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Price determination for hydrogen produced from bio-ethanol in Argentina

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ABSTRACT

A massive penetration for hydrogen as a fuel vector requires a price reduction against fossil fuels (up to lower or at less equal to current prices). That is why it is important to calculate the current prices, so that we can determinate the gap between them and work in reducing them. In order to follow properly prices evolution it is necessary been able to compare data generated by Universities, Laboratories and Industries. So that, DOE creates in 2003 a tool (H2A) to determine prices for hydrogen, with some assumptions and pre defined values, to facilitate transparency and consistency of data. In this work we will use the H2A tool to calculate de price of hydrogen produced in a bio-ethanol semi-industrial Plant in Argentina, and we will compare it with the prices of USA studies.

1. Introduction

Hydrogen is not free in nature. It is always combined with other atoms and could be obtained by breaking this joints using energy; that is why it is considered as an energy carrier or vector. There are a lot of processes to obtain hydrogen, been the most important the natural gas steam reforming (black hydrogen), electrolysis (blue hydrogen) and alcohol steam reforming (green hydrogen). The Catalytic Process Laboratory (LPC for their initials in Spanish) from School of Engineering of Buenos Aires University (FIUBA for their initials in Spanish), in collaboration with the Institute of Design and Development (INGAR for their initials in Spanish), is working in the last way since 1990 [1,2], which passed through successfully the laboratory and pilot plant stages.

In Argentina, as in the rest of the world, hydrogen is principally used as a feedstock to chemical, food, refinery industries from more than fifty years [3]. But in the last decade, hydrogen began to be seen a promising alternative to fossil fuels [4]. It says something is an ‘‘invention’’ when it functioning is demonstrated in a laboratory; but is consider ‘‘innovation’’ when can be used repeatedly trouble-free, in big scale and with affordable costs [5]. The use of hydrogen as an energy carrier is in it way between ‘‘invention’’ and ‘‘innovation’’, where economic viability is one of the most key factors. A massive penetration for hydrogen as a fuel vector requires a price reduction against fossil fuels (up to lower or at less equal to current prices). That is why it is important to calculate the current prices, so that we can determinate the gap between them and work in reducing them.

Nineteen studies of hydrogen price had been made and published by DOE using H2A[6], using different technologies and production capacities, in USA. There are no records of Argentinean prices of hydrogen in it use as an energy carrier for fuels applications.

In this work we will use the H2A tool to calculate the price of hydrogen produced in a bio-ethanol pilot Plant in Argentina, and we will compare it with the prices of USA studies.

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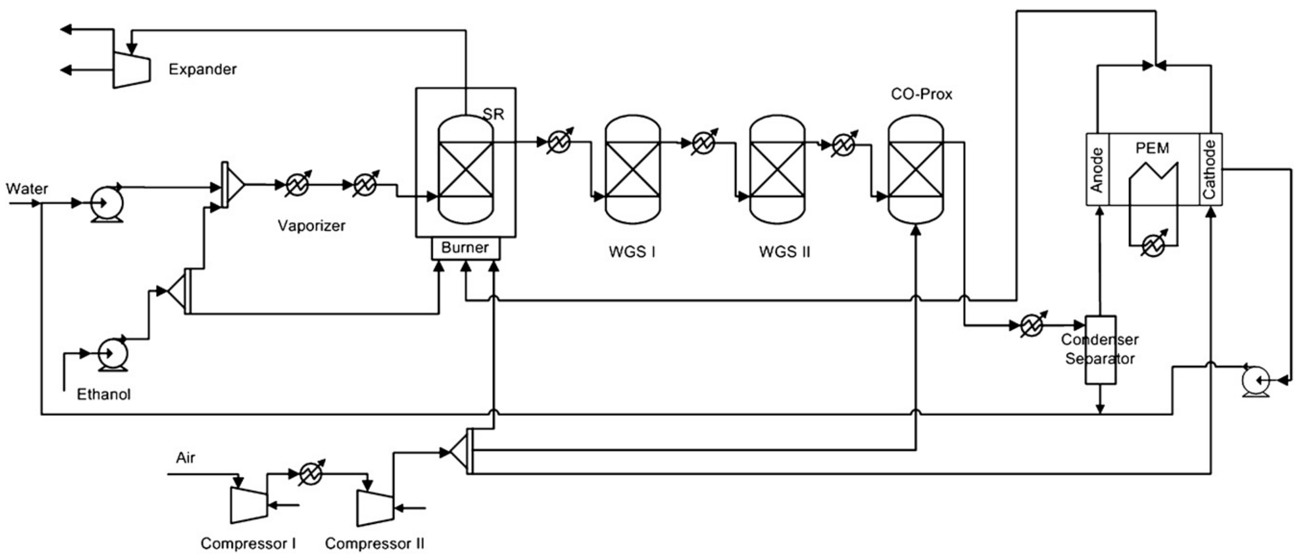

Fig. 1 – Flow-sheet of hydrogen production.

2. Project description

This Plant is the third step of four in an R&D Project guided by the LPC. The group is working in the reforming of ethanol to obtain hydrogen since 1990, which passed through successfully the laboratory and pilot plant stages (steps 1 and 2).

The objective of this stage is to design, build and operate a prototype Plant for producing synthesis gas (rich in hydrogen) and hydrogen, using ethanol and water mixture. This process is an alternative of natural gas steam reforming, the most used technology in Argentina and the world to produce synthesis gas and hydrogen. The prototype has been designed, in collaboration with INGAR, to produce 5 m^3/h NPTC (equivalent to 5 kW or 11 kg of H_2/day) of hydrogen with less than 10 ppm of CO. This alternative seeks to replace the hydrogen storage tanks with ''in situ'' hydrogen production, which only requires to storage an ethanol and water mixture. The purpose is to establish operating conditions to maximize hydrogen production and optimize the energetic balance in the integrated system, included PEM cell of 5 kW.

The plant of 1 m^3/h NPTC (equivalent to 1 kW or 2.2 kg of H_2/day), which connect laboratory and semi-industrial stage, is actually operating successfully. Price determination for the 1 kW Plant was not possible, although an Evaluation Study of it was conducted [7].

This Plant is considered semi-industrial, instead of it size, because use commercially available industrial equipments. The fact that the plant could be used commercially, allows the sense of making a price calculation.

The process of catalytic production and purification of hydrogen consist on three serial reactors:

1) Steam reformer (SR)
2) Hydrogen Purification
    a. Water Gas Shift Reaction (WGS)
    b. CO preferential oxidation (COPROX)

As shown in Fig. 1. The plant also has a PEM (proton exchange membrane) fuel cell and auxiliary equipments as pumps, compressors, heat exchangers, condenser, separator, and measurement equipment.

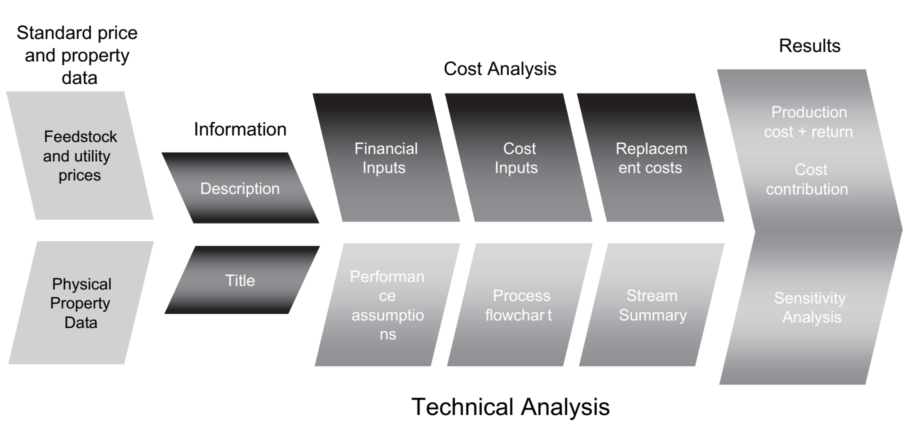

Fig. 2 – Basic architecture of H2A tool (reproduced from [8]).

The systems allow extracting 3 qualities of hydrogen: synthesis gas (output of steam reforming), hydrogen for high temperature fuel cells (output of WGS) and hydrogen for PEM cells (output of COPROX). The composition of this last product is 62% of H_2 with less than 10 ppm of CO, but also H_2O and CO_2 are present in the effluent. This specification would be very important when we compare our price with DOE's studies.

3. Summary of doe methodology

H2A [8], which stands for Hydrogen Analysis, was first initiated by DOE in February, 2003 to better leverage the combined talents and capabilities of analysts working on hydrogen systems, and to establish a consistent set of financial parameters and methodology for analyses. The foundation of H2A is to improve the transparency and consistency of the approach to analysis, to improve the understanding of the differences among analyses, and to seek better validation of analysis studies by industry. To accomplish this, H2A have its own objectives:

1. Establish a standard format and list of parameters for reporting analysis results for production, and delivery.
2. Seek better validation of public analyses through dialog with industry.
3. Enhance understanding of the differences among publicly available analyses and make these differences more transparent.
4. Establish a mechanism for facile dissemination of public analysis results.
5. Work to reach consensus on specific analysis parameters for production and delivery.

The first task the H2A effort has chosen to tackle is to develop a standardized approach and set of assumptions for estimating the lifecycle costs of hydrogen production and delivery technologies (and the resulting cost of hydrogen). Applying the same methodology to each technology and choosing appropriate assumptions will lead to an equitable comparison across technologies.

Information about each analysis case is summarized in a standardized H2A spreadsheet tool that documents the:

- Original source(s) of all the data (i.e., report title, authors, etc.)
- Basic process information (feedstock and energy inputs, size of plant, co-products produced, etc.)
- Process flow-sheet and stream summary (flow rate, temperature, pressure, composition of each stream)
- Technology performance assumptions (e.g., process efficiency and hydrogen product conditions)
- Economic assumptions (after tax internal rate of return, depreciation schedule, plant lifetime, income tax rate, capacity factor, etc.)
- Calculation of the discounted cash flow (the calculation procedure is built into the standardized spreadsheet so that all technologies use the same methodology)
- Results (plant-gate hydrogen selling price and cost contributions in $/kg H2, operating efficiency, total fuel and feedstock consumption, and emissions)

Table 1 – Key economic assumptions for H2A tool.

Assumption	Value	Utilization
Analysis Methodology	Discounted Cash Flow (DCF) model that calculates a levelized H2 price that yields prescribed IRR	Yes
Reference year dollars	2005	Yes
Debt versus equity financing	100% equity	Yes
After tax internal rate of return	10% real	Yes
Technology Development Stage	All Central and Forecourt cost estimates are based on mature, commercial facilities	Yes
Inflation rate	1.9%	Yes
Effective total tax rate	38.9%	No
Working Capital Rate	15% of the annual change in the total operating costs	Yes
Facility Life = Analysis Period	40 years for Central with case exceptions; 20 years for Forecourt with case exceptions	Yes
Construction Period and Cash Flow	Varies per case for Central; 0 for Forecourt	No
Capacity Factor	90% for Central, with case exceptions; 70% for Forecourt	No
Depreciation period and schedule	MACRS (20 yrs for Central and 7 yrs for Forecourt)	No
Forecourt Maintenance and Repair	5%/yr of initial depreciable capital cost for small capacity and 3%/yr for large capacity	Yes
Co-produced and Cogenerated Electricity Price	$30/MWh with sensitivities based on 20$/MWh low and 50$/MWh high	Yes
Salvage Value	10% of initial capital, with case exceptions; 0% for Forecourt	Yes
Decommissioning	10% of initial capital, with case exceptions; 0% for Forecourt	Yes
Hydrogen Purity	98% minimum; CO $<$ 10 ppm, sulfur $<$ 10 ppm	No

- Sensitivity of the results to assumptions (e.g., feedstock cost, co-product selling price, capital cost, operating costs, internal rate of return, conversion efficiencies, etc.)
- Quantification of the level of uncertainty in the analysis.

A scheme of the basic architecture of H2A spreadsheet tool works it is shown in Fig. 2.

DOE has published nineteen cases of study, from different energies such as biomass, ethanol, electrolysis, coal, natural gas and nuclear energy. There are also current/future and central/forecourt alternatives from each energy source.

4. Adopted assumptions

DOE funded the development of H2A Analysis tools in order to address the need for consistent and transparent hydrogen production and delivery analyses. To allow for consistent and comparable results across technology options, it is necessary to use a common set of economic assumptions and approaches. The following set of key economic parameters was selected by the H2A analysts to use within their analyses. The user of the H2A analysis model tools is free to change these parameters to any value they chose for their own purposes. Table 1 shows the key economic assumptions, and those that have been changed are highlighted in column three.

The explanation for each decision about the DOE assumptions follows. We will comment only those which we changed or those which could be more debatable. As general criteria we used DOE assumptions unless we have good reasons for changing them, so that to permit for consistent and comparable results across options.

After tax internal rate of return: we do not consider the different risk scenario between Argentina and USA, because the decision of which rate to use is itself a matter of opinion. We agree on use a base case IRR of 10%, but to also examine a wide range of IRRs, as H2A Analysis Group advise [8].

Inflation rate: it is a very variable and unpredictable parameter, so that we consider appropriate to keep the assumption. It is easy to adjust the study after with real inflation rates.

Effective total tax rate: we use the Argentinean rate, which is 35%.

Construction Period and Cash Flow: we use 6 months (0.5 year) which is the estimated value for our plant.

Capacity factor: we use the LPC and INGAR's estimation, which is 93%.

Depreciation period and schedule: we use straight line as a depreciation type, which is the method allow in Argentina.

Co-produced and Cogenerated Electricity Price: it is clear that Argentina does not have the same energy prices that USA, but we adopted similar criteria than with the inflation rate. Moreover, in order to use Argentinean data it is needed to estimate our own predictions, which exceed the objectives of this work.

Hydrogen Purity: this is the most important parameter, because it is the product specification. The plant we study produces hydrogen with less than 10 ppm of CO and sulfur, but it is mixed with CO_2 and water (see Project Description). This is very significant, but do not attempt against the objective of this paper, which is obtain a first price approximation; but we have to be careful in the comparison analysis.

5. Results and discussion

As was expected, the price of hydrogen produced in the 5 kW Plant using ethanol as feedstock is considerably higher that DOE's calculation [9] (u$s 31.06 versus u$s 3.10 and u$s 2.84). The three estimations are shown in Fig. 3. It is also shown the DOE Hydrogen Program numeric objective (3 u$s/kg of H_2) [8].

There are 2 key differences between our plant and those which are considered in DOE's cases: the plant design capacity and the product specification. The capacity of US plants is 1.500 kg of H_2/day (more than 100 times LPC's Plant) and it follows the H2A product specification (see Adopted assumptions). Although, this do not disqualify the analysis because our objective was to have a first estimation to a local price of hydrogen from ethanol for been used as an energy carrier.

A bigger price was expected and the order of the difference is very reasonable because in our plant the total capital invest is u$s 407.969 to produce 11 kg of H_2/day compared with the u$s 1.255.483 and 1.051.233 to produce 1.500 kg of H_2/day in the Current and Future cases of study. DOE's cases of study invest between 2.5 and 3 times LPC's Plant, but produce more than 100 times the amount of hydrogen. This is consistent with the fact that in our Plant the capital investments explains the 57% of the price and the feedstock price only explains the 14% of it. The order of importance of this variables are inverted to DOE's cases, which are 17% and 76% for the Current case, and 14% and 74% for the Future case.

6. Conclusions

Generally the first steps are less striking, but more important. Calculating the first price in Argentina of hydrogen produced from ethanol for it use as an energy carrier is a starting point to work in reducing it so that this energy alternative could be economically competitive with fossil fuels. It was also

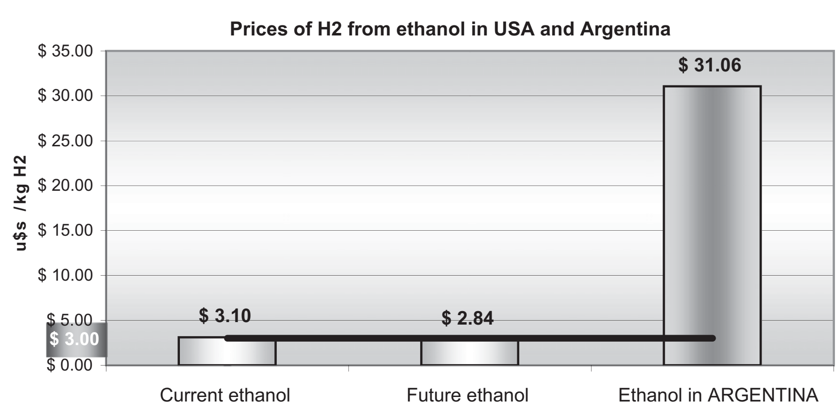

Fig. 3 – Hydrogen prices from ethanol (DOE's Cases of Studies and our calculation).

significant to introduce in Argentina the use of a tool (H2A) which seeks for consistency and comparability of the different calculations that are published in this road to reach the Hydrogen Economy. Compare is all about finding the differences, and H2A allows doing this quicker and easier.

We think that R&D Projects should be accompanied with economical calculation even in their earlier stages, so that to point in with directions to move forward in order to achieve it application in society. That is the main reason to make this calculation, because our Plant is still in R&D phase, and the introduction of an economic variable as price, helps to get focus in reaching social implementation.

It would be interesting to complement this typical economic analysis (see Analysis Methodology in Table 1) with complements as real options [10–12] or alternative methods as use-and-transformation model [13].

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