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PINK AMMONIA PRODUCED THROUGH NUCLEAR CO-GENERATION

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ABSTRACT

In the reduction of CO_2 context, "pink hydrogen," generated via electrolysis powered by nuclear energy, can play a pivotal role in emissions reduction when employed in the production of ammonia. Nuclear energy boasts low CO_2 emissions, , and it holds distinct advantages over solar and wind energy sources due to its consistent power generation without intermittency. Moreover, the recent advent of Mini and Small Modular Nuclear Reactors that can be directly integrated into the energy industry makes nuclear generation an excellent choice for ammonia production. The aim of this work is to check if it's doable and how much it would cost to set up a mini nuclear plant for making ammonia in the state of São Paulo. What we found shows that it's technically possible, and if we go ahead with it, it could help Brazil make its own ammonia and become self-sufficient in making this chemical.

Keywords: Reactor, Hydrogen, Electrolysis, High-temperature, Haber-Bosch.

Introduction

The search for solutions that minimize CO_2 emissions has been a constant on the agenda of world organizations, traditional sources of wind and solar generation are growing and already represent 22.3% of the Brazilian energy matrix [1]. The current trend shows that energy storage through hydrogen has proven to be an excellent alternative [2]. Hidrogen is produced through the electrolysis of water. , which can be made with different technologies. The most common technologies are Low- Temperature Electrolysis (LTE), High-Temperature Steam Electrolysis (HTSE) [3] and the Polymer Electrolyte Membrane or Proton Exchange Membrane (PEM). Those technologies are specially interesting in the cases where heating is necessary and where the thermal energy can be supplied by the nuclear reactors. Electrolysis of water at a higher temperature (800 and 1000 ºC) demands less electrical power [3], making nuclear energy more advantageous compared to sources that do not produce thermal energy.

Conventional nuclear energy reactors are designed as large enterprises of approximately 1GW of rating power, while small, mini or micro modular reactors with powers of less than 10 MW [4] are promising solutions. With these small-scale reactors, it will be possible to implement a mini cogeneration plant with nuclear energy close to the industry where the hydrogen and electricity is needed. In this case, hydrogen produced from a nuclear source is named “pink hydrogen” [5].

The NH_3 ammonia extract has nitrogen and hydrogen as components, which in most cases is produced through gas and coal, which in its global production result in 420 Mt CO_2 emissions. That is, more than 1% of global emissions [6], which can be reduced, once hydrogen can be produced through HTSE from nuclear generation, and the processes of separation of Nitrogen and final production of Ammoniaalso use electrical energy, which can be supplied through cogeneration with nuclear energy.

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The production of pink ammonia (made through nuclear generation) emerges as an alternative because it generates only 12g gCO_2/KWh [7]. In addition, nuclear energy does not suffer from intermittence like the sources solar and wind power, that may limit their applicability [8].

Finally, as Brazil imports 81.5% of its ammonia consumption [9], this work proposes the implementation of an ammonia production industry in the State of São Paulo, where the entire process will be supplied by a cogeneration with nuclear energy that's doable to make hydrogen using a high-temperature electrolysis process, which requires less electricity and puts the thermal energy from the nuclear process to good use.

Problem description

As already mentioned in the previous item, due to the intermittence of solar and wind sources limiting their applicability and also considering that natural gas cogeneration, which can also be an alternative to low temperature electrolysis but which can only be used in places where there is gas pipelines. The Municipalities of the State of São Paulo with the greatest potential to receive solar and wind generation were mapped [10] and to depart from this work we found the cities that are less viable for the implementation of these sources, as they would be, in theory, the most favorable to receive a cogeneration plant with nuclear energy. Fig. 1 shows which municipalities meet these requirements:

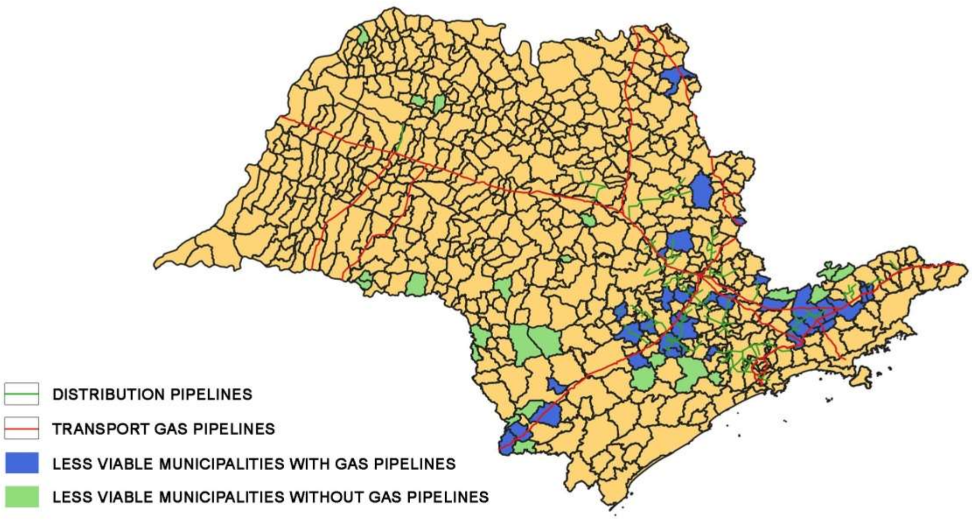

Figure 1. Thematic map showing municipalities with less viability for wind and photovoltaic and pipeline circuit.

Of the selected municipalities, the one with the lowest average solar irradiation and lowest wind speed is the city of Igaraçu do Tietê, which will be chosen for the project's application. Besides having fewer demographic density (236.99 inhabitants/m2) compared to the average in São Paulo cities (which is 330 [20] and it's more than 300 Km from the City of São Paulo, beside this is also near some big highways in the State of São Paulo, making things safer. The town is also pretty close to the Tietê River, which is a major water source for the city. This is so important for making sure the nuclear reactor keeps getting enough water.

Test Case

Figure 2 shows the ammonia production process, the ASU operates in the separation of nitrogen from the Air and the Haber-Bosch transforms the hydrogen provided by electrolysis together with nitrogen into ammonia [6], the hydrogen undergoes a compression process and storage before conversion to ammonia.

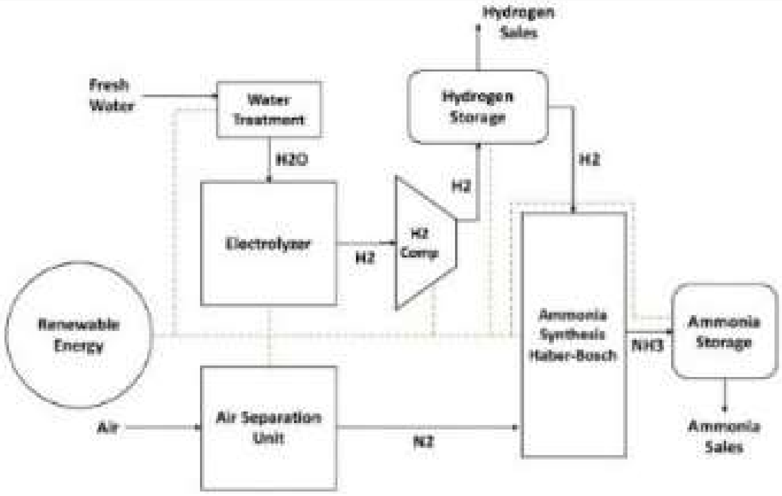

Figure 2. Ammonia manufacturing process [11].

With the hydrogen produced through high-temperature electrolysis, there is no need to use water for electrolysis, since it is done in the water vapor produced in the nuclear power plant. For the understanding of H_2, water cooling is used because hydrogen is generated at a high temperature.

The nuclear power plant can be built using a Micro Modular Reactor (MMR) that operates between 3.5 and 15 MWe [12], and its efficiency in the production of electrical energy is approximately 28% and the rest is dissipated in thermal energy and temperatures above 200 °C [13] required for high-temperature electrolysis [14].

Case study

To study the viability of the process, we conducted a study of an ammonia industry producing 100,000 T/year of ammonia, which in this case has 17,640.00 T of H_2 and 82,360 T of N_2. Table 1 shows the technical data of the micro nuclear power plant, and the electrolysis process and Table 2 shows the costs of the process.

Table 1 - Technical data of the manufacturing process of Pink Ammonia.

Description	Values	References
lifetime HB+ASU (y)	30	[6]
Electric consumption HB-ASU (MWh/tNH_3)	0,64	[6]
Electricity requirement for Storage capacity (kW/kg)	0,000137	[3]
Max ramp pre-compression (+/- % load/ h)	20	[6]
Water consumption for Compressor cooling (L*kg/h)	22,68	[3]
Electrolysis HTSE (MW/kgH_2)	2,63*10^-7	[3]
Electrolysis HTSE - Thermal Energy (MWth/MWe)	1,14	[3]
Lifetime Electrolysis (year)	20	[15]
Thermal energy Production in comparison with Energy Power in Nuclear Power (MWth/MWe)	2,48	[13]
Refuel Nuclear (USD each 20 years)	20.000.000	[17]

Table 2 - Technical data of the Pink Ammonia manufacturing process.

Description	Values	References
CAPEXHB (USD/kW)	580	[6]
CAPEXASU (USD/kW)	224	[6]
OPEXHB+ASU (% CAPEX/y)	2	[6]
CAPEX Storage (USD/kg)	0,74	[3]
OPEX Storage (%CAPEX/Y)	5	[3]

OPEX Water for compressoor cooling (USD/L)	0,0058	[3] [16]
CAPEX Electrolysis (USD/MW)	2.480.686,70	[3]
OPEX Electrolysis (% CAPEX/y)	10	[3]
CAPEX Nuclear with MMR (USD/KW)	17121	[17] [19] [20]
OPEX Nuclear with MMR (USD/Kwe.YEAR)	321,12	[17] [18] [19]

Based on the parameters in tables 1 and table 2, the energy values and investments to produce 100 t NH_3/year were calculated, the data are shown in Table 3

Table 3 presents the results of the case studied and equivalent costs.

Description	Energy Data	CAPEX (USD)	OPEX (USD)
Annual electrical consumption HB-ASU (MWe/year)	64.000,00		
Daily electric consumption HB-ASU (MWe/Day)	175,34		
Capacity HB+ASU (MWe)	7,31	5.873.972,60	117.479,45
H2 storage hourly flow (kg H2/h)	2013,69863		
H2 Capacity Buffer - Nuclear (Kg)	10068,49315	7.447,11	503,42
Buffer Power Eletric. (KWe)	1,376225987		
Buffer Consumption (MWe/ano)	12,05573964		
Water Consumption ($m^{\wedge 3}$/H) - Buffer Cooling	228,39		58.141.134,55
high temperature electrolyser Power eletric. (MWe)	4,654722537	11.546.908,27	1.154.690,83
Annual consumption of the high temperature electrolyser (MWe/ano)	40775,36942		
Annual consumption of the high temperature electrolyser (MWe/dia)	111,7133409		
Nuclear Power eletric required (MWe)	11,96203484	205.452.000,00	321,12
Thermal Power Required (MWth)	13,64		
Refeulling			20.000.000,00
lifetime Nuclear Power Plant (y)	20		
Total		222.880.327,98	79.414.129,37

The high temperature electrolysis process requires a thermal power of 13.64 MWth, as a 12 MWe plant produces approximately 29.76 MWth, so the proposed mini nuclear power plant supply the demand.

Despite the high costs for implementing cogeneration with nuclear energy, it offers many advantages over solar and wind sources, as both pass intermittently due to the need for solar irradiation and the wind speed are inconsistent, and also do not produce heat for electrolysis. high temperature, requiring more electricity for the process.

Conclusion

This study provided indications that nuclear energy cogeneration has significant potential as a source for ammonia production. This is primarily due to its low CO_2 emissions during the production process and its inherent resilience against generation interruptions, a key advantage over solar and wind sources. Additionally, the thermal energy released in the nuclear process can be effectively utilized to facilitate high-temperature electrolysis, reducing the overall reliance on electrical energy for the production process.

The choice of Igaraçu do Tietê as the location for the plant was deliberate, as it happens to be one of the areas in the state of São Paulo with lower potential for solar and wind energy sources as well as gas cogeneration beside the locations make favor to safe. The primary objective of this study was to identify regions where there are deficiencies in energy generation from these sources and to introduce nuclear energy cogeneration as a viable alternative. However, it is crucial to acknowledge that the current cost of nuclear cogeneration remains relatively high, emphasizing the necessity for public policies aimed at incentivizing and making this alternative energy source economically viable.

As mentioned in Table 3 the CAPEX to implant Pink Ammonia is 222.880.327,98 and OPEX is 79.414.129,37 which can be considered so high, but the tender is reducing the Nuclear Costs, beside this this process will solve a lot of CAPEX of electricity bill using High Temperature electrolysis.

Finly, considering that Brazil currently imports 1 million tons of ammonia [9], this research aims to make a meaningful contribution towards enabling Brazil to achieve self-sufficiency in the production of this crucial chemical used in fertilizer manufacturing.

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