

Using this equation, the calculation of the annual tons of hydrogen generated and consumed from the provided data was carried out. This process allowed for a quantitative representation of the annual production, as detailed in Figure 1, highlighting that a total of 756 tons are released into the atmosphere per year.

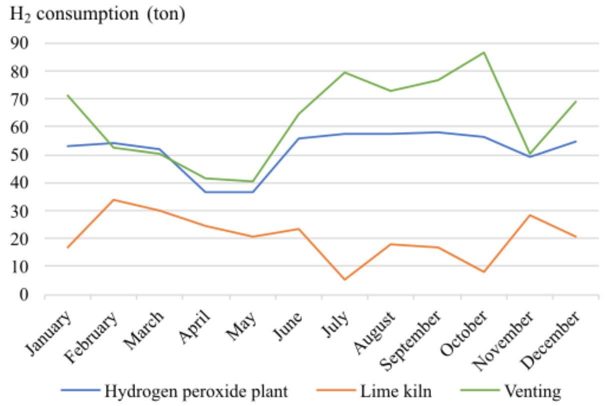

Fig. 1. Hydrogen Consumption in the Plant.

C. Applications

The options considered for the utilization of surplus hydrogen generated in the operations of the industrial plant under study are presented and discussed below. Each application is examined individually, highlighting its merits and challenges in terms of technical, economic and environmental feasibility specific to the case study.

1) *Power-to-Power Energy Storage:* Converting surplus hydrogen into "Power-to-Power" (PtP) represents an effective strategy to enhance stability in industrial operations and reduce energy fluctuations. This approach allows using H_2 during peak energy demand, decreasing reliance on non-renewable sources. When there is high demand, the hydrogen is converted back into electricity, avoiding the need to rely on less sustainable sources. This not only improves resilience in industrial operations but also contributes to decarbonization by reducing greenhouse gas emissions. Additionally, PtP can help stabilize electrical grids by releasing stored electricity when needed, especially valuable in areas with intermittent renewable energy generation [3],[7].
However, it was not identified as viable for implementation in the analyzed plant. The

difficulty lies in Kemira's dependence on the cellulose production company for energy supply. Incorporating surplus hydrogen conversion as an energy supply method poses a significant challenge, especially during energy fluctuations caused by cellulose manufacturing processes. The complexity associated with this situation hinders the feasibility of using this approach to meet the company energy needs. However, a potentially viable alternative could be the installation of a boiler exclusively for the company. This approach would allow it to achieve independence in steam generation for certain internal processes. Furthermore, it could optimize the capacity to generate more electrical energy, as the cellulose plant could redirect those resources to electricity production instead of supplying them. This proposal offers a strategic perspective deserving further analysis and consideration in the context of energy resource management between both entities.

Other possibilities with a similar use would be to supply other companies located in the region, within a radius of up to 100km, such as the cement industry, which already has its own boiler and uses a process similar to the one proposed.

2) *Sustainable Mobility:* The use of hydrogen fuel cells represents a considerable step forward in the search for sustainable solutions in the mobility sector. These cells convert the chemical energy of H_2 into electricity and result in clean production with high efficiency [3],[7]. In addition, the versatility of H_2 allows it to be used in conjunction with other fuels, giving some vehicles flexibility that doesn't require alterations for their use. Combining it with conventional fuels, such as diesel, in internal combustion engines paves the way for gradual transitions towards cleaner mobility. However, a significant challenge arises as there are currently no hydrogen refueling stations in the country, hence no vehicles running on this fuel [8].

3) *Substitution of Fossil Fuels to Reduce CO_2 Emissions:* To in order to carry out a comparison of emissions according to energy source and be possible a feasibility study, it is essential to obtain the CO_2 emission rates associated with each type of fuel, excluding in this case the emissions related to the production and distribution of the fuel [7]. For this instance, values of consumption rates and average range found in the literature were used for two fuel cell electric vehicles (FCEV) and two conventional vehicles (CV). A representative passenger vehicle, as well as a heavy-duty vehicle, from each category were selected for comparison [9], [10]. In an initial calculation to determine the autonomy of the FCEV vehicles and the equivalence in liters of fuel equivalent in autonomy and CO_2 emissions, using the 750 tons of hydrogen available annually, which is reflected in Table II.

Full utilization of vented H_2 in light transport could lead to a considerable reduction of 18810 tons of CO_2 released into the environment.

In the context of heavy transport, the viability of this transition is more promising. It is estimated that implementing hydrogen in cargo transportation could result in a reduction of around 9000 tons of CO_2 emissions no longer being released into the environment.

To contextualize these figures, it is relevant to consider the distance between Kemira's mill and the pulp mills it supplies with its products in Uruguay, which is approximately 200 kilometers. Using the yield data provided in Table II, it can be calculated that a total of 84 trucks could make two trips per day on this route.

These calculations provide an initial perspective on the potential environmental impact and opportunities that could arise from the adoption of hydrogen-based technologies in the transport sector, highlighting the importance of exploring sustainable solutions to reduce CO_2 emissions in the industry.

Table II. Range in kilometers for the annually available H_2 and CO_2 emissions in vehicles

Vehicle	FCEV Passenger vehicle	FCEV Heavy-duty vehicle	CV Passenger vehicle	CV Heavy-duty vehicle
Consumption (Kg/100Km)	0,8	7,8	-	-
Range with 750 tons of H_2 (Km)	9375×10^4	$967{,}7\times10^4$	-	-
Consumption (L/100 km)	-	-	8,8	36
CO_2 emissions per liter (Kg)	0	0	2,3	2,6
Total CO_2 emissions (tons)	0	0	$18{,}81\times10^3$	$9{,}05\times10^3$

4) *Distribution and Use of Power-to-Gas:* Implementing "Power-to-Gas" (PtG) technology is a viable option for hydrogen distribution and storage in locations with a natural gas network infrastructure. Injecting this new fuel into the grid, whether mixed with natural gas or converted into synthetic methane, offers an effective solution for energy storage and subsequent distribution [7],[11]. This option contributes to greater flexibility in energy management and reduces dependence on fossil fuels. While this technology can be highly effective in many countries, it became evident that its application in our region poses significant challenges. The lack of a pipeline infrastructure in the area greatly affects the feasibility of this solution, highlighting the importance of adapting

strategies to the specific conditions of the local environment.

5) *Power-to-Liquid Synthetic Fuel:* Utilizing surplus hydrogen in synthetic fuel production, or "Power-to-Liquid" (PtL), holds great potential in sectors such as heavy-duty transportation, aviation, and maritime navigation [3]. In the case of heavy-duty transportation, the surrounding industrial infrastructure experiences a constant flow of trucks, making the incorporation of hydrogen as fuel an attractive alternative. Additionally, the proximity of a port nearby suggests a promising market for applications in maritime navigation. Capturing and utilizing CO_2 generated by the cellulose plant for methanol production is a promising prospect. The combination of CO_2 and H_2 to generate synthetic fuel, also known as e-fuels, is a process that can significantly contribute to reducing carbon emissions in the heavy transport sector. These e-fuels can be used directly in existing combustion engines [12]. This alternative entails a considerable economic investment and necessitates involvement from third parties, such as the cellulose production company for the CO_2 source, as well as maritime, aviation, or heavy transport companies interested in utilizing this fuel.

3. Discussion of proposed applications

In view of the limitations identified in the previously considered options, it becomes essential to explore alternatives that are both strategic and feasible to maximize the utilization of surplus hydrogen generated. One such alternative is promoting sustainable mobility through the adoption of fuel cells or PtL technology for heavy-duty transportation.
Firstly, the use of CO_2 emitted by the cellulose plant is an interesting strategy, whether through gas synthesis to produce methanol or through the Fischer-Tropsch process for synthetic fuels from the combination of CO_2 and H_2 [12],[13]. This has the potential to harness the H_2 released by Kemira and reduce carbon emissions in heavy transport. Additionally, fuel cell vehicles that transform H_2 into electricity and emit only water as a by-product are growing in popularity, beginning to receive greater attention from national authorities and consequently generating greater interest in receiving subsidies and incentive laws in general to strengthen its entry and permanence in the market. It is projected that by 2030, there will be approximately 6,500 heavy-duty vehicles running on hydrogen fuel cells in Uruguay [14], so installing a hydrogen refueling station at the plant site is a strategic measure that would facilitate logistics and hydrogen supply to trucks arriving at the facility. This infrastructure would not only meet future local H_2 needs, but would also open up the possibility of exploitation by international users, following the aforementioned projection, and also of export to other countries through the available port on site.

Regarding the utilization of surplus hydrogen as fuel in a boiler, it was calculated that for the month of lowest generation and with a 90% efficient boiler, approximately 3000 kg of steam per hour could be produced at 10 bar, as seen in Table III. This would allow a significant portion of the energy contained in this surplus to be used, improving the overall efficiency of the generating company itself. This would open up the possibility for other companies that use similar technology to use this input to improve their processes, such as companies already established and operating in the region.

Table III. Steam Generation

Medium-Pressure Steam Generation	
Hydrogen Calorific Value (MJ/kg)	120,0
Hydrogen Flow (kg/h) *	57,0
Available Energy (MJ/h)	6840,0
Boiler Efficiency	0,9
Usable Energy(kJ/h)	6156000,0
Latent Heat at 10 bar (kJ/Kg)	2046,0
Steam Mass (Kg/h)	3008,8
* Month of lower generation	

4. Conclusion

The detailed assessment of the possibilities for utilizing surplus hydrogen has revealed the infeasibility of certain options due to specific challenges in the local environment. For instance, the effectiveness of "Power-to-Gas" in other regions contrasts with issues in our area due to the lack of gas pipeline infrastructure. The possibility of decarbonizing other nearby productive sectors, such as the possibility of producing a more sustainable or environmentally friendly cement, alternative approaches have been considered. However, due to the considerable distance from the nearest plant, the option of compressing and transporting hydrogen for use as a fuel in these plants was also considered unfeasible. This is primarily due to logistical and economic challenges in the current context. These findings emphasize the importance of considering local conditions and available infrastructure when evaluating the implementation of hydrogen-related technologies to effectively harness its potential as a clean and sustainable energy resource.
Despite these challenges, strategic and feasible alternatives have been identified, such as promoting sustainable mobility through hydrogen fuel cells and PtL technology for heavy-duty transport. This strategy leverages the capture of CO_2 from the cellulose plant, combining it with hydrogen to produce synthetic fuel and contribute to emissions reduction in heavy-duty transport. The installation of Uruguay's first hydrogen refuelling station (hydrogen station) at the plant site is seen as a strategic measure to facilitate logistics and hydrogen supply for both internal use and export via the available port on-site.
The proposal to use hydrogen in the company's own boiler stands out as a promising strategy to achieve independence in steam generation and optimize efficiency

in energy resource management between it and the cellulose production company. This approach would not only enhance the operational autonomy but also offer the opportunity to redirect resources towards electricity generation, thus contributing to progress towards a more sustainable and energy-efficient model.
Combining local solutions with global sustainability goals can significantly maximize the potential of hydrogen as a key component in the future energy matrix, whether implemented by the company or through commercial partnerships with third parties, such as in the case of the hydrogen station or PtL.

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