LIFE CYCLE ASSESSMENT OF HYDROGEN ENERGY PATTERN

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1. Introduction

Since the last decades, transportation sector is a priority for environmental research. Indeed, it is the most impacting sector because it involves greenhouse emissions and fossil resources exhaustion. The Group of "Ecole des Mines" (GEM), in France, carries out studies concerning clean and renewable energies for this sector with the "H2-PAC" project.

The GEM with four teams studies energy patterns for transportation sector and more particularly hydrogen pattern. The four teams of the GEM work each one on a process of this pattern. More precisely, the team of Albi studies biomass gasification in order to product synthesis gas. The team of Nantes studies purification of this gas to obtain pure hydrogen and hydrogen storage on activated carbon. The team of Paris studies fuel cell use and especially Polymer Exchange Membrane Fuel Cell. Finally, the team of St Etienne evaluates this pattern along its life cycle from an environmental point of view.

This paper presents this environmental evaluation which is realized according to Life Cycle Assessment (LCA) methodology.

2. Life Cycle Assessment : an environmental evaluation tool

To carry out an environmental evaluation of this system, the GEM had to choose the most suitable tool according to the context and the finalities of the study, the nature and the complexity of the system. Taking into consideration these various criteria, it appears that the most relevant tool is Life Cycle Assessment (LCA) for an ecodesign approach.

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LCA is a tool recently standardized by the ISO between 1997 and 2006 [1-4]. It makes it possible to identify and quantify environmental aspects and impacts, throughout the life cycle of the systems of the product. Thus, with each life cycle stage, associated emissions and environmental impacts are quantified. The existence of pollution transferred into space and/or in time and the significant flows or stages are identified.

LCA is carried out neutrally by an external expert. The results of LCA are used in a decision-making process. In the aim of communicating the results to the public, a peer review must be carried out in order to check the study conformity compared to the standards [1-4].

LCA is an iterative method which is composed of four following stages:

• goal definition and scoping;
• inventory analysis;
• impact assessment;
• improvement assessment.

3. LCA of hydrogen pattern

This paper follows the ISO methodology [1-4].

3.1 Goal definition and scoping

Goal definition and scoping is an essential stage for the realization of a LCA. It makes it possible to determine the goals, the nature of the system, the functional unit and the system boundaries. This stage must be carried out according to the standard ISO 14041 recommendations [2].

The GEM determined two finalities for the study of hydrogen pattern :

• to select an energy pattern for transportation sector : determination of the less or the most "impacting" pattern on the environment. It is a question of determining the position of hydrogen patterns (direct hydrogen and bioethanol-hydrogen) compared to gasoline pattern;

• to improve hydrogen pattern developed by the GEM : identification of the weak points (life cycle stages) of this pattern from an environmental point of view.

After having determined the aims of this LCA, the scope of the study must be defined. It is a matter of clarifying the nature of the system, the functional unit and the system's boundaries have to be fixed.

The studied system is small car motorization. For this function, hydrogen pattern has been studied. This pattern will have to be compared with gasoline and bioethanol patterns. This paper only presents the results for hydrogen patterns.

For this LCA, a functional unit (FU) has been defined. The functional unit (FU) is the quantification of the function. The functional unit is "a reference on which inputs and outputs are dependent" [1]. For that, it must be clearly defined, measurable, in adequacy with the study finalities and reflect the current performances in the concerned sector (lifespan, yield, autonomy…). So the functional unit is the consumed fuel quantity to cover 150.000 km during 15 years (it is the average lifespan of internal combustion engine).

3.2 Inventory analysis

This step consists to obtain data for all life cycle stages [2]. Gathered data come from different sources like GEM teams, industrials and literature. This heterogeneity does not allow to estimate data uncertainty. The flow chart, which is realized thanks to these data, allows to evaluate impacts for this pattern.

3.3 Impacts evaluation

This step is the key point of the LCA. Indeed, thanks to inventory data, we are able to quantify impacts for each stages of the studied life cycle [3]. For this study, we use LCA software, Gabi 4. After the keyboarding of data, Gabi 4 calculates impacts indicator for each stages of life cycle of hydrogen pattern. Different models exist to evaluate impacts. We have chosen two of them : CML 2001 and Ecoindicator 99. These models are the most use since they represent two different schools [5]. Indeed, CML 2001 is a classic method which tries to model impacts effects whereas Ecoindicator 99 is a method which tries to model impacts damages. These two models are used to check results reliability. However, as soon as this reliability has been checked, the method which will be used to examine the results is CML 2001 method (Table 1).

For each impacts category, the two most impacting processes for hydrogen pattern are identified according to CML 2001 method. When the second process is not present on this table, it means that the first process represents more than 90% of the impact. Actually, a great majority of impacting processes contributes more than 90% to the impact. The process of PEMFC production is clearly the most impacting process for this pattern. However this process is not studied by the GEM and is not sufficiently known. So it seems to be difficult to suggest some improvements.

Table 1

The two most impacting process of hydrogen patterns according to CML 2001 method

	First process	Second process
Fossil resources exhaustion	Diesel refining 87%	Electricity production 11%
Acidification	PEMFC production 99%	
Eutrophication	PEMFC production 96%	
Aquatic ecotoxicity	PEMFC production 61%	Electricity production 28%
Greenhouse effect	PEMFC production 99%	
Human toxicity	PEMFC production 99%	
Marine aquatic ecotoxicity	PEMFC production 99%	
Ozone layer reduction	Diesel refining 93%	
Photochemical pollution (SMOG)	PEMFC production 99%	
Radiation radioactive	Copper production 82%	Diesel refining 18%
Terrestrial ecotoxicity	Diesel refining 49%	Electricity production 41%

This process hides the other processes which contribute to impacts. So we decide to study results of impacts evaluation without the process of PEMFC production (Table 2).

Table 2

The two most impacting process of hydrogen patterns according to CML 2001 method without PEMFC production process

	First process	Second process
Fossil resources exhaustion	Diesel refining 87%	Electricity production 11%
Acidification	Hydrogen transport 75%	Electricity production 12%
Eutrophication	Carbon activation 91%	Pressure Swing adsorption 7%
Aquatic ecotoxicity	Electricity production 73%	Diesel refining 19%
Greenhouse effect	Hydrogen transport 24%%	Electricity production 3%

Human toxicity	Electricity production 49%%	Diesel refining 22%
Marine aquatic ecotoxicity	Electricity production 92%	Diesel refining 6%
Ozone layer reduction	Diesel refining 93%	
Photochemical pollution (SMOG)	Pressure swing adsorption 20%	Hydrogen transport 14%
Radiation radioactive	Copper production 82%	Diesel refining 18%
Terrestrial ecotoxicity	Diesel refining 49%	Electricity 41%

3.4 Interpretation

This last step of LCA allows to analyse results and to suggest some improvement means for stages which present important impacts [4].

The process of PEMFC production contributes to seven impacts out of eleven. This process is composed of raw materials extraction, PEMFC manufacture and necessary energy. The transport of raw materials is not taken into account. The PEMFC process is not developed by the GEM. The team of Paris works just on its use. So it seems difficult to suggest some improvements to reduce these impacts because of bad knowledge of this process.

The process of diesel refining contributes to three impacts in an important way. This process allows the goods carriage. It is just possible to suggest reducing distance of transport between hydrogen production places and distribution places. For the moment, the sustainable distance is not yet evaluated. For electricity process, it is possible to advise to improve energetic yield and/or to develop renewable energy production on production site.

In an eco-design approach, it is possible to act on two processes : carbon activation (a step of activated carbon production) and Pressure Swing Adsorption process (a step of synthesis gas purification after gasification). For these processes, we can suggest filters installation and/or the use of gas in the process. More specifically, for activation carbon, it seems relevant to think about another adsorbent or another hydrogen storage mode like compression or liquefaction.

4. Conclusions

This LCA takes its place in “H2 – PAC” GEM project. The purpose of it is to select an energy pattern for transportation sector and to improve hydrogen pattern which is developed by the GEM. Three patterns have to be compared for an equivalent function : gasoline, bioethanol and hydrogen patterns. Only hydrogen pattern is presented in this paper.

Inventory step has been realized with many difficulties because of the lack of GEM reliable and available data.

After this inventory, impacts evaluation has been carried out according to two characterisation methods : CML 2001 and Ecoindicator 99. After the check of results reliability, only CML 2001 method is used for the study.

Results highlight the most impacting process which is PEMFC production for hydrogen and bioethanol patterns. This process is not developed by the GEM, so it is difficult to advise some improvements. Other processes present impacts for the two patterns such as diesel refining, electricity production, and fuel transport (fuel is bioethanol or stored hydrogen on activated carbon). For these processes, we advised respectively to improve energetic yield and to reduce distance transport.

Two other processes can be improved : activation carbon and Pressure Swing Adsorption with thanks to filters installation or gas reuse. The weak point of this pattern, according to environment and technology, seems to be hydrogen storage because of its severe conditions of temperature and pressure.

These final results will be compared with gasoline and bioethanol patterns results in order to determine which the most impacting pattern is.

REFERENCES

[1]. *ISO*. 2006. 14040 Environmental management - Life cycle assessment - Principles and framework. 28 p.

[2]. *ISO*. 1998. 14041 Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis. 28 p.

[3]. *ISO*. 2000. 14042 Environmental management - Life cycle assessment - Life cycle impact assessment. 24 p.

[4]. *ISO*. 2000. 14043 Environmental management - Life cycle assessment - Life cycle interpretation. 26 p.

[5] *K. Kahlifa*. 2002. Analyse du Cycle de Vie – Méthodes d'évaluation des impacts. Techniques de l'ingénieur. 20 p.