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CONTRIBUTION TO THE STUDY OF THE ENVIRONMENTAL IMPACT FROM THE FUEL CELLS AND HYDROGEN, USING THE DELPHI METHODOLOGY

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Abstract. *The evaluation of the future systems of energy supply is of paramount importance to get information of potential of probable environmental impacts of some new processes.The work has as main objective to make a forecast of the environmental impact of low and average temperature fuel cells, in the long run, analyzing all the stages of their useful life and final disposal of the materials that constitute them, using the Delphi methodology.*

Data-collecting of Life Cycle Analysis of PEMFCs (Proton Exchange Membrane Fuel Cells) evaluate the environmental impact that the new materials and processes will cause in the manufacture, operation and final disposal, after they complete the useful life The work also presents the nuclear hydrogen production methods.

The research uses the Delphi Methodology. The input data, the method to be used in the study of the future scenes as well as the results obtained from the first round of the questionnaire used by the Delphi Methodology are presented in this work.

Keywords: *Fuel cell, Environmental impact, Delphi methodology*

1. INTRODUCTION

The global warming is a fact already well established and is occurring due to the emission of greenhouse gases, especially Carbon Dioxide (CO2). In reply to the society, some potential solutions such as clean energy technologies have been developed, including conservation of energy through the increase of the efficiency and the reduction in the fuel consumption.

The fuel cells are a supply system of energy for the future, producing clean energy and being able to be used in stationary or mobile applications. The stationary applications are in small residences and in the co-generation systems. In transport, their largest application are in the automobile industry for cars or trains and even boats.

The emission of a stack alone will be really zero in cases that the Hydrogen proceeds from clean processes as electrolysis if the electrical energy used in process is non-fossil. The hydroelectric, solar and nuclear energy can be used. [1].

In the present work only the PEMFC (Proton Exchange Membrane Fuel Cells) will be analyzed.

This research has as main objective the study of the environmental impact forecast, in the long run, modifying the project and the use of new materials in fuel cell life cycle.

1. PRODUCTION OF FUELS USED IN FUEL CELLS

The chain of fuel production was thoroughly studied, and these studies the environmental impacts of these chains in some countries and applications were included. In the case of the stacks, four types of fuels are more generally used: Hydrogen, Methanol, gasoline, natural gas and, Ethanol.

Hydrogen in an energy carrier, not an energy source and therefore its production requires energy. A Hydrogen economy only is carried out if the Hydrogen is produced with sustainable, non fossil, non-greenhouse gas energy. In the Figure 1 some process used to produce Hydrogen are presented.

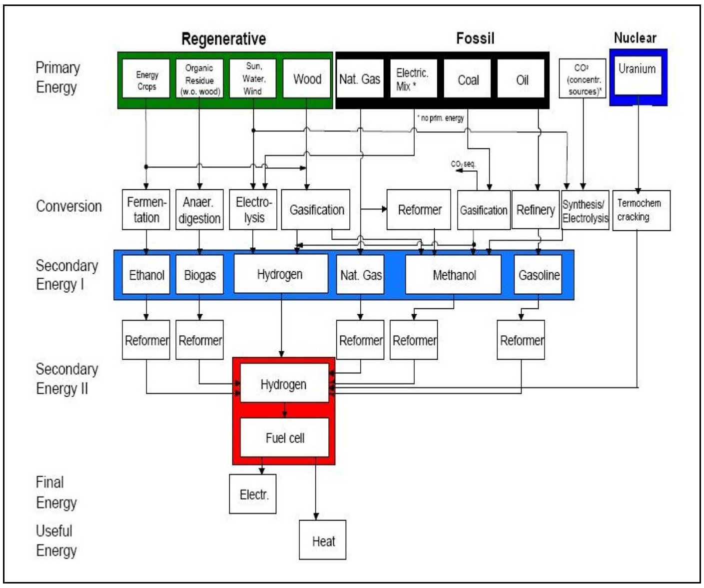


Figure 1- Hydrogen production processes [2]

Two candidates for large-scale production of hydrogen in the near future are nuclear assisted thermochemical water splitting and natural gas steam reforming.

There are 3 main alternatives to Hydrogen production nuclear assisted:

-Electrolysis of water – First is produced the electricity and then this is used in electrolysis.

-Natural gas steam reforming – Based on nuclear, but this technology is similar to natural gas case, only the heat is supplied by nuclear energy.

-Thermochemical water cracking – High temperature heat supplies energy to a chemical process to split water into its two components: Hydrogen and Oxygen.

The main difference among the three methods lies in the required coolant outlet temperature from the nuclear reactor. Electrolysis is possible with the present technology with an outlet temperature of modern pressurized water reactors (PWR). The disadvantage of this technology is that the efficiency is limited by the electrical efficiency of the nuclear power plant, around 33% [3] for PWRs and in addition there will be some loss of efficiency in the electrolysis process which reduces the overall efficiency to approximately 24% [3].

The Thermochemical water cracking is a promising and realistic option for large scale hydrogen production in the future and one of the most attractive process is the called Iodine-Sulphur (I-S) cycle. This process needs outlet coolant temperature above 850°C and therefore this implies in a new reactor technology to supply heat. A range of different technologies are expected to be able to deliver such temperatures.

General Atomics [4] performed a feasibility study and found a Helium cooled high temperature reactor most suited for the task because the required high temperature (950°C). This reactor will use Uranium as fuel with an average enrichment of approximately 13% U235, some will be 19.9% U235 and some with natural Uranium (0.71% U235).

The reactions involved in Hydrogen Production process are presented in the Figure 2: Water and heat are supplied to the process and Oxygen and Hydrogen are extracted.

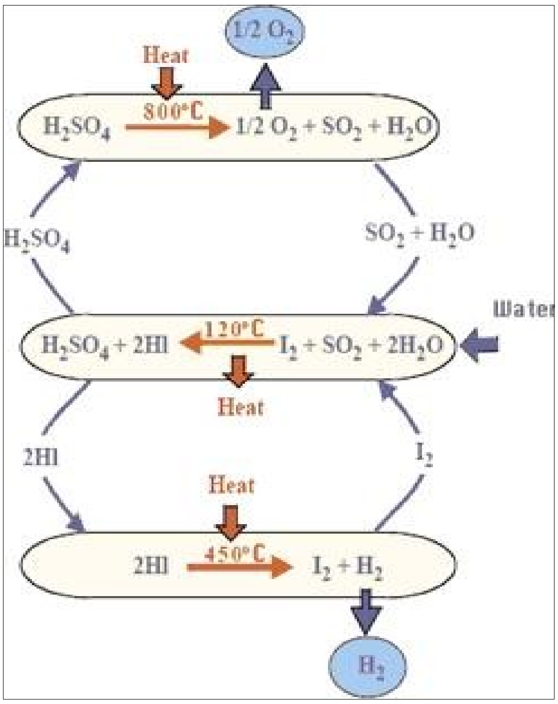


Figure 2 – Sulphur Iodine Thermochemical Water Splitting Cycle

The Figure 3 gives a simplified overview of the nuclear hydrogen producing system. In ref. [5] Soli performs a comparative environmental assessment between the hydrogen production by nuclear process and steam reforming. Life cycle assessment has been published on different process for hydrogen production using nuclear energy in reference [6], and the results are presented in Figure 4.

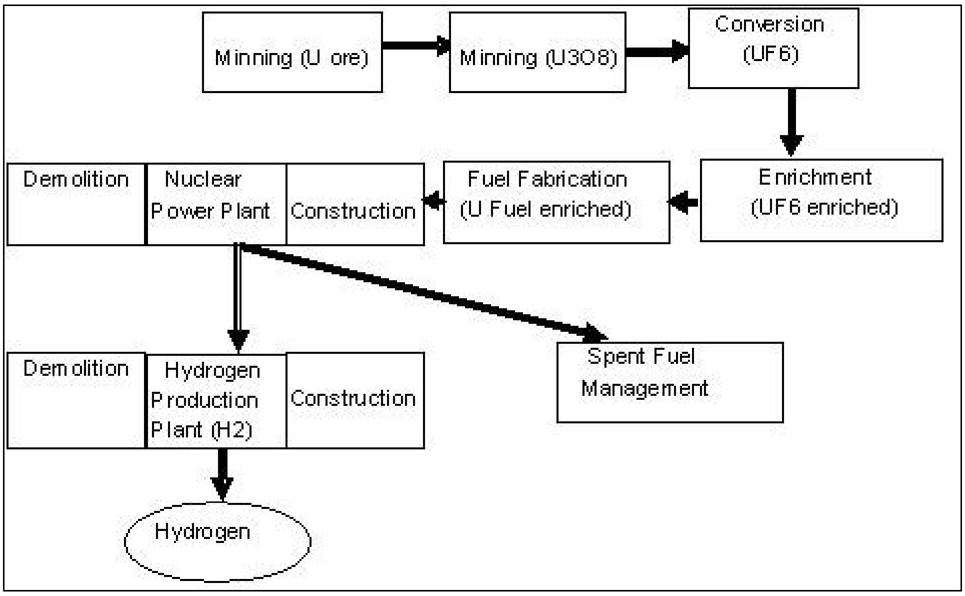
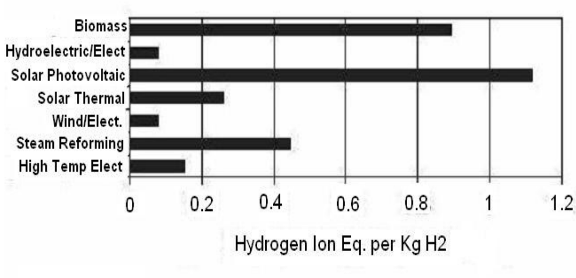


Figure 3- Overview of the nuclear hydrogen production system



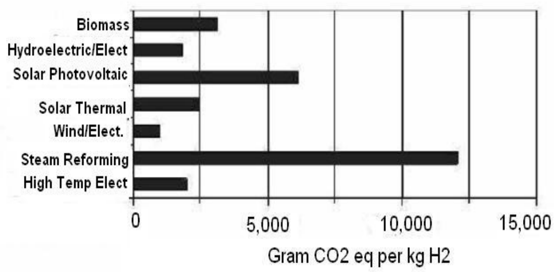


Figure 4A- H2 production greenhouse gas emissio

Figure 4B- H2 production acidification potencial

2. FUEL CELLS

The environmental impact of the fuel stacks has been studied in detail by PEHNT [6], analyzed the environmental impact of PEMFCs, during the manufacture phase, since the prospection of the raw material until the final disposal /recycling after the end of its useful life. In that study, the use of catalyst (Platinum), graphite for bipolar plates, PTFE for membrane and some other common materials were studied.

One of the materials used in the fuel cells which imply in greater environmental impact is the Platinum. According to the UK Department for Transport [7], there are significant environmental impacts associated with platinum mining and refining. These include groundwater pollution and atmospheric emissions of sulphur dioxide, ammonia, chlorine and hydrogen chloride. However these impacts are reducing, as the industry becomes more environmentally aware.

Also according to the UK Department for Transport [7], fuel cell stacks for hydrogen-fuelled cars currently use about two ounces of platinum, which represents a ten-fold reduction in loading since 1994. Further reductions are expected with an ultimate goal of about 0.2 oz per car. In comparison, auto-catalysts use about 0.05 oz platinum and 0.15 oz palladium. The carbon emitted through the mining and processing of platinum is currently about 180 kg C per ounce. This equals 360 kg for a current fuel cell car; or 36 kg for a future car with the target platinum loading of 0.2 oz. Recycling of platinum from fuel cell stacks is expected to be technically and commercially viable when there is a large market for fuel cell cars [7].

3. DESCRIPTION OF THE DELPHI RESEARCH TO BE CARRIED OUT BY SPECIALISTS IN THE AREA OF FUEL CELLS

The Delphi survey, under development, includes characteristics as to the technological topics, the selected questionnaire, specialists and the methodology for sending the questionnaires, which will be used in the two rounds of the Delphi research with scholars, company and government staff.

The Delphi survey about the environmental impact of the fuel cells, under development, is similar to the classical Delphi. In the classical Delphi the data are collected in some round numbers, and in each stage the results from the previous round up to the present procedure show some stability which, in general, results in a consensus increase. The main characteristic of classical Delphi is the anonymity, the interactions, the controlled feedback, the statistics treatment and answers stability among the respondents to a specific question. As the classical Delphi, the Delphi survey in course, allowed the anonymity because the respondents do not know the knowledge of the other participants and their answers are treated privately. Also, there will be two interactions in the survey, supplying the respondent, in the second round, with one feedback, in bar form, including the answers distribution, with the respondent answer, in the first round, so that the specialists can keep their answers or change them due to a new reading or reflexion about the question, besides including their comments in a special space designed, if considered necessary.

All the specialists were chosen looking for representing academic, industrial and governmental sectors. Besides the specialists some technological topics were chosen, but in this work only two topics will be presented. For the first group, there is also a subdivision in 4 subtopics, as detailed in Table 1.

The questionnaire used in the survey was composed of some questions, but only 10 questions is referring to this work. Evaluating the answers, it is noticed that an auto-qualification was done; therefore the respondents chose from data bases and crossed indication of specialists in the area of fuel cells and hydrogen production.

The first question to be answered in the questionnaire, for each of the technological group age, referred to the level of knowledge of the respondent on the topic in question, whose options of answers were shown in Table 2. This auto-evaluation of the participants, allowed that the answers were separated in function of specialty level of the respondent, making possible the evaluation of its influence in elapsing the Delphi surveyed.

At last the questions had been sent to the academic, industrial and governmental specialists. All Delphi questionnaires were done using Questionpro software and the participants had received by email an invitation with a link for accessing the questionnaire.

Table 1 -Groups and topics of the research

Group	Description	
Group 1	Environmental impact due to PEM Fuel Cell production and operation	Catalyst Bipolar plates Membrane Other materials(Plastics, steel, aluminum, phenolic resin, carbon black, etc)
Group 2	Environmental impact due to Hydrogen production	

Table 2-Options for auto evaluation of the participants

Specialization level	Description
EXPERT	You assign yourself if considered inside the group of people that are currently dedicated to this topic deeply.
KNOWLEDGEABLE	You assign this classification in the following cases: a. If you are becoming an expert, but lack some experience to dominate the topic. b. If you were an expert in the topic some time ago, but you consider at the moment out-of- date in the topic. c. If you work in a correlated area, but contribute regularly with subjects related to this topic.
FAMILIARIZED	You designate if you know the majority of the used arguments in the quarrels on the topic, you read about the subject, and have an opinion about it.
UNFAMILIAR	You assign this option if you are not fit in none of the previous categories.

3.1. Results of the First Round of the Delphi Consultation

The number of participants was considerable (approximately 4500), but the number of respondents was of 123, from 26 different countries. The Figure 5 shows the distribution graphic of the respondents by continent.

The first part of the questionnaire is related to the forecast of ambient impact for the PEM Fuel Cell and the results are presented in the Figure 6 to 7.In Figure 6, answers to the expectations of relative substitution or modification of the PEMFC catalyst, specifically the question mentioned only for catalysts from group PGM. In Figure 7, the results show the forecast of the PGM catalysts recycling group, used in PEM and PAFC.

In Figure 8, is the forecast of environmental impact, in the long run, considering the local production and the production far from the consumer are presented.

The results about forecast of reduction in environmental impact due to the use of new processes and new raw materials is in Figure 9. In Figures 10 and 11 they are the results of forecast for environmental impact of different known for hydrogen production. In Figure 12, the foreseen results of ambient impact, for a long stated period, considering different source types for hydrogen production.

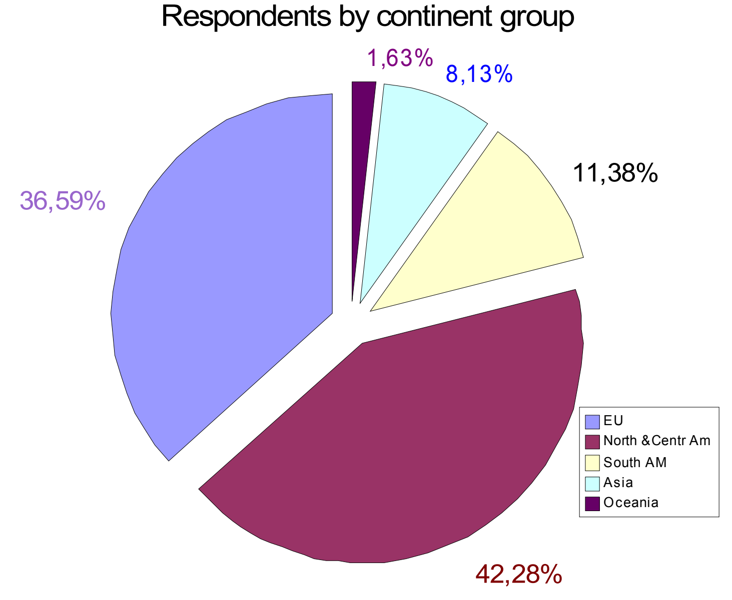


Figure 5. Respondents by continent group

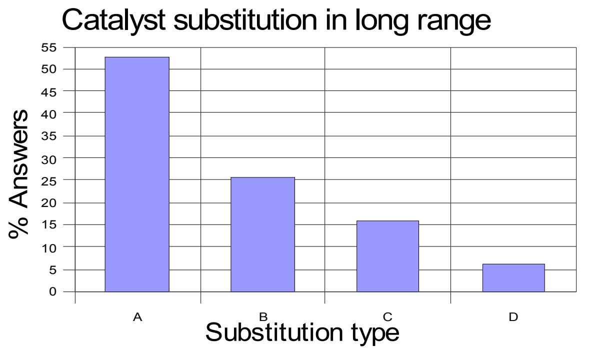


Figure 6. Forecast for PGM catalyst substitution, in long range

A-Substitution of the catalysts will occur
B-Substitution of the catalysts will not occur but there will be a reduction in the concentration through the mixture with other materials (with lesser environmental impact)
C-Substitution of the catalysts will not occur, but there will be a great reduction in the concentration
D-Substitution of the catalysts will not occur and there will be a small reduction in the concentration

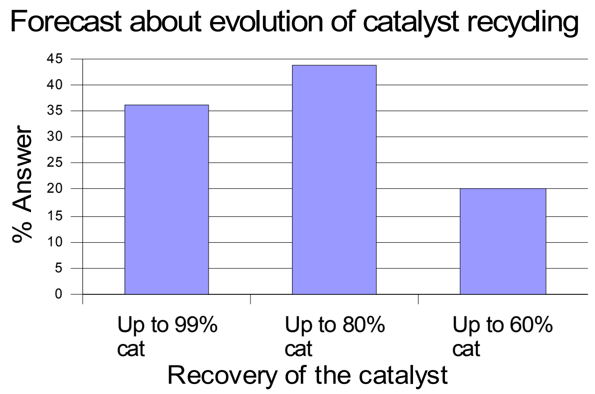


Figure 7. Forecast about evolution of catalyst (PGM) recycling

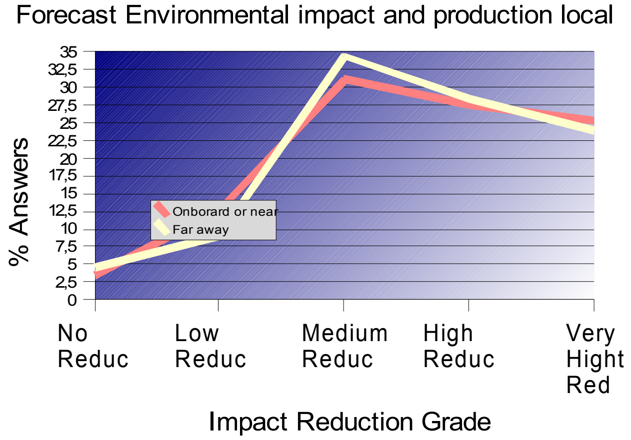


Figure 8. Forecast of reduction in environmental impact and production local (far away or onboard /near consumption place)

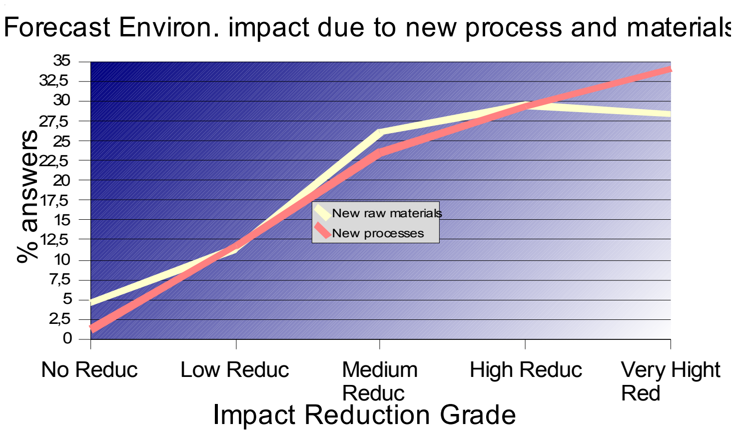


Figure 9. Forecast of reduction in environmental impact due to the use of new processes and new raw materials

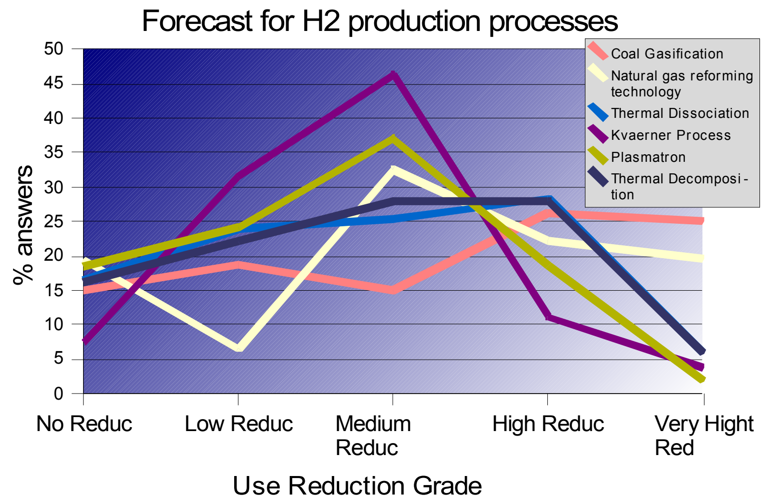


Figure 10. Forecast for someH2 production processes

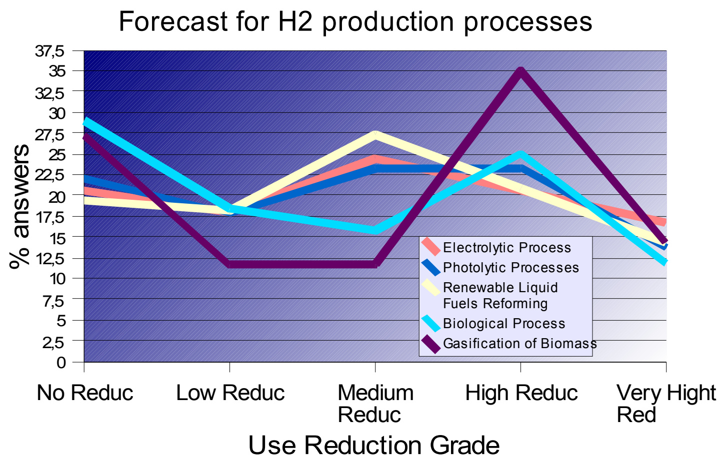


Figure 11. Forecast for some H2 production processes

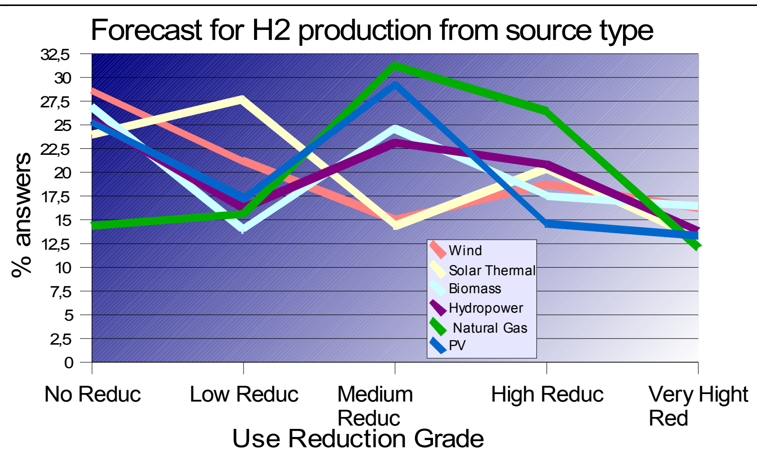


Figure 12. Forecast for H2 production by source type.

4. CONCLUSIONS

As the research made possible that the respondent skipped the questions not wished to answer, it was observed that most respondents did not answer the questions for which they considered not to have much knowledge on the subject.

-The respondents knowledge level didn't appear to influence the answers.

-With reference to the catalyst of the group of metals PGM, a great part of the respondents believe in its substitution, in the long run, despite the studies in this area do not demonstrate advances yet.

-The position of the recycling, with recovery of more than 80% of metals PGM, is seen as certain for more than 70% of the respondents.

- The reduction level in the environmental impact, in the long run, for the studied types of fuel cells, is expected to be only medium.

This work will continue with the second round of the questionnaire when will be verified if the consensus was reached .

The life cycle emissions data, obtained in bibliography, indicates that the high-temperature electrolysis process is far superior to the conventional steam-reforming process for hydrogen production with respect to the global warming potential and acidification potential. The environmental impacts of the process are comparable to those of the solar thermal process.

In the next round of the questionaire will be included questions about the hydrogen nuclear process production.

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