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SOLAR-HYDROGEN GENERATED AMMONIA FOR THE SYNTHESIS OF NITROGEN FERTILIZERS IN THE STATE OF CEARÁ - BRAZIL

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Abstract. *A mathematical and computational model was elaborated for the verification of the feasibility of producing ammonia through electrolytic solar hydrogen in the State of Ceará – Brazil. The model considers interrelationships of parameters such as population, energy demand, gross internal product per capita of the State of Ceará and makes long term estimates for the production of hydrogen, and ammonia, prices of energy, necessary area for photovoltaic panels, capacity of desalination plant, capital investments, costs of operation and maintenance and environmental impacts were also included in this model. Results presents interesting scenario for the implantation of a system like this where the production of ammonia through solar-hydrogen certainly will impact on the future market of nitrogen fertilizers of the State of Ceará.*

Keywords: *Hydrogen, Solar Energy, Ammonia, State of Ceará*

1. INTRODUCTION

In face of the steady growth of the world population, it is clear the importance that should be given to the quality of human life. Everybody must have some concern about the future generations and how can be created sources of food for a growing population in a context of increasingly scarce resources.

The great challenge of the agricultural sector in the coming decades will be to increase food production to meet the growing world population. Brazil is one of the few countries with great possibilities to participate in this process, because it has a relatively sustainable technology to achieve increased productivity in many crops.

Today the country would have to increase by 88 million hectares of cultivated areas to get the same result achieved today if it were not for the use of fertilizers, an important component of technology package in the agriculture sector, and one responsible for the significant increase recorded in the average productivity of Brazil in recent decades.

In this context, this article has as focus the technical and economic analysis of a possible a sustainable electrolyte ammonia production, or, in other words, ammonia arising from the hydrogen produced by electrolysis plant that uses solar photovoltaic. Such ammonia plant is really necessary, given that much of the fertilizers used in Brazil is imported, mainly the used in the Northeast region of Brazil and also because the lack of raw material for production of nitrogen fertilizers is relatively high.

The ammonia production based on water electrolysis is an interesting technology and competitive for countries with abundant availability of resources for obtaining electricity at competitive prices, or in situations where the production of fertilizers is made to meet an agricultural region which has no raw material based on fossil fuels or the transport of these products get expensive. However, the electrolysis of water is still considered by some experts as an alternative unconventional and not economical for ammonia production on a large scale to replace fossil fuels. This should be questioned, because renewable energy is expanding fast and consequently more competitive, enabling the electrolysis process, including the case of ammonia production. Only a small part of the world's fertilizer is based on hydrogen produced by electrolysis of water. However, the steady increase in the price of natural gas results in an interest in the technology of water electrolysis, as the basis for production of relatively small amount of fertilizer. This alternative is particularly interesting for developing countries. Such approach has been considered as a means of storing energy off-peak to french nuclear power plants in connection

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with alternative energy sources such as OTEC (Ocean Thermal Energy Conversion) (Grundt and Christiansen, 1982).

The above work presents an introduction to the Norsk technology of water electrolysis and ammonia production based on this technology. It also gives a brief review of other technologies for ammonia production (steam reforming of natural gas, partial oxidation of heavy fuel and partial oxidation of coal), and makes a comparison of energy demand and cost of various technologies. Ammonia proves to be an excellent fuel for vehicles or for industrial purposes, with appropriate combustion conditions, produces only water and nitrogen as products. Thus, it is seen as an interesting candidate as a future fuel that will mitigate air pollution and can be produced with the OTEC technology in quantities sufficient to satisfy world needs. Ammonia is produced in large quantities in the United States and is used as raw material for the synthesis of nitrogen fertilizers and plastics.

The current process requires the use of 1,090 cubic meters of natural gas as source of hydrogen per ton of ammonia produced. Due to huge demand, the system of transportation, storage and distribution already exist, which would facilitate their entry as a future replacement for fossil fuels (Avery, 1988).

It is necessary an alternative to fossil fuels to meet a global demand for energy in order to offer it to the needs of basic services in the poorest communities. For remote areas, this probably requires the production of energy near the place of use due to lack of supply infrastructure. Ammonia is an excellent hydrogen carrier and may later be used in fuel cells as an attractive option for its ease of decomposition, high availability, by low pressure storage and byproducts of the conversion process is environmentally friendly.

According to Rollinson *et al*. (2011), recently there have been publications which refer to the use of urea, a product of ammonia, as a source of energy for use in hydrogen fuel cells. Urea is a product cheap and widely available with well developed manufacturing infrastructure and a growing volume of production. In comparison with other industrial chemicals previously considered, urea has the advantage of not being toxic, stable and therefore easier to carry and store. Urea may be a future solution for providing sustainable hydrogen in the long term and that the present state of scientific knowledge required to use this product is mostly understood.

Ammonia is an important input for agriculture and is widely used as a feedstock for the chemical industry. It was recently proposed that ammonia is a sustainable fuel and is also a convenient way to store hydrogen. Solar energy is considered as an alternative to cheap, renewable energy in the synthesis of NH_3 under ambient pressure and without using natural gas as feedstock. It has an economically viable production happening in an ideal plant with a capacity of approximately 900 tons per day being conservative with a reasonable price around $ 28 per ton of NH_3 (Michalsky *et al*., 2012)

Production of energy and combating climate change are among some of the most important challenges we face today. A barrier to the implementation of a hydrogen economy is the storage of this product. Ammonia and some chemicals can be used as an alternative energy carrier. Similar to hydrogen, ammonia itself is free of carbon in the final use, despite emits CO_2 in a conventional production using natural gas as feedstock. In recent years there have been significant advances in fuel cells using ammonia directly to generate electricity for use in transport. With the development and application of these technologies, it is possible a reduction in CO_2 emissions in the transport (Lan *et al*., 2012).

The potential benefits and technical advantages of the use of ammonia as a sustainable fuel for power generation in vehicles is analyzed in the work of Zamfirescu *et al*. (2009). The cooling effect of ammonia is another advantage which is inserted in the calculation of efficiency and, if taken into account can raise system efficiency in 11% ammonia by replacing hydrogen in cars which already have this technology.

2. SOLAR-HYDROGEN ENERGY SYSTEM

In the mid 70s, Veziroglu and Basar first presented the mathematical model for the long term calculation of technical, socioeconomic and environmental parameters related to the universal introduction of solar hydrogen as an alternative energy carrier instead of fossil fuels. After its first appearance, the model was applied to many countries and regions as for example, Libya (Eljirushi and Vezirogu, 2009), Pakistan (Lutfi and Veziroglu, 1991), Egypt (Abdallah *et al*., 1999), Spain (Contreras *et al*., 1999), Brazil (De Lima and Veziroglu, 2001), United Arab Emirates (Kazim and Veziroglu, 2000), Saudi Arabia (Almogren and Veziroglu, 2004), and recently for the State of Ceará (Sacramento, 2007, 2008; Sacramento *et al*., 2008; Sales, 2010; Patricio *et al*., 2012).

Throughout these 37 years, this model has received few significant changes around the world, or none in relation to changes in the equations and the program ends. But in 2007 there was the first significant change in the mathematical model made by Sacramento (2007) which used not only solar energy but inserting into the model equations related to wind energy since the State of Ceará is already harnessing such energy commercially.

There was another significant change in the model. Sales (2010) chose to conduct his work exclusively with wind energy, being the first work based on this mathematical model that did not make use of the equations of photovoltaics, also focusing on Ceará as the study area. Another change was to analyze the possible

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replacement of natural gas by hydrogen, opposed to previous work that analyzed the replacement of other fossil fuels such as gasoline, fuel oil, diesel and liquefied petroleum gas (LPG).

Seizing the versatility of this mathematical model, this paper will also introduce innovations, for the first time will not be used as main focus the analysis of demand and supply of energy, but direct our attention to another concern of society, which is increasing the demand for food to meet the growing world population.

The following parameters are included in the model: Population of the study site, energy demand, Gross Domestic Product (GDP) rate of introduction of hydrogen, ammonia imports, prices of hydrogen and ammonia, air pollution index of quality of life, environmental savings due to more efficient utilization of hydrogen, agricultural gain, gain on sale of ammonia, gain on sale of generated oxygen, volume of water demanded by deionization plant, total capital investment, operating costs and maintenance support due to the system, the cost of ammonia production by the solar plant and total income of the same.

In the following subsections, we present the relations between the above mentioned parameters. Due to space limitation equations for the estimation of population, energy demand, gross product and hydrogen production were not explicitly written in this paper. They are published in an article of two of the present authors Patricio *et al.* (2012).

2.3 AMMONIA PRODUCTION

For an ammonia plant with production of approximately 280 tons/day is required the installation of a hydrogen production plant with a capacity of 23,000 Nm ³ / h, using the process of electrolysis, reaching the following equation [1].

$$CD_n = 6{,}03 \cdot \boldsymbol{H}_n \tag{1}$$

Where, CD_n is the production capacity of electrolytic ammonia and H_n is the capability of producing hydrogen to produce the corresponding ammonia, both in GJ.

All input data of the model were calculated based on an ammonia production plant of 100 tons/day, remembering that for a plant with this scale of production is more advantageous to use of electrolytic hydrogen instead of natural gas by reforming steam (Espínola, 2008; Lutfi and Veziroglu, 1990).

2.4 AREA PHOTOVOLTAIC CELL AND THE TOTAL LAND AREA

The total project area of photovoltaic cells, A_{cn}, is given by:

$$A_{cn} = A_{hn} + A_{wn} \tag{2}$$

Where, A_{hn} is the area of photovoltaic cells for the production of hydrogen and A_{wn} is the area of photovoltaic cells for the desalination plant.

In order to avoid the shading of photovoltaic panels and allow farming must be some spacing left between the panels.

The total land area of the project, A_{pn}, is given by:

$$A_{pn} = A_{cn} / \beta \tag{3}$$

Where the term β is a coefficient which adds to the cell area, A_{cn}, the spacing between them, its value is given by 0.34 (Patricio, 2010).

2.4.1 TOTAL AREA OF PHOTOVOLTAIC CELLS FOR THE PRODUCTION OF HYDROGEN

The area of photovoltaic cells required to satisfy the total production of hydrogen in the year t_n, can be calculated by the following equation:

$$A_{hn} = H_n / \left(\eta_{pv} \cdot \eta_{et} \cdot S_{av}\right) \tag{4}$$

being η_{pv} the efficiency of the photovoltaic system, η_{et} the efficiency of the electrolyser and S_{av} the annual average insolation per unit area in photovoltaic panels.

The most important parameter is photovoltaic cell conversion efficiency. Great efficiencies mean more power produced and low costs. The major causes of inefficiency in solar cells are red and blue spectral losses and room temperature. These losses are related to the ability of a cell to use certain range of the solar spectrum. Other causes of inefficiency are reflection factor, voltage and other [24].

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2.4.2 AREA OF PHOTOVOLTAIC CELLS FOR WATER DESALINATION

With the purpose of fill the electrolyser with fresh water for irrigation, the water needed to be deionized using a reverse osmosis process where the solvent (H_2O) must pass a hypertonic medium to a hypotonic medium, needing obviously energy for performing this process. Thus an area, A_{wn}, of additional photovoltaic cells should be required to generate electricity for the deionization of water.

If W_{dn} is the total water demand in the year t_n in m³/year and E_1 is the energy of the deionization plant in GJ/m³, then:

$$B_{wn} = E_1 \cdot W_{dn} \tag{4}$$

and

$$A_{wn} = B_{wn} / \left(\eta_{pv} \cdot \eta_{re} \cdot S_{av} \right) \tag{5}$$

Where, B_{wn} total energy is required in the year t_n in GJ and η_{re} is the efficiency of the rectifier.

2.5 CAPACITY OF WATER DESALINATION PLANT

The relationship that represents the water demand (W_{dn}) in the year t_n will be given by:

$$W_{dn} = W_{hn} + W_{in} \tag{6}$$

Where, W_{hn} is the water demand for hydrogen production, W_{in} is the demand of water for irrigation and, W_{hn} e W_{in} can be calculated by the formulas below:

$$W_{hn} = W_1 \cdot H_n \tag{7}$$

$$W_{in} = W_2 \cdot A_{an} \tag{8}$$

Where, W_1 is the consumption of the electrolyzer by GJ of hydrogen produced, W_2 is the annual demand for irrigation per unit area.

One area to be used for agricultural purposes, leaving some room for access roads, columns of concrete poles, etc. Assuming the ratio of the area of land cultivated, A_{an}, and the total project area A_{an}, and the total project area A_{pn}, it follows that:

$$A_{an} = \delta \cdot A_{pn} \tag{9}$$

Taking into account various parameters such as evaporation, crop coefficient, effective precipitation and others to determine an average value for the water demand for irrigation in the region, where it is proposed to install the project.

2.6 ENVIRONMENTAL BENEFITS

One of the benefits the introduction of energy-based solar hydrogen is the replacement of the current system, where the fertilizer production is from fossil fuels (in this case the gas), causing it to reduce air pollution, acid rain and the greenhouse effect, which result in savings due to reduced damage to the environment.

In the case where no is the introduction of hydrogen, the cost of environmental damage is:

$$D_{en} = E_n \cdot C_p \tag{10}$$

Where D_{en} are the costs of environmental damage in the year t_n, E_n is the energy consumption year t_n, C_p is the cost of environmental damage per unit of fossil energy consumed.

After introduction of hydrogen, the cost of environmental damage decreases can be expressed by:

$$D_{hn} = \left(F_{dn} + \varepsilon H_n \right) \cdot C_p \tag{11}$$

Where D_{hn} is the cost caused by the hydrogen and fossil fuels, F_{dn} is the demand for fossil fuel in year t_n and ε is the ratio of pollution produced between hydrogen and fossil fuels.

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The equation for economy of environmental damage, S_{en}, in year t_n can be expressed by:

$$S_{en} = D_{en} - D_{hn} \quad (12)$$

or

$$S_{en} = \eta_r \cdot H_n \cdot C_p - \varepsilon \cdot H_n \cdot C_p \quad (13)$$

2.7 ENVIRONMENTAL IMPACT (POLLUTION)

Currently air pollution is mainly caused by the use of fossil fuels. The introduction of hydrogen in the production sector of fertilizer in place of natural gas has the effect of reduction of air pollution. The equation relating the pollution of fossil fuel consumption and hydrogen can be seen in the equation below:

$$P_n = U\left(F_{dn} + \varepsilon H_{pn}\right) \quad (14)$$

Where P_n is the amount of pollution year n, U is pollution per unit of fossil energy consumed, and ε is the ratio of pollution produced by hydrogen per unit of fossil energy and the pollution produced by fossil fuels per unit of energy.

To calculate the amount of initial pollution P_0, the study region adopted, just replace the values of F_{dn}, H_{dn}, U and ε in the above equation (14).

3. DATA AND COMPUTATION

Considering the year 2010 as the starting year, it was studied future trends of the parameters described in section 2.4. Two different rates of time to double the amount of hydrogen introduced were studied, in order to show the consequences of the introduction of hydrogen in the energy and quality of life:

$$\theta_{hn} = 2.0 + 0.2(n-1) \quad (15)$$

$$\theta_{hn} = \infty \quad (16)$$

The doubling time given by equation (4) is the fast rate of introduction of hydrogen. In the case where the doubling time goes to infinity corresponds to no introduction of solar hydrogen in place of natural gas to produce ammonia for agricultural purposes.

It was assumed that the solar-hydrogen for ammonia production will be introduced in the energy state of Ceará after year 2020. Thus it would have been for the time interval between 2010 and 2020 hydrogen production would start $H_n = 0$ and after 2020, Initial would be H_n = 2.75 TJ/year. The area occupied by the project is calculated taking into account spacing for agriculture (Almogren and Veziroglu, 2004): δ = 0.60. The ratio of the efficiency of utilization of hydrogen and the efficiency of fossil fuel use η, is included in equation (18) where this value is used: $\eta = 1.36$. The conversion efficiency of the PV module, the efficiency of electrolyzers and the local average annual irradiance, are respectively:

$$\eta_{pv} = 0.12$$

$\eta_{el} = 0.75$ (by 2050, after which the efficiency of electrolyzers tend to increase for

$\eta_{el} = 0.90$), and

$$S_{av} = \frac{6.7 \frac{GJ}{m^2}}{year}$$ [9]

The environmental impact coefficient U and the ratio between the pollution produced by hydrogen per unit of fossil energy and the pollution produced by fossil fuels per unit of energy ε are included in equation (14), and brings the following values: U = 43.15 kg/GJ; ε = 0.117

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Initial data for the State of Ceará and for the world used in the present article are presented in the article of Patricio et al. (2012) due to space limitation.

The process of desalination of seawater by reverse osmosis requires an energy consumed by m³ of water, E_1, is: E_1 = 24.8 MJ/m³ water consumption for the electrolyzer per GJ of produced hydrogen, W_1, is: 90 x 10^{-3} m³ of water per H_2. The annual demand for irrigation water per unit area, W_2, is (Coelho *et al.*, 2005): 5.66 x 10^5 m³/km²/year. The cost of environmental damage per unit of fossil energy consumed is (Veziroglu et al., 2005): C_p = 12.52 US$/GJ

Credit for oxygen per GJ of produced hydrogen, C_0 was taken as (SEAGRI, 2012): C_0 = 3.50 US$/GJ. The average income of the agricultural resources per unit area, Γ, is given as (Myers et al., 2003): Γ = 5.0 x 10^5 US$/km². The capital required by the electrolyzer per GJ of produced hydrogen, C2, is C_2 = 3.40 US$ /GJ. The cost of storage, compression and transmission hydrogen is shown in Chart 8 below:

Table 1 - Costs of storage, compression and distribution of hydrogen

Type	Cost (US$/GJ)	Quantity stored (GJ)
Compressed gas – short period	1.84 1.53	20,300 130,600
Compressed gas – long period	12.34 7.35	391,900 3,919,000

Source: Hydrogen delivery technology roadmap, 2005.

Where the short period is 1-3 days and the long period is 1 month. The hydrogen storage system used in the model will be a short period for large amounts of energy retained, assuming an infrastructure for marketing and use to absorb all production within three days.

The capital expenditure on desalination plant per m³ of water, C4, according to: 0.617 US$/m³. The annual cost of operation and maintenance per GJ of produced hydrogen, C_6 e C_7, required for electrolysis and storage, compression and transmission, respectively, are determined as follows (Myers *et al.*, 2003) : C_6 = 0.68 US$/GJ; C_7 = 0.4 US$/GJ. The annual cost of required O & M for the desalination plant m³ of water, C_8, is of the form: C_8 = 0.3 US$/m³ of water. The capital required for the ammonia production plant, C_9 is: C_9 = 13.27 US$/GJ. The cost of operating and maintaining the plant for production of ammonia, C_{10}, is: C_{10} = 0.07 US$/GJ

4. RESULTS AND DISCUSSION

We will analyze various types of curves that characterize the state of Ceará in the two scenarios mentioned earlier in this paper. These curves are intended to present the variation of the most important vectors generated by the program. These parameters are population, Gross Domestic Product, Fertilizer Demand, Cost of Investment and Operation and Maintenance and other parameters. The graphs show what happens with these vectors between the years 2010 and 2110, as long as the imported fertilizer from natural gas, are replaced by fertilizers produced arising from electrolytic hydrogen from solar. Taking into account that hydrogen will be introduced in the energy matrix of Ceará in 2020, Figure 1 shows projected demand for energy in the State of Ceará, which tends to grow over the years between 2010 and 2110 following the growth in population and economy. It is observed the same increase in energy demand of the state in the two scenarios introduced between

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2010 and 2055 with an energy demand of 1.6 EJ. In last year of projection difference will be 0.36 EJ between the two scenarios.

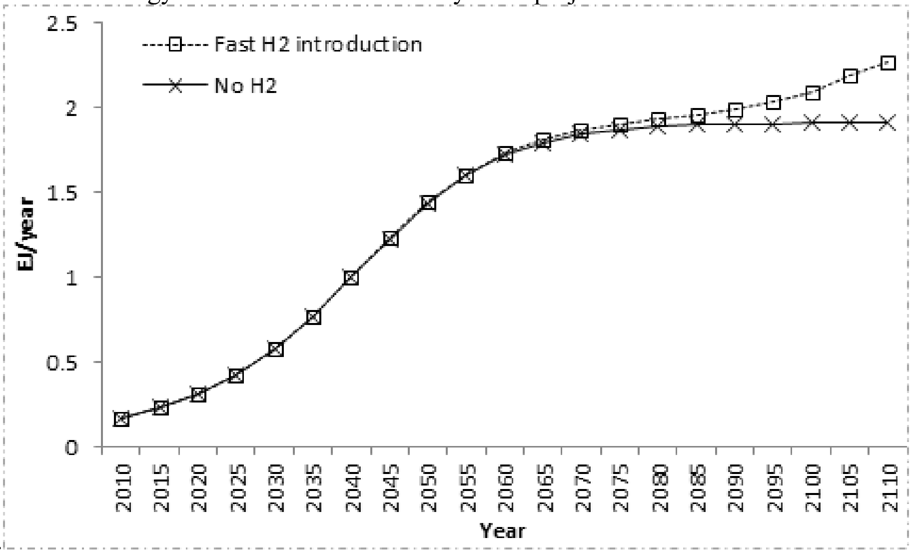

Fig. 1 – Energy demand of the State of Ceará

Figure 2 shows the projection of the Gross Domestic Product (GDP) of the state of Ceará. Both scenarios present the same growth by the year 2060, reaching a value of US$ 12,000 per capita. From the year 2065 it is possible to perceive a higher growth of GDP with the introduction of hydrogen in the matrix of the state, reaching a value of US$ 15,800 until the last projection year, generating a difference of US$ 2,500 if there is no introduction of hydrogen.

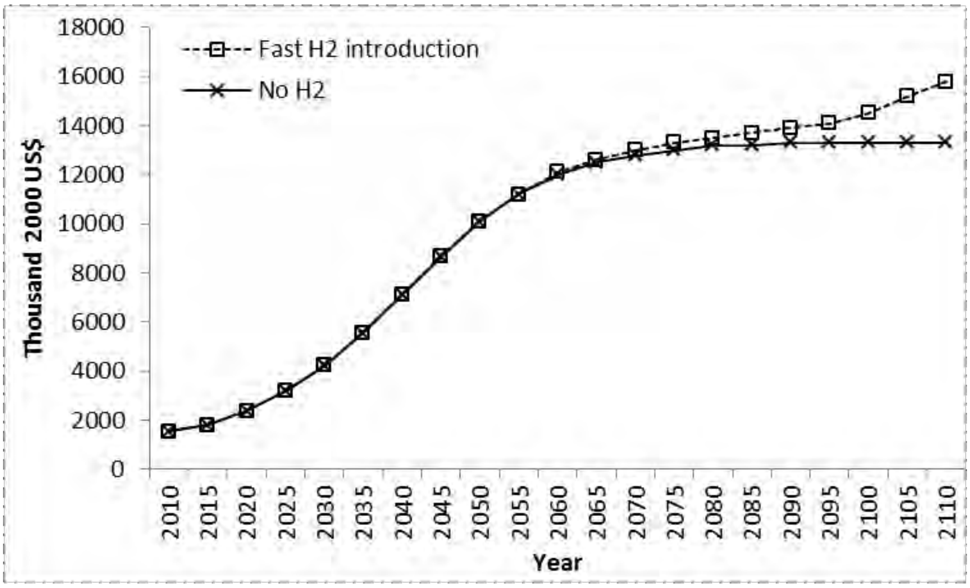

Fig. 2 – Gross Domestic Product per capita for State of the Ceará.

In Figure 3 we can see the demand for fertilizers in the State of Ceará, with an initial value of energy of 0.836 TJ equivalent to 37,000 tons. In both scenarios the growth rate is the same up to the year 2055, reaching the final year of the projection with a difference of 1.82 PJ.

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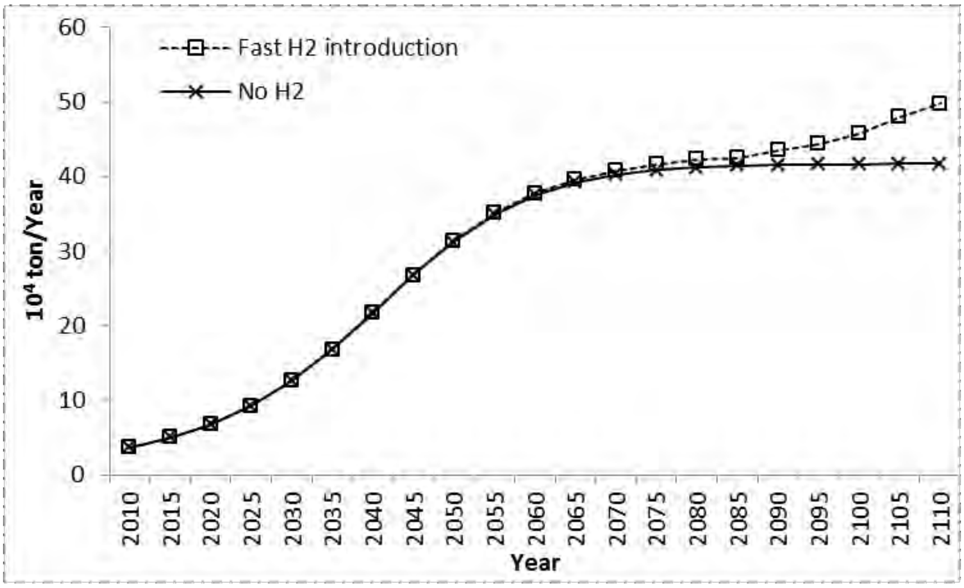

Fig. 3 – Fertilizer Demand in the State of Ceará.

Figure 4 shows a comparison between the production of ammonia, which is the raw material for nitrogen fertilizers, with the increased demand of Ceará for nitrogen fertilizer, phosphate and potassium, which are the NPK mixture. It is observed that from 2070 there will be a surplus production of ammonia produced in relation to the total demand for fertilizer and can be exported to neighboring states in the northeast. The increase in ammonia production is due to increased production of hydrogen. Already in 2070, there is a production of 40,800 tons of ammonia above the fertilizer demand in the state.

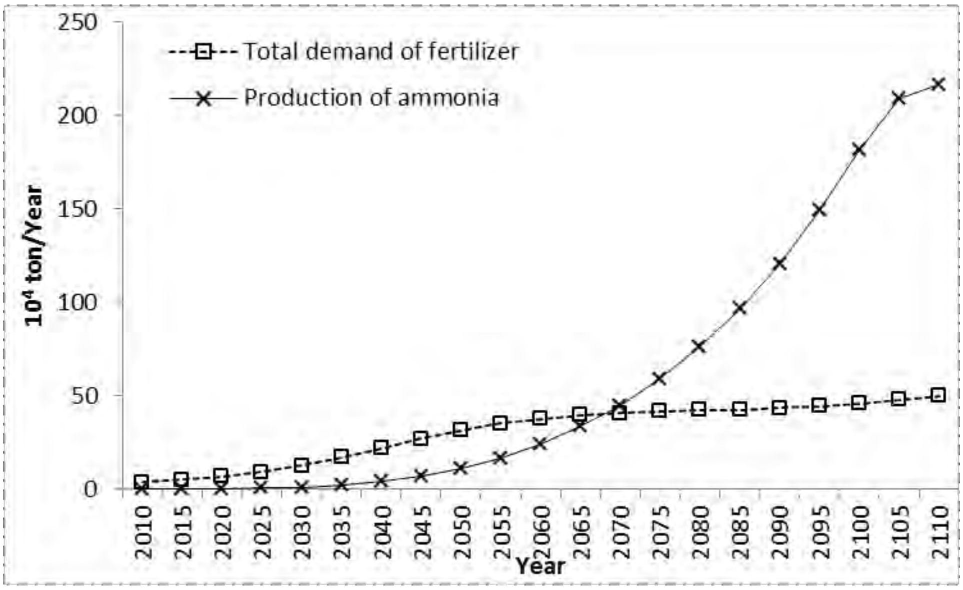

Fig. 4 – Fertilizer demand x ammonia production.

Figure 5 shows the characteristic curve of parameter pollution rate in both scenarios: Introduction of hydrogen and no introduction of hydrogen for the production of nitrogen fertilizers in the energy matrix of the State of Ceará. This figure shows the projection of the pollution generated by a plant that would produce ammonia using electrolytic solar-hydrogen as raw material (fast introduction), compared with the projection of the pollution generated by an ammonia production plant that uses natural gas as feedstock (no introduction), maintaining the same production capacity of ammonia. In case of non-inclusion of hydrogen in the energy of the

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state, provides a ratio of 7.5 in the year 2110.

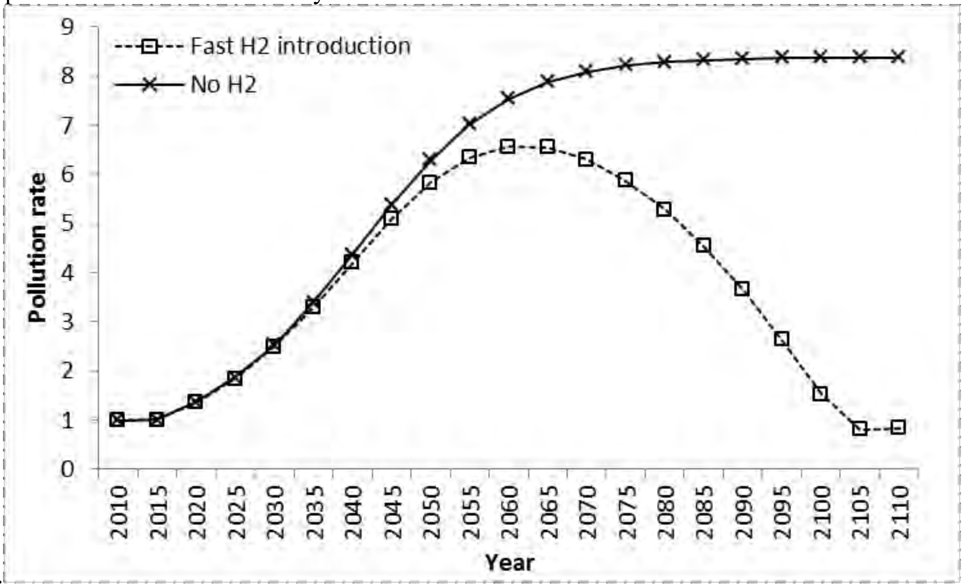

Fig. 5 – Pollution rate

Figure 6 shows the cost curve of photovoltaic panels installed to generate electric power for the project. This graph shows a profile characteristic of this type of renewable energy, where the cost of operation and maintenance is minimal compared to any other type of obtaining electric energy, requiring only periodic cleaning of the cover glass. The plates represent a large part of the investment costs of the system of producing hydrogen, reaching a peak of 297 million in 2105.

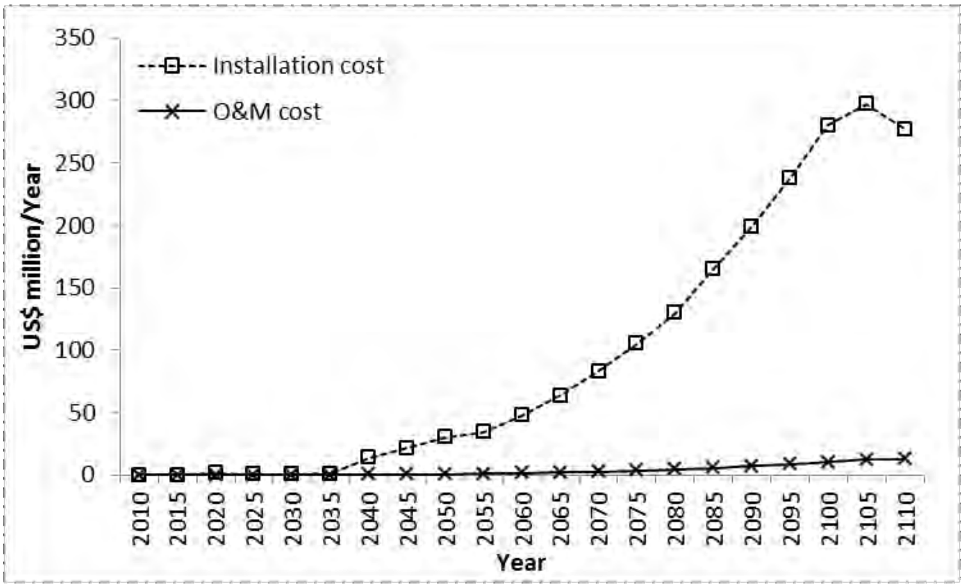

Fig. 6 – Cost photovoltaic's.

Figure 7 shows the curve of investment costs and costs of operation and maintenance of the ammonia ammonia. Taking as standard an ammonia plant through electrolysis of water with daily output of 100 tonnes, in figure presents significant increases in line costs for initial investments and subsequent investments with increased demand for production of ammonia, with values around $ 503,000. The operation and maintenance cost increases each year, reaching 3.42 million dollars annually, making it the main cost to the ammonia plant after 40 years of the start of production.

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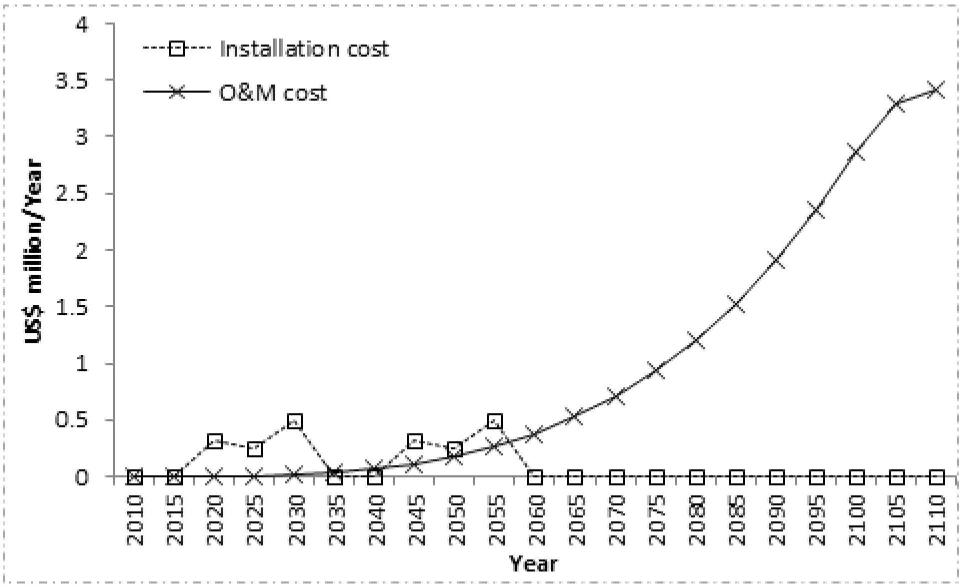

Fig. 7 – Cost of the ammonia plant.

In Figure 8 are shown the curves of gross earnings and total cost. The beginning of the project by 2050 the focus will be environmental benefits, since the ammonia will be produced through electrolysis instead the steam-reforming process of natural gas, thus there will be a mitigation of air pollution. Between 2050 and 2055 the net comes up with a balance of $ 4.2 million, reaching a value of 236 million in 2110.

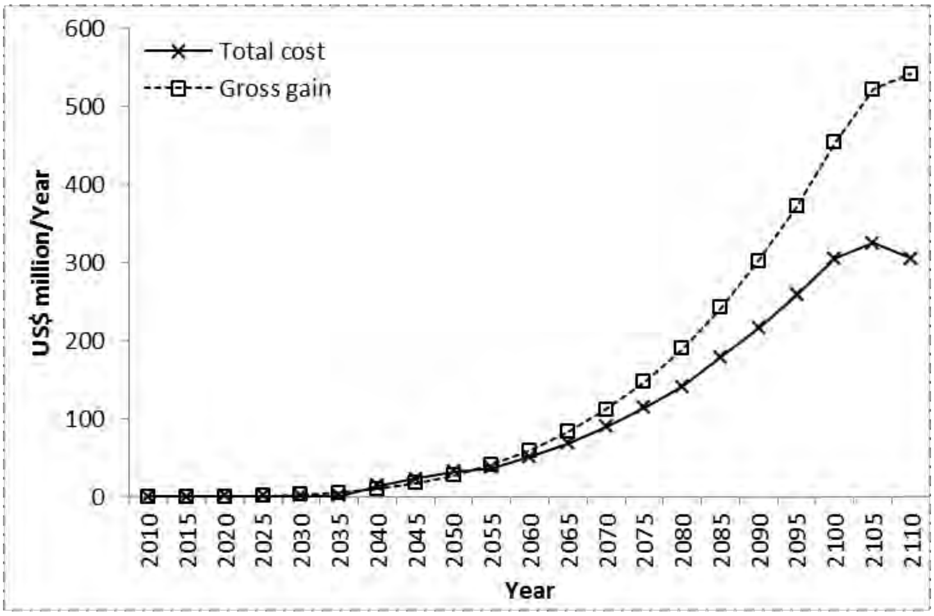

Fig. 8 – net profit.

The Figure 9 presents the temporal evolution of the prices of ammonia produced through electrolytic solar hydrogen compared to the price of ammonia produced through steam reforming of natural gas. The initial value of the price of ammonia produced with hydrogen through the electrolysis process is US$ 21,5/GJ and the price of ammonia arising from another process, which uses natural gas as feedstock, has value US$ 6,88/GJ in the same

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year. Only after the year 2030 values of ammonia (H_2 solar) will already be competitive with the values of ammonia (GN).

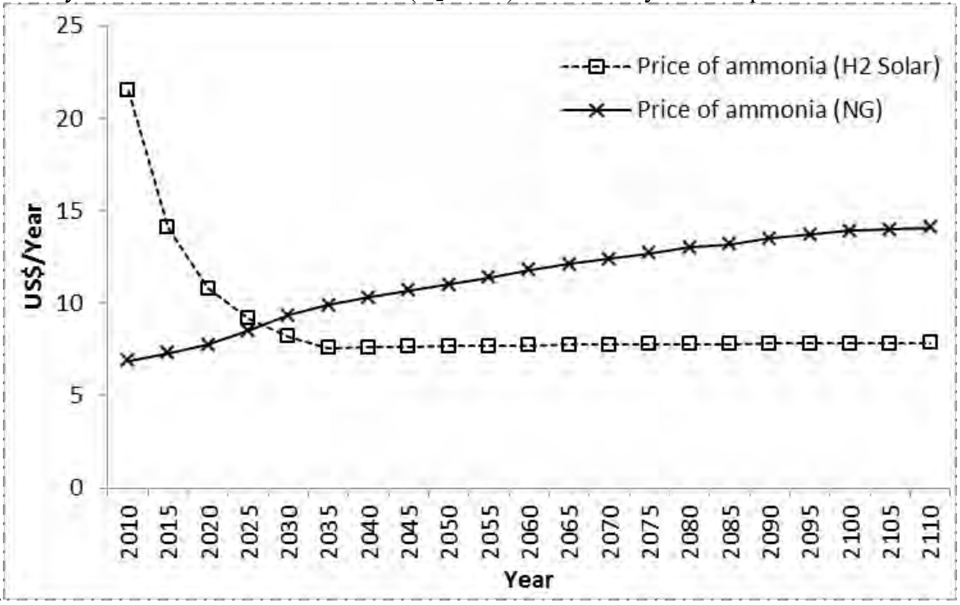

Fig. 9 – Temporal Evolution of the Prices of Ammonia.

5. CONCLUSION

The worldwide use of natural gas as feedstock for ammonia generation instead of producing renewable hydrogen fertilizers generates an increase in the concentration of carbon dioxide in the atmosphere, that entail changes in the global climate. It is important to find ways to reduce air pollution through energy conservation and renewable energy use, as the use of solar energy for the production of electrolytic hydrogen to serve as feedstock replacing natural gas, as proposed in this work.

There is a heavy reliance on external dependence and something close to 73% of the fertilizers sold in Brazil are imported. This is due to the minimal amount of these materials in the country and the low level of investment in the development and consequently the implementation of projects that produce such fertilizers. Profits are generated with electrolytic ammonia production reaching a surplus for the consumption of the state, which can be sold to neighboring states, since the entire Northeast consumes imported fertilizers. This product is really necessary before the disability that many soils is due to geography, physical and chemical, and important for optimal use of resources, with positive results in commercial agriculture through higher levels of productivity.

The hydrogen obtained from the electrolysis of desalinated water from dams or rivers near the project area, using photovoltaic solar energy as an energy source would contribute to the mitigation of air pollution. These reductions in pollutant emissions would result in an economy with public spending to preserve the environment, as well as spending on public health policies.

The investment in the hydrogen economy will provide the State of Ceará is a gradual increase in GDP and an improved quality of life of the population of the state in general, but especially the needy that surrounds the region covered by the project, as it is predicted 60% of total project area for the cultivation of irrigated agriculture to generate income for them.

Technological advances, particularly in the area of solar photovoltaic, will result in a reduction in the cost of supply of electricity obtained from this renewable source, generating greater competitiveness with conventional generation of electricity.

6. ACKNOWLEDGEMENTS

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