TECHNICAL-ECONOMIC EVALUATION FOR IMPLEMENTATION OF A PILOT PLANT FOR THE PRODUCTION OF HYDROGEN FROM PEM-TYPE ELECTROLYZERS IN THE PORT AREA OF PECÉM

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Abstract: This study evaluates the implementation of a pilot plant for green hydrogen production using PEM electrolyzers at the port complex of Pecém, CE. Technical and economic assessments were conducted and supplemented by case studies and research. The Hyjack software determined a nominal capacity of 175 tons and costs for some equipment, with additional research for remaining costs. The total estimated initial investment was US$33,148,313.19, with an annual fixed cost of US$148,934.31 and an annual variable cost of US$992,895.4. However, after economic and sensitivity analyses, it was concluded that the project is not economically viable due to low returns and cash flow, resulting in an inability to recover the investment or generate profit.

Keywords: green; hydrogen; production; electrolysers; Hyjack;.

AVALIAÇÃO TÉCNICO-ECONÔMICA PARA IMPLEMENTAÇÃO DE PLANTA PILOTO DE PRODUÇÃO DE HIDROGÊNIO A PARTIR DE ELETROLISADORES TIPO PEM NA ZONA PORTUÁRIA DE PECÉM

Resumo: Este estudo avalia a implementação de uma planta piloto para produção de hidrogênio verde utilizando eletrolisadores de membrana de troca de prótons (PEM) no complexo portuário de Pecém, CE. Avaliações técnicas e econômicas foram conduzidas seguindo e complementadas por estudos de caso e pesquisas. O software Hyjack determinou a capacidade nominal da planta em 175 toneladas e os custos de alguns equipamentos, sendo necessárias pesquisas adicionais para os custos restantes. O investimento inicial total estimado foi de US$33,148,313.19, com um custo fixo anual de US$148,934.31 e um custo variável anual de US$992,895.4. No entanto, após análises econômicas e de sensibilidade, concluiu-se que o projeto não é viável economicamente, devido ao baixo retorno e fluxo de caixa, resultando na incapacidade de recuperar o investimento ou gerar lucro.

Palavras-chave: hidrogênio; verde; produção; eletrolisadores; Hyjack;

1. INTRODUCTION

Green hydrogen () is a renewable energy source that is being considered a promising fuel with the potential to replace fossil. Its application will contribute to reducing greenhouse gas emissions, helping to mitigate the negative impacts of climate change (SIZING & COSTING, 2022). This material presents characteristics such as minimal environmental impact and is considered the fuel of the future, acting as an energy carrier. Its high energy release per unit of mass, two to three times greater than fuels such as ethanol, natural gas, and biodiesel, makes its usefulness evident(NAGASAWA, 2021).

However, since hydrogen is not found freely in nature, processes are required to obtain it, such as water electrolysis, which results in the production of hydrogen and oxygen gases (SIZING & COSTING, 2022). This technology has different classifications depending on the materials that compose the electrolyzer structure and the chosen electrolyte. A PEM-type electrolyzer stands out for its higher energy efficiency and operational safety. It has a solid electrolyte, the polymeric membrane, usually made of Nafion (sulfonated polymer), and needs to be hydrated for protons to pass through the membrane. Through an ionomer, protons are conducted from the anode to the cathode, where they combine with electrons and form gaseous hydrogen. Oxygen is released at the anode (OLIVEIRA, 2022).

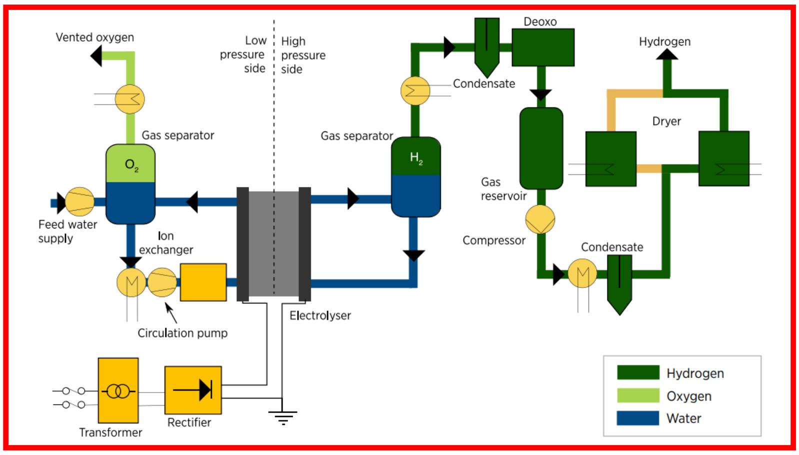
2. METHODOLOGY

The methodology used for the development of this research was based on case studies using a process flowchart, conducted through a literature search in the Capes portal, to define the basic flowsheet for this research.

The database used for the economic evaluation followed the following aspects: Process regime definition; Plant location; Nominal process capacity; Cost and investment assessment; Economic analysis; and Sensitivity analysis.

After the research, the flowsheet determined by Irena Analysis, (2018), for the hydrogen production system through PEM-type electrolyzers was employed, as shown in Figure 1.

Figure 1. Flowsheet of production through PEM-type electrolysis.



Source: Irena Analysis, 2018

2.1. ECONOMIC ANALYSIS

To conduct the economic analysis, the equipment costs were calculated by adjusting the process flowsheet to the ideal conditions and using the methodology proposed by PETERS & TIMMERHAUS (2003). CAPEX (Capital Expenditure), refers to investments in acquisitions such as equipment and facilities, with a significant impact on cash flow and a medium to long-term return (PETERS, 2003). On the other hand, operating costs, referred to as OPEX (Operational Expenditure), pertain to the plant's operational expenses, with an immediate impact on cash flow and operation quality (OLIVEIRA, 2022).

For the economic analysis, the raw material specification and its cost were collected, followed by the definition of equipment and cost gathering, and subsequently the sensitivity study. The project's analysis also considers key economic indicators to propose project feasibility, such as the payback period, net present value, and internal rate of return.

The electrolysis plant was sized considering data from Porto de Pecém, CE, where local productivity and the potential of Ceará state for green hydrogen production were evaluated, taking into account raw materials, energy, labor, and investments in the area (PELLEGRINI, 2000). Ceará stands out for its wind and solar energy potential, enabling the operation of electrolyzers. Additionally, the state offers fiscal incentives through the Program of Incentives for the Renewable Energy Production Chain (PIER). The nominal capacity of the plant will be 175 tons of hydrogen per year based on the hydrogen demand of the Port of Pecém. The equipment has been sized according to the nominal capacity of the plant (PETERS, 2003).

3. EQUIPMENT SPECIFICATIONS

For the production of green hydrogen through PEM electrolysis, the equipment for the industrial plant was listed. The Hyjack simulation platform, a free platform used for designing and modeling in hydrogen projects, was used for the technical-economic evaluation and theoretical foundation of each stage and apparatus of the process.

Thus, based on the selection of equipment with their specific specifications, the table below presents the prices of each equipment and the total investment value.

Table 1. Equipaments Values.

Equipment	Total Cost (US$)	Equipment	Total Cost (US$)
Gas Separator	6,841.25	Condenser	16,067.50
Gas Separator	7,451.25	Gas reservoir	511,245.00
Chemical Transformer	51,886.25	Compressor	576,408.75
Rectifier	3,537.50	Dryer	187,500.00
PEM Electrolyzer	3,510,122.50	Purifier	108,71.25
	TOTAL	**4,881,931.25**	

Source: Hyjack,2023

4. IMPLEMENTATION INVESTMENTS

For the calculation of the implementation investment of the pilot plant, the methodology proposed by Peters & Timmerhaus, 2003, which is based on the costs of equipment and physical states of materials throughout their production process. The fixed investment (FI) involves the cost of equipment and constructions and accounts for 80 to 90% of the total base investment of the plant (PETERS, 2003).

Based on the mapping conducted, all other costs, such as Total Investment (TI), can be estimated from the fixed investments of the plant, using the information obtained below:

Table 2. Investment Components and Related Values.

Components		**% of Fixed Investments**	**Value (US$)**
Direct Costs	***% of Estimated Investment***		
Purchased Equipment	15-40	20	4,881,931.25
Equipment Installation	6-14	10	2,440,965.63
Instrumentation and Control Equipment (installed))	2-8	5	1,220,482.81
Piping (installed)	3-20	10	2,440,965.63
Electrical Network (installed)	2-10	5	1,220,482.81
Constructions	3-18	3	732,289.69
Surrounding Improvements	2-5	4	976,386.25
Utility Services	8-20	12	2,929,158.75
Land	1-2	1	244,096.56
Indirect Costs			
Construction Costs	4-21	12	2,929,158.75
Custos de Construção	4-16	8	1,952,772.50
Fee	2-16	2	488,193.13
Contingencies	5-15	5	1,220,482.81
Fixed Investments			23,677,366.56

Source: Author

Considering IT = 1.40 * FI
Total Investment: US$33.148.313,19

4.1. PRODUCTION COSTS

For the efficient operation of the electrolysis plant, it is necessary to use raw materials that meet the equipment's requirements throughout the process. In this regard, the water used in the electrolyzer must be fed in accordance with ASTM classification,which determines the level purification classification of water used at a maximum allowable concentration of contaminants, ensuring the absence of impurities that could affect electrode surfaces or membranes. Preference is given to water with a maximum conductivity of 1μS and minimum resistivity of 1MΩ at 298K(PERLINGEIRO, 2005).

The energy-related tariffs for the system were based on the electricity rate for the Port of Pecém Terminal. According to the Regulatory Agency of the State of Ceará, the base tariff was approximately US$0.15 per kWh used.

Following the methodology proposed by Perlingeiro, (2005), from the calculations of variable costs in the projects, we can define fixed costs as 15% of this project, remaining unchanged throughout the year and related to all administrative aspects of the factory, such as taxes and insurance costs (PERLINGEIRO, 2005).

Table 3. Production Costs

	WATER	ELETRICITY
Ceará Tariff	0.92 (U$)/m³	0.15 (US$/kWh)
Daily Consumption Daily	6.48m³/dia	41,281.00 KWh
Daily Consumption (US$)	5.96	**4,128**
Annual Consumption (US$)	2,175.4	**990,720**
Variable Cost (US$ per year)	992.895.4	
Fixed Cost (US$ per year)	148,934.31	

Source: Author

4.2. ECONOMIC EVALUATION OF THE PROJECT

4.2.1. CASH FLOW

Cash flow considers the financial transactions conducted by companies, categorizing them as revenues and expenses over a specific period. Based on our cash flow, we can determine the attractiveness rate for carrying out the plant investment (PELLEGRINI, 2000).

Considering the assumptions for the cash flow (Table 4), we were able to develop our cash flow for a 10-year period for the project (Table 5).

Table 4. Assumptions for Cash Flow

Fixed Investment	US$ 23,677,366.56
Annual Revenue	US$ 2,808,412.2
Operating Cost	US$ 93,614
Annual Depreciation	US$ 2,367,736.66
Income Tax (on taxable profit)	35%

Source: Author

Table 5. Depreciation Cash Flow over a period of 10 years.

Year	Invest. ($MM)	Annual Revenue ($MM)	Total Annual Costs ($)	Import Content Sheet ($MM)	Depreciation ($MM)	Taxable Profit ($)	IR($MM)	Cash Flow II ($MM)
1	-23,67	$0.00	$0.00	-$23,68	$0,00	-	$0,00	-23,67
2	$0,00	2,8	-$148,934.31	$2,66	2,3	291,741.23	0,102	2,56
3	$0,00	2,8	-$148,934.31	$2,66	2,3	291,741.23	0,102	2,56
4	$0,00	2,8	-$148,934.31	$2,66	2,3	291,741.23	0,102	2,56
5	$0,00	2,8	-$148,934.31	$2,66	2,3	291,741.23	0,102	2,56
6	$0,00	2,8	-$148,934.31	$2,66	2,3	291,741.23	0,102	2,56
7	$0,00	2,8	-$148,934.31	$2,66	2,3	291,741.23	0,102	2,56
8	$0,00	2,8	-$148,934.31	$2,66	2,3	291,741.23	0,102	2,56
9	$0,00	2,8	-$148,934.31	$2,66	2,3	291,741.23	0,102	2,56
10	$0,00	2,8	-$148,934.31	$2,66	2,3	291,741.23	0,102	2,56

Source: Author

It can be observed that in the year of the factory's inauguration, considered year zero, there was no revenue generation or production costs, resulting in a negative final cash flow due to the investment made. Starting from the first year and over the next twenty years, with the operation of the plant, there will be revenue inflows and the occurrence of production costs, including depreciation and taxes.

5. ECONOMIC ANALYSIS OF THE PROJECT

For the economic analysis, a deterministic approach was used, considering the internal rate of return (IRR) and net present value (NPV), which takes into account the discounted value for the investment in year zero based on the minimum attractive rate of return (MARR) for analysis.

Table 6. Project Investments

Years	Financial Incomes	Total Cost	Cash Flow	VP (Present Value)	TR (Rate of Return)
0	$0,00	$23.677.366,56	-$23.677.366,561	$23.677.366,56	$23.677.366,56
1	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$1.474.851,76	$22.202.514,80
2	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$1.305.178,55	$20.897.336,25
3	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$1.155.025,27	$19.742.310,98
4	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$1.022.146,25	$18.720.164,73
5	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$904.554,21	$17.815.610,53
6	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$800.490,45	$17.015.120,08
7	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$708.398,63	$16.306.721,45
8	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$626.901,44	$15.679.820,01
9	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$554.780,03	$15.125.039,98
10	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$490.955,78	$14.634.084,20
11	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$434.474,14	$14.199.610,05
12	$2.808.412,20	$1.141.829,71	$1.666.582,49	-$384.490,39	$13.815.119,66

Source: Author

To analyze the MARR, the project risk was estimated to range from 10% (low investment risk) to 15% (high risk). The electrolysis plant considered a MARR of 13%, representing a medium-high risk rate.

Based on the MARR value of 13%, the NPV was calculated to be USD -8,720,417.19, which suggests that the electrolysis plant is not economically viable according to data interpretation. To reinforce this estimation, the analysis of the internal rate of return (IRR) was also conducted, and the value found was approximately -3%, indicating the economic infeasibility of the investment in this aspect.

When examining the payback period (PP) of the investment, which indicates the time in years required for the plant to recover the invested amount during its implementation, it was evident that it was impossible to establish a payback period, making the plant unfeasible.

6. SENSITIVITY ANALYSIS

The project's sensitivity analysis covered various variables, including the price of electricity and the sale of green hydrogen, in relation to the fixed Internal Rate of Return (IRR) at 13% as the Minimum Attractive Rate (MARR). It was found that the maximum viable value for the final product would be $8.75 per kg of hydrogen. However, when considering the total cost divided by the mass of produced, a revenue of $2,808,412.2 with a selling price of $16.00 per kg of was obtained.

Considering the final value of Hydrogen according to the United States Department of Energy, an estimated cost for energy purposes is around $2/kg or $0.1797/N³. However, if this value is taken into account in our financial statements, our plant does not show a financial return.

Another factor that prevents a good financial return from our plant is due to our associated capacity, as it was found that its specific location would be viable. Factors such as good financial returns and government incentive plans can help a positive response to the plant in the Port of Pécem. Nevertheless, it is estimated that with the depletion of fossil fuel reserves, the equipment costs for hydrogen production may decrease, making this utilization more economically viable (SHIVA, 2019).

7. CONCLUSION

In summary, based on the results obtained after the investment calculations for the Port of Pecém, it is concluded that the green hydrogen production process was not profitable due to the high cost of electricity. This factor significantly contributed to the final price of hydrogen, making it less competitive in the market. The indicative factors of a Net Present Value (NPV) index of US$ -8,720,417.19 and an Internal Rate of Return (IRR) of -3%, which is lower than the established Minimum Attractive Rate (MARR) of 13%, support this conclusion.

Given this finding, it is necessary to conduct future projections and a more in-depth market analysis. Exploring alternative, more viable energy sources and equipment that can further reduce the electrical costs involved in the production process is essential. This approach could potentially lower energy tariffs and, consequently, make hydrogen consumption feasible.

Although the current cost of energy via hydrogen makes the profitability of the hydrogen production process at the Port of Pecém unfeasible, which has proven to be a great place for implementation, the search for an efficient nominal capacity opens the way for a promising future in the use of hydrogen as a resource energetic.

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