# CONTRIBUTION TO FORECAST OF ENVIRONMENTAL IMPACT, IN THE LONG RUN, FOR FUEL CELLS OF LOW AND AVERAGE TEMPERATURE USING THE DELPHI METHODOLOGY

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## ABSTRACT

*Assessing future energy systems is of major importance for providing information on potential environmental awareness of some life cycle stages of innovative technologies, for determining competitive advantages compared to conventional technologies and for developing scenarios of future.*

*Today, intense activity of P&D in cells is verified in fuel cells, practiced in centers of research, university, and laboratories of great companies, what it seems to indicate the use in wide scale of these generating right-handers of energy, before long.. The work has as main objective, in the long run, to make a forecast of the environmental impact of low and average temperature full cells, analyzing all the stages of their useful life and final disposal of the materials that constitute them, using the Delphi methodology.*

*The results of the environmental impact evaluation of the main materials used in the stacks are presented, considering their manufacture, operation and final disposal after their useful life ends.*

**Keywords**: Delphi method, environmental impact, fuel cells

## INTRODUÇÃO

The global heating is a fact already well -established and is occurring due to the emission of gases, especially the Carbon dioxide (CO2). In reply to the society need for a clean energy technology, some potential solutions 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. Depending on the type of stack, the stationary applications they can be included are in small residences and in the co-generation of average transport. In transport, their largest application is in the automobile industry for utilitarian cars or trains and even boats.

The emission of a stack alone will be really null in cases that the Hydrogen proceeds from clean processes as electrolysis, affected by the photovoltaic conversion. But currently this process is still economically impracticable. The hydroelectric energy can also be used. [1].

In the present work the following types of fuel cell will be analyzed: PEM (Polymer Electrolyte Membrane ), PAFC ( Phosphoric Acid Fuel Cell) and MCFC ( Molten Carbonate Fuel Cell).

This research main objective was to study the environmental impact forecast, in long range, due to the development, modifying or transformation in the project and the use of new materials.

## METHODOLOGICAL ASPECTS

The evaluation problems of future technologies are associated with the development of products in initial period of experiment. The problem, common to many products of strategic importance, it is the discrepancy between the importance of the technological evaluation of products in initial development, when many options of development exist, and the knowledge state on the systems of the product,. (Hungerbuhler, 1999 cited in [2]).

In the present work the Delphi Methodology was chosen to evaluate the ambient impact of the stacks in the long run (a horizon of 20 years).

The Delphi technique has the objective to evidence the convergences of opinions and to detach a certain consensus on very concrete subjects, using specialists interrogation by means of successive interactive questionnaires that preserve the anonymity in the answers. The most common objective in the research using the Delphi is to help the clarifications of the specialists on zones of uncertainties with the objective of assisting in the making of future decisions [3].

## PRODUCTION OF FUELS USED IN FUEL CELLS

The chain of fuel production was thoroughly studied, and there are some studies about the environmental impact of these chains in some countries and applications.

In the case of the stacks, four main types of fuels are more generally used: Hydrogen, Methanol, gasoline, natural gas and, in the case of Brazil, the case of ethanol is also studied.

Hydrogen can be made from fossil fuels, renewable fuels or by electrolysis of water. The more common process uses the fossil fuels and causes the increase of the global warming.

If the fuel is produced from renewable sources of energy and if the stacks possess high efficiency, this can mean a great reduction in the emission of gases that cause pollution and also reduction of the fossil fuel consumption.

Some factors are of great relevance for the analysis of the environmental impact:

- the primary energy associated with the consequences in the global warming and the use of abiotics sources. For example: the raw oil conversion for natural gas causes reduction in the $CO_2$ intensity because the relation Hydrogen for Carbon is greater in the natural gas. Of course, the use of renewable primary energy would diminish even more this impact along the production chain.

- the efficiencies and impacts of the processing are also very important. Currently, the fuels based on oil have an energy efficiency of ~90% production. The natural gas steam altered for Hydrogen production and methanol, respectively, are less efficient. In this case, it is necessary to distinguish between the gasoline production in the conventional refineries and the new plants (new units constructed to deal with the increase of the demand of a specific product and that show a significantly better performance).

- the third important factor in the ambient evaluation are the previous and posterior chains to the process, e. g., the different requirements for transport and distribution of fuels. The possibility of use of linking products (e. g. carbon black in the Hydrogen manufacture in the Kvaern process) can reduce the ambient impacts in case market for by-products exists.

## FUEL CELLS

The environmental impact of the fuel stacks has been studied in detail by PEHNT (2002), analyzing the environmental impact of the fuel cell type PEM, 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 [4], 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 [4], 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. Recycling rates are likely to be up to 98% as it is easier to recycle platinum from a fuel cell stack than from an auto-catalyst[4].

## 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 are 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, *in*cluding 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 reflections 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, 4 technological topics were chosen. These topics enclosed four main groups of performance. For the first 3 groups, there is also a subdivision in 4 subtopics, as detailed in Table 1.

**Table 1** -Groups and topics of the research

| *Group* | *Description* | |
|---|---|---|
| 1 | Environmental impact due to PEM Fuel Cell production and operation | Catalyst<br>Bipolar plates<br>Membrane<br>Other materials(Plastics, steel, aluminium, phenolic resin, carbon black, etc) |
| 2 | Environmental impact due to Phosporic Acid Fuel Cell production and operation | Catalyst<br>Bipolar plates<br><br>Other materials(Plastics, steel, aluminium, phenolic resin, carbon black, etc) |
| 3 | Environmental impact due to Molten Carbo-nate Fuel Cell production and operation | Catalyst<br>Bipolar plates<br><br>Other materials(Plastics, steel, aluminium, phenolic resin, carbon black, etc) |
| 4 | Environmental impact due to Hydrogen production | |

The questionnaire used in the survey was composed of 13 questions. 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 groups 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.

**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. |
| KNOWLED-GEABLE | you assign this classification in the following cases:<br>a.If you are becoming an expert, but lacks some experience to dominate the topic.<br>b.If you were an expert in the topic some time ago, but you consider at the moment out-of- date in the topic.<br>c.If you work in a correlated area, but contribute regularly with subjects related to this topic. |
| FAMILIARI-ZED | you designate if you know the majority of the used arguments in the quarrels on the topic,you read about the subject, and has an opinion about it. |
| UNFAMILIAR | You assign this option if you are not fit in none of the previous categories. |

At last, the 13 questions, approaching 4 technological topics, 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.

## 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 different countries.

The Figure 1 shows the distribution graphic of the respondents by country and the Figure 2 shows the distribution of the respondents by continent.

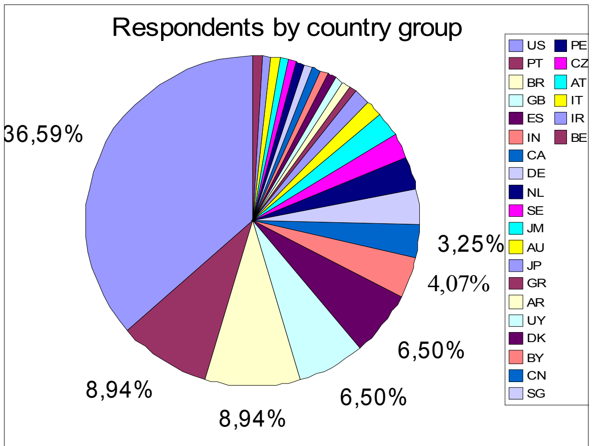


**Figure 1.** Respondents by country group

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 3 to 8. The results obtained to the degree of reduction of the ambient impact in the production, operation, maintenance and final disposal of the PEMFC are in Figure 3, separated by component.And in Figure 4, the results only for the PEMFC membrane are presented, with separate results for the qualification of the respondent and the variance analysis showing that the reply qualification was independent of the respondent.

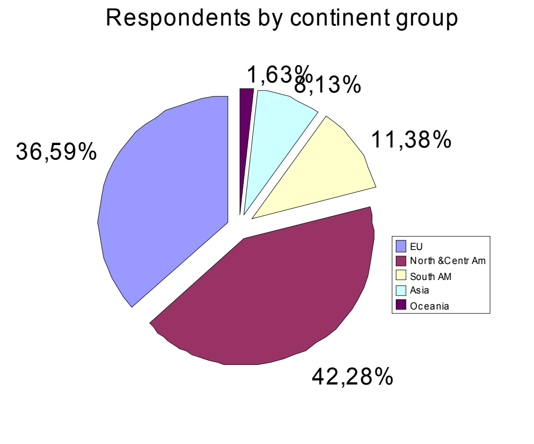


**Figure 2.** Respondents by continent group

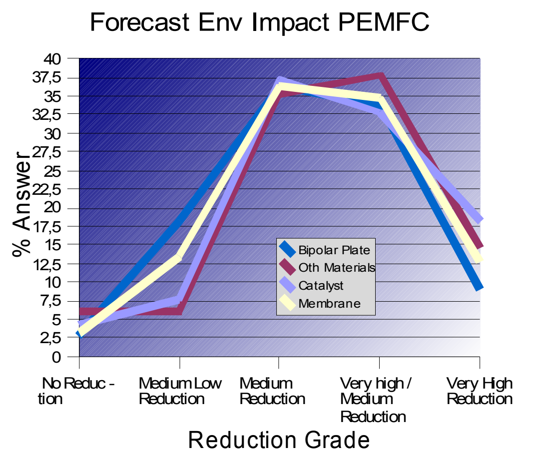


**Figure 3.** Reduction grade of some PEMFC components

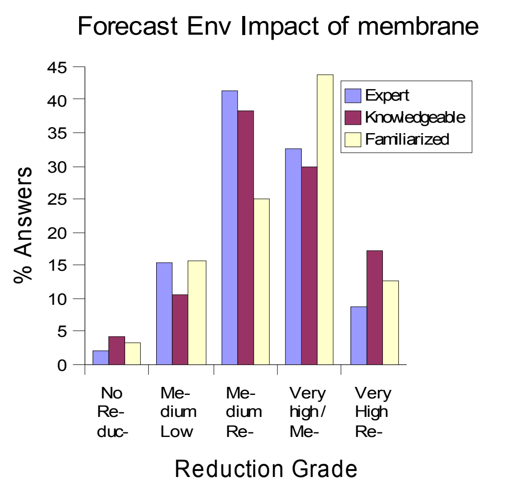


**Figure 4.** Reduction grade in environmental impact for membrane component in PEMFC, by respondent qualification

In Figure 5, the results of expectation of evolution for another type of project for the PEMFC are shown, where the ambient impact can be diminished with the substitution or even abolition of its main parts.

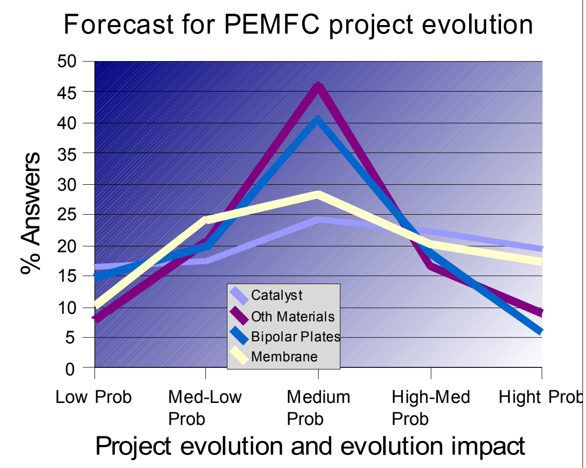


**Figure 5.** Probability grade of environmental impact from new project in PEMFC with abolition or substitution of some main items

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.

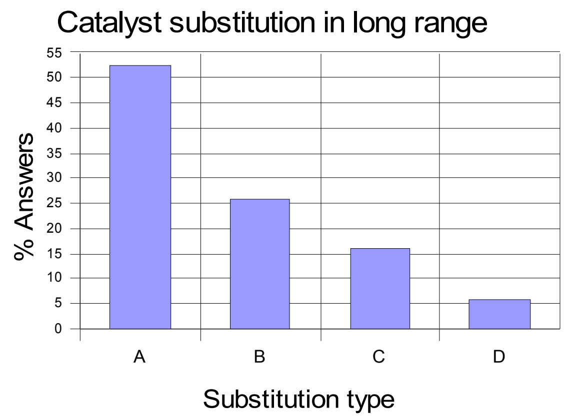


**Figure 6.** Forecast for PGM catalyst substitution, in long range

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 big reduction in the concentration

D-Substitution of the catalysts will not occur and there will be a small reduction in the concentration

In Figure 7, the results show the forecast of the PGM catalysts recycling group, used in PEM and PAFC and, in Figure 8, the correspondent results of the reduction forecast for the amount used in stacks PEM and PAFC of the catalysts.

The answers to the specific questions for the PAFC are in Figures 9 and 10. In Figure 9, the results of the reduction degree of the ambient impact of the diverse items composing the PAFC are presented.

The correspondent answers to the specific questions for the MCFC are in Figures 11 to 13. In Figure 11, the results forecast of the reduction degree of the ambient impact concerning the production, operation, maintenance and final disposal of the MCFC.

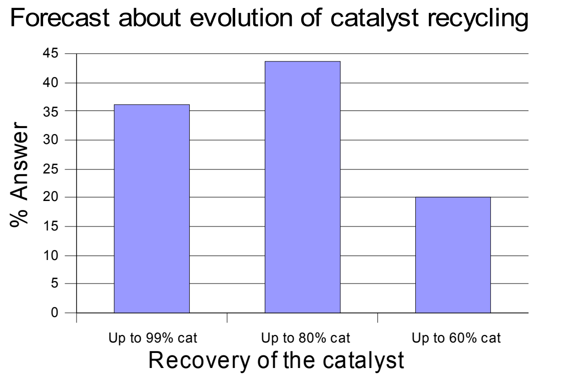


**Figure 7.** Forecast about evolution of catalyst (PGM) recycling

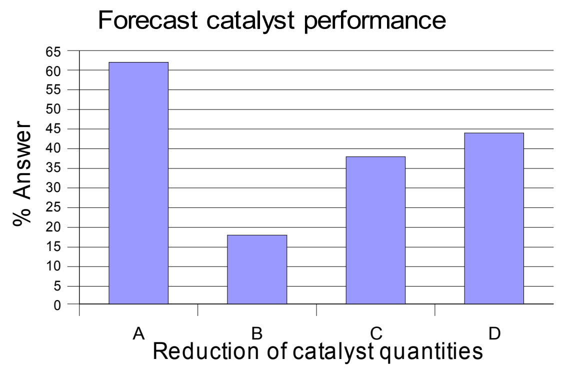


**Figure 8:** Forecast for catalyst (PGM) performance in PEMFC e PAFC

A- A medium evolution with reduction of metals up to 400%.

B- A very big evolution with reduction of metals up to 1200%.

C- A big evolution with reduction of metals up to 700%.

D- A small evolution with reduction of metals up to 100%.

In Figure 12, the forecasts for the results of expectation of evolution for another type of MCFC project are shown, where the ambient impact can be diminished due to the substitution or even abolition of its main components.

In Figure 13, the substitution/abolition of catalysts in the MCFC are shown with the result of the question on expectations for ambient impact.

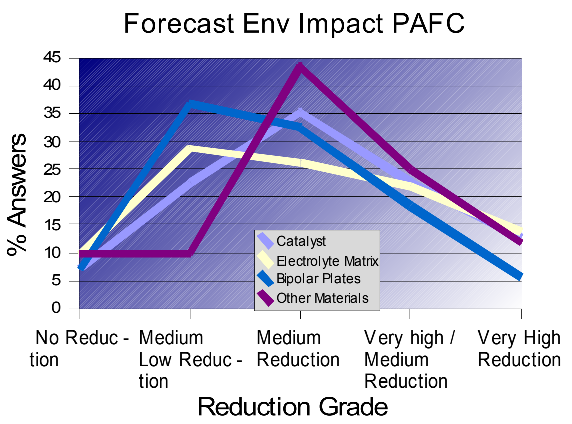


**Figure 9.** Forecast of reduction grade of environmental impact in PAFC

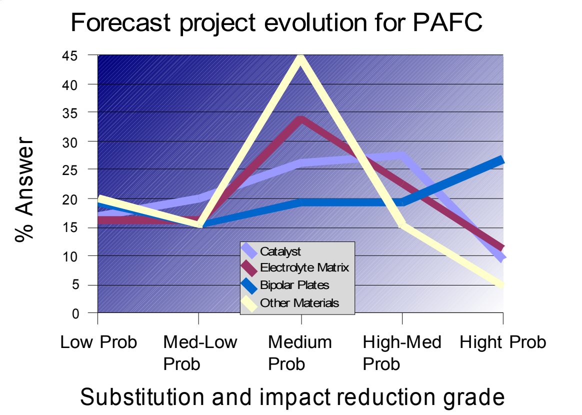


**Figure 10.** Probability grade of environmental impact from the new project in PAFC, due to new project.

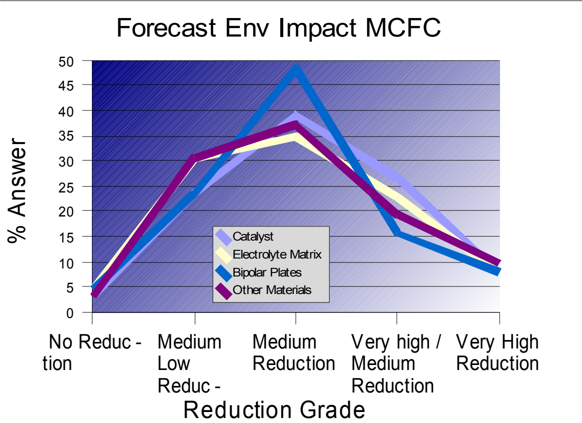


**Figure 11.** Forecast of reduction grade of environmental impact in MCFC

The results of the environmental impact forecast, in the stage of hydrogen production are in figure 14 to 18.

In Figure 14, is the expectations of environmental impact, in the long run, considering the local production and the production far from the consumer are presented.

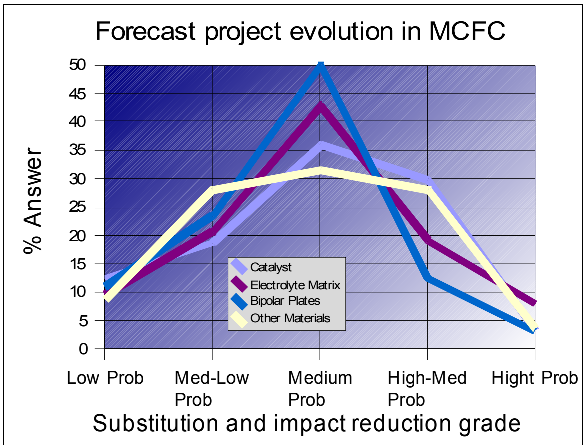


**Figure 12.** Probability grade of environmental impact from substitution of current materials by new materials in MCFC

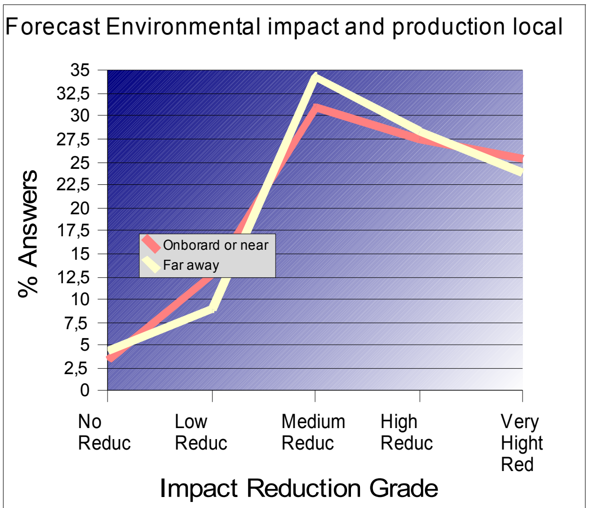


**Figure 14.** Forecast of reduction in environmental impact and production local (far away or onboard /near consumption place)

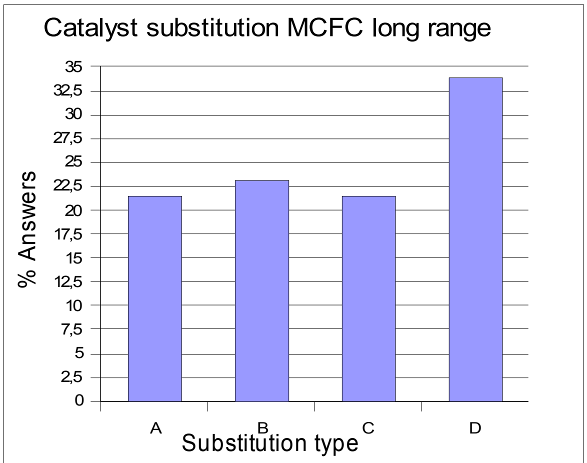


**Figure 13.**Forecast catalysts substitution in long range for MCMFC
A-Substitution of the catalysts will occur
B-Substitution of the catalysts will not occur but there will be a reduction in the concentration through the mixture with other materials (with lesser environmental impact)
C-Substitution 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

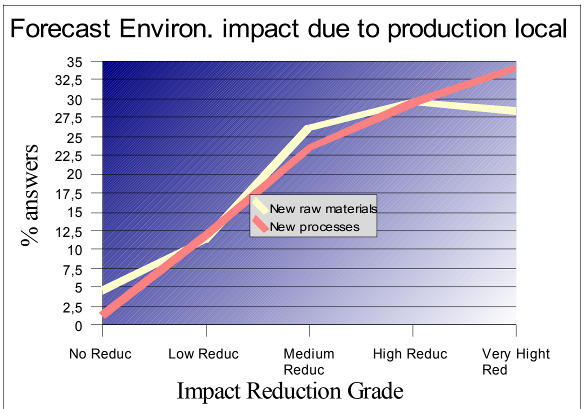


**Figure 15.** Forecast of reduction in environmental impact due to the use of new processes and new raw materials

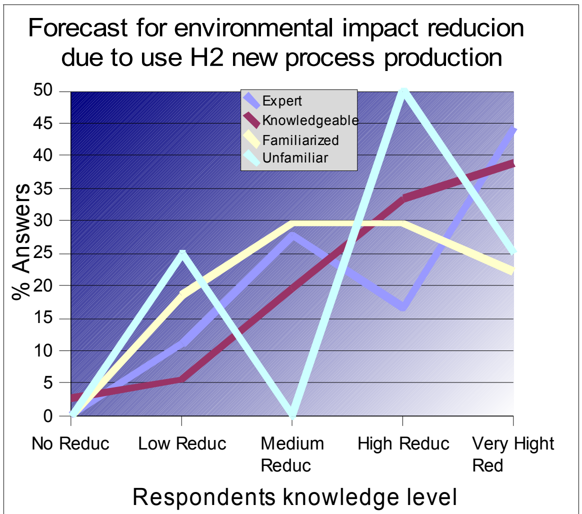


**Figure 16.** Forecast of reduction in environmental impact due to the use of new processes (figure. 15) according to respondents knowledge level.

The results about forecast of reduction in environmental impact due to the use of new processes and new raw materials is in Figure 15. And in Figure 16 is the forecast about use of new process presented in Figure 15, according to respondent knowledge level.

In Figure 16 the answers for qualification level and the results obtained for ambient impact from the Hydrogen production for new processes.

In Figures 17 and 18 they are the results of forecast for environmental impact of different known for hydrogen production.

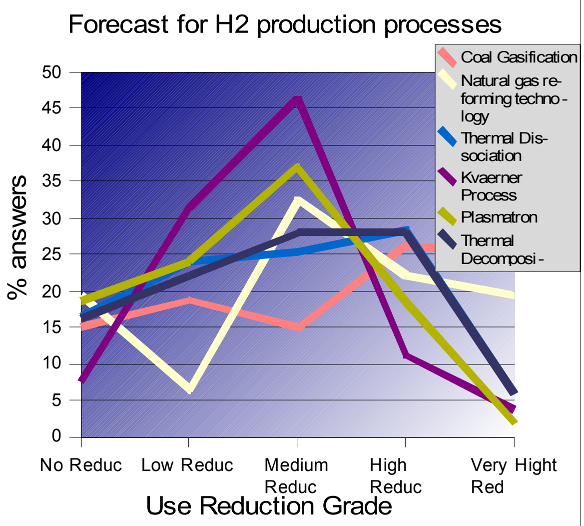


**Figure 17.** Forecast for someH2 production processes

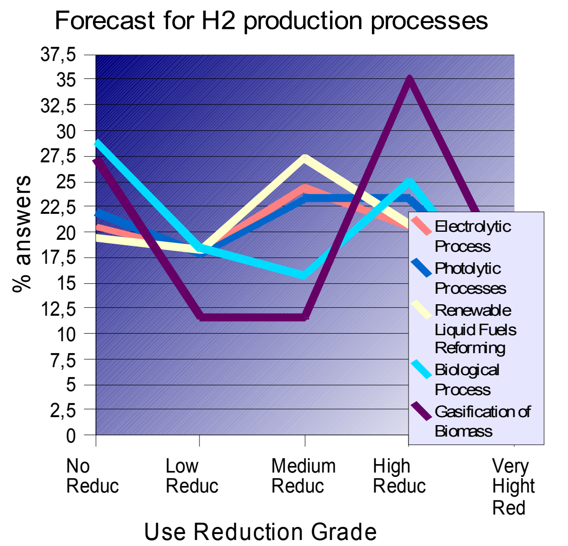


**Figure 18.** Forecast for some H2 production processes

In Figure 19, the foreseen results of ambient impact, for a long stated period, considering different source types for hydrogen production.

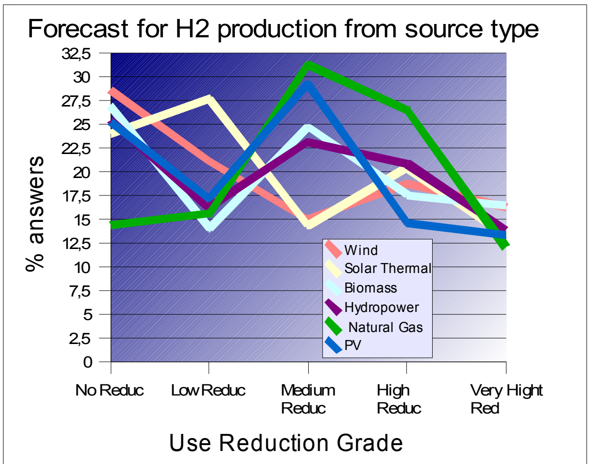


**Figure 19.** Forecast for H2 production by source type.

## CONCLUSION

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 most important findings are:

-The final stage of the stack disposal seems to be less studied since the recycling technology is still not solid in relation to the materials that will be really used, when the technology allows a process of production in wide scale. The material that causes more concerns seems to be the Platinum, since it is a precious metal.

-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 .

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