Design and Validation of a Methodology for the Elaboration of Technological Maps Applied to Fuel Cells

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ABSTRACT

This article reflects the current stage of progress in the project "Determining Technological Trends in Energy Generation." At first, it was oriented towards finding out those trends by employing such tools as the scientometric community had proved and accepted as effective for getting reliable results. Because a documented methodological guide for this purpose could not be found, the decision was made to reorient the scope and aim of this project by changing the degree of interest in pursuing the objectives. Therefore, it was decided to propose and implement a novel guide from the elements and techniques found in the available literature. This article begins by explaining the elements and considerations taken into account when both implementing and applying this methodology, and the tools that led to the implementation of a software application for patent revision. Univariate analysis helped recognize the technological leaders in the field of energy, and steered the way for a multivariate analysis of this sample, which allowed for a graphical description of the techniques of mature technologies, as well as the detection of emerging technologies. This article ends with a validation of the methodology as applied to the case of fuel cells.

1. CONCEPTUALIZATION OF TECHNOLOGICAL BENCHMARKING

This task refers to "the organization making the continuous, systematic, organized effort to observe, gather, analyze, and accurately spread and recall information about the facts of its economic, technological, social or commercial environment which are relevant to it due to their ability for signaling an opportunity or a threat for it" (Palop and Vicente, 1999). The cited authors pose "what" and "how" as the two key questions for starting any benchmarking project. Escorsa (1998) proposes to obtain from technological maps information about what it is occurring in a specific technological area: subjects under research, the lines of research currently emerging, leading research companies and teams, among other aspects.

2. METHODOLOGY

2.1. Representativeness. This process of patent revision is taken as a census, because all of the individuals (patents) having the characteristics of the object of study are taken into account. The patents analyzed in this study were selected from the United States Patent Office database, freely accessible via internet at http://www.uspto.gov.

Table 1. Words excluded from the study.

a	as	for	may	than	when	about	at	from	more	that	which
above	be	has	not	the	while	also	being	in	of	then	with
an	between	into	or	thereby	within	and	by	is	other	these	without
any	can	it	so	this		are	each	its	such	to	

Table 2. Sample of some words considered synonyms

WORD	WORD	WORD	WORD	WORD	WORD
		providing	provides	provided	provide
production	product	producing	produces	produced	produce
				processing	process
			including	includes	include
generator	generation	generating	generates	generated	generate
			converter	gases	gas
				conversions	conversion
				controls	controlling
controllers	controller	controlled	controllably	controllable	control
				anodes	anode

2.2. Patent selection. The study was limited to the innovations generated in the last five years. In line with this criterion, the selected patents have an application date between January 1st, 2000 (01/01/2000) and July 13th, 2005 (13/07/2005). Dates selection was done based on previous work in this area available to compare results. The second criterion consisted in that the patents should include in any field the keywords selected by the research team. These were the words *biomass, energy, and generation.* The combinations of these words resulted in three database queries with the criteria: *biomass; energy and generation,* and lastly *energy and biomass.*

2.3. Storage. Seeking ease of storage, formatting and further processing, the decision was made to save only the abstract of the patents, because this allowed to perform the study with minimum loss of non-representative information. This is justified in the fact that the information under study is present in both the abstract and the full text of a patent. Two tools of the *Microsoft Office* suite were employed for storage and depuration of the initial information: *Microsoft Word* and *Microsoft Excel.* They were chosen because of their relatively low cost and high penetration in the Colombian workplace. Storage in word processor format was temporary and followed two reasons: the difficulty of directly transferring the text of the patent to a spreadsheet with the desired format, and the convenience of some editing features absent in *Excel,* which are needed for the application of the selected tool.

2.4. Processing. Once duplicated entries were deleted, the most words that appeared with the most frequency in the selected patents were identified. The most frequent words were purged of adverbs, adjectives and other words

that, for grammatical reasons, tend to reappear but do not constitute a trend or a significant contribution to the studied technique. In this revision, a list of excluded words was made and summarized in table 1.

Besides, a synonym list was built as well (Table 2). It comprises those words that, despite not having exactly the same meaning, are considered as such for the technical purpose of reducing the number of keywords and, therefore, dispersion.

With the lists of excluded words and synonyms completed, the patents underwent revision prior to the elaboration of a table where the intersection of each patent with a given keyword corresponded to zero (0) if it was not found, and to one (1), otherwise.

3.UNIVARIATE ANALYSIS OF THE PATENTS

Univariate analysis helps identify other important aspects for competitive intelligence, such as technological leaders (countries or institutions that hold the most patents on a subject), as well as a specific subject's growth or decrement in patentability, which is useful in the detection on emerging technologies or the assumption of the coming-of-age or extinction of others.

3.1. Technological leaders in innovation patents

3.1.1. Technological leaders in energy generation

The following table shows the institutions holding the most patents on energy generation within the selected sample.

Table 3. Technological leaders in energy generation

Institution	Patents
General Motors Corporation	18
Ballard Power Systems AG	10
General Electric Company	9
Honda Giken Kogyo Kabushiki Kaisha	9
Clean Energy Systems, Inc.	6
Delphi Technologies	6
Ford Motor Company	6
Toyota Jidosha Kabushiki Kaisha	5
Canon Kabushiki Kaisha (Tokyo, JP)	4
Fujitsu Limited (Kawasaki, JP)	4
Hitachi Ltd	4
L'Air Liquide SA	4
Matsushita Electric Industrial Co Ltd	4
Plug Power Inc.	4
Relion, Inc.	4
The Boeing Company	4
Ballard Power Systems Inc. (Burnaby, CA)	3

The clear leader in energy generation is the automobile company *General Motors Corporation,* followed by the German *Ballard Power Systems AG,* which holds a total 13 patents if its U.S. filial *Ballard Power Systems Inc.* is counted in.

4.1.2. Technological leaders in biomass-based energy generation. In this field one institution leads with two patents. The other ones hold one each. The following table (Table 4) shows their distribution according to number of patents.

Table 4. Technological leaders in biomass-based energy generation

Institution	Patents
PureVision Technology, Inc. (Fort Lupton, CO)	2
Babcock & Wilcox Volund APS (Esbjerg, DK)	1
Ethopower Corporation Inc.	1
Future Energy Resources Corporation (Norcross, GA)	1
Greenpower Engineering & Technologies S.A. (Curio, CH)	1

After having identified the keywords and the technological leaders, the following chapter shows the technological maps and some comments on them.

4. TECHNOLOGICAL MAPS MADE FROM THE EXAMINED PATENTS

4.1. Technological map of the whole sample. In order to detect dominant trends, a map was elaborated with all the patent information. The groups of words that appeared nearest each other in the map indicated that they are mentioned together in several patents; this is known as *concurrence*. The elaboration of

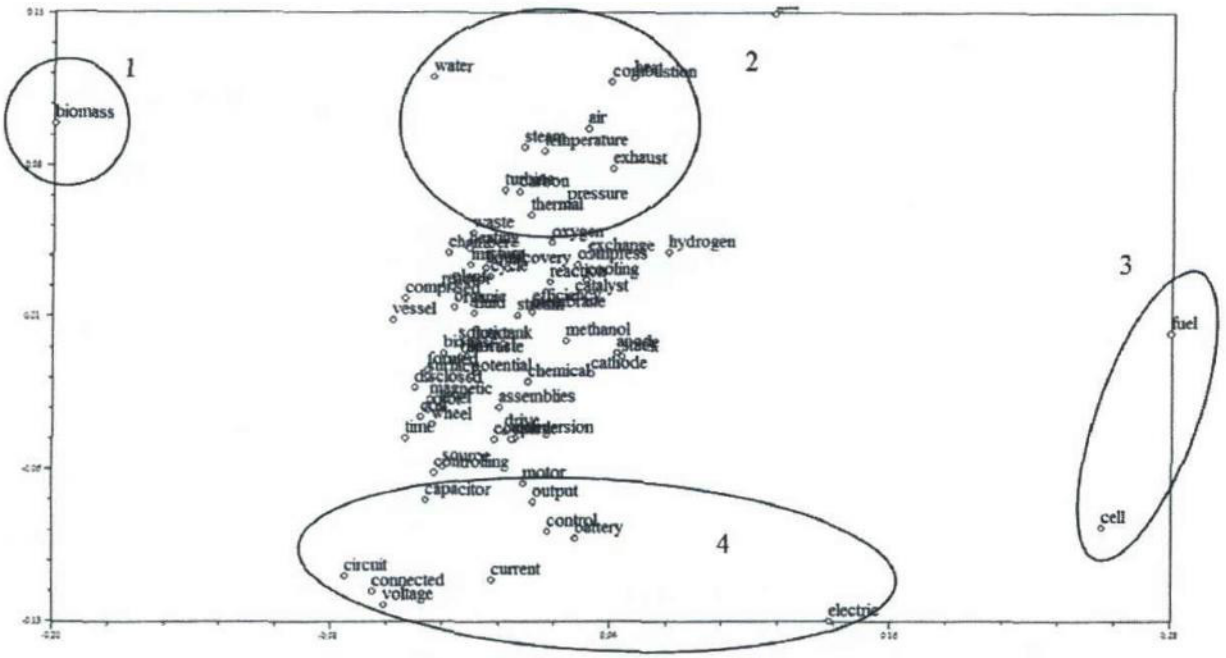

Figure 1. Technological map of energy generation.

A detailed description of each group follows:

Table 5. Different groups of trend words found

Group 1	Not really a group since only the word *biomass* is present. The growth in patent applications in this field during the last five years may be considered a trend, although the existence of a trend in biomass-based energy generation cannot be stated with assurance.
Group 2	Composed of the words *water, heat, combustion, air, steam, temperature, exhaust, turbine, thermal, carbon and pressure.* This group doubtless corresponds to a mature technology, i.e. steam-based energy generation, which does not constitute a new trend.
Group 3	Composed of the words *fuel and cell.* Observation of the sustained growth of patent applications with the word fuel prompts the suspicion that a technological trend exists involving both words *fuel and cell.* A revision of the technological leaders found that three out of the top seven patent holders have product lines with fuel cells, which may mean that a trend has been detected.
Group 4	Composed of the words *electric, battery, current, voltage, circuit, capacitor,* among others. This group corresponds clearly to innovations in devices for conventional ways of generation of electricity.
Group 5	Left unmarked due to its diversity and illegibly superimposed items. A more detailed analysis of this group requires the strategy shown below.

this map did not consider the words *generate, energy and power,* which were present in nearly all the selected patents, so that less obvious associations between words could be found.

In this first map (figure 1), five word groups can be distinguished (four encircled and one left unmarked). Concurrence of words within a group may be due to one of two main reasons: they either correspond to a mature technology or belong to a growing one. This is why it is important to contrast with univariate analysis.

4.2. Technological maps for confirmation of trends. A trend appears in a technological map as a set of words that appear near each other and separated from the central items. A trend can be confirmed by tracing a new map, where the words corresponding to other groups suspected to constitute trends as well are intentionally left out.

4.2.1. Technological map without biomass. Observation of this map confirms the fuel cell trend, because once the information corresponding to biomass is left out, this group stays together, far from the central cloud (group 1).

It is noteworthy to remark on the presence of group 4, (contains the words *anode, catode, methanol, hydrogen and membrane),* which serve to explain the functioning and classification of fuel cells. Also, the groups related to electricity and steam-based generation (groups 2 and 3) are still observed (Figure 2).

4.2.2. Technological map without fuel cells. Upon deletion of the words corresponding to fuel cells, the biomass-based energy generation trend is confirmed (Figure 3). However, specifications about how these innovations work cannot be drawn from this map. The

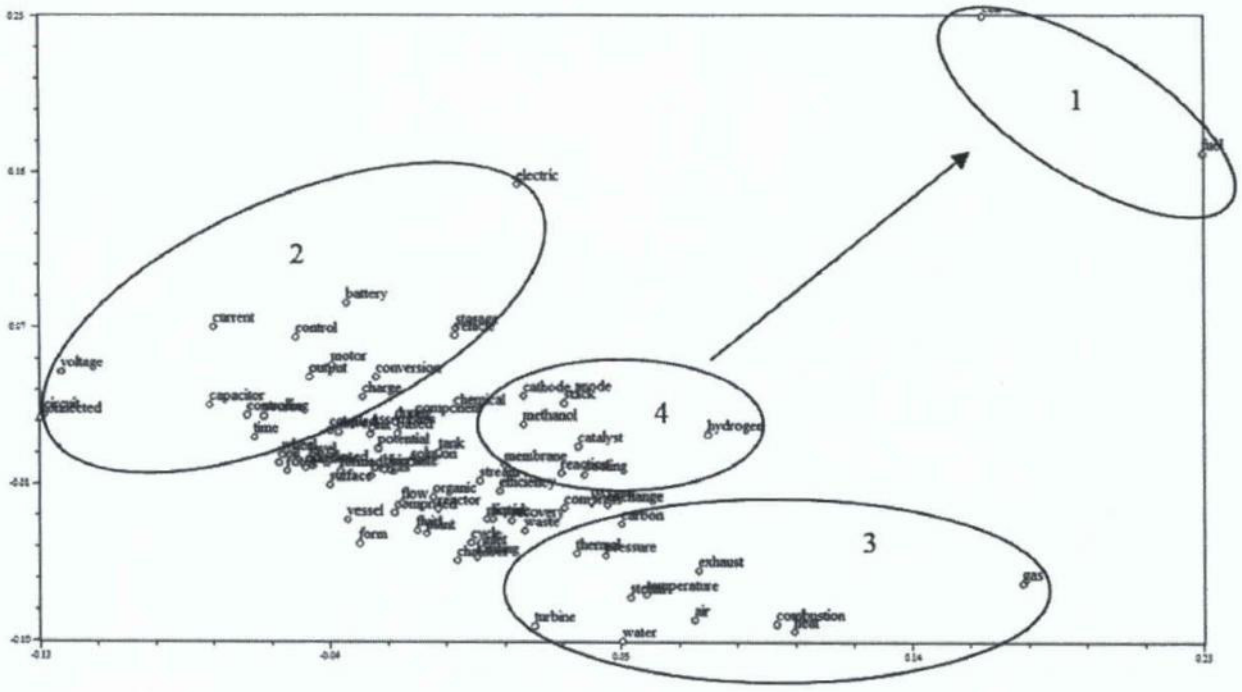

Figure 2. Technological map of energy generation, traced without taking biomass into consideration

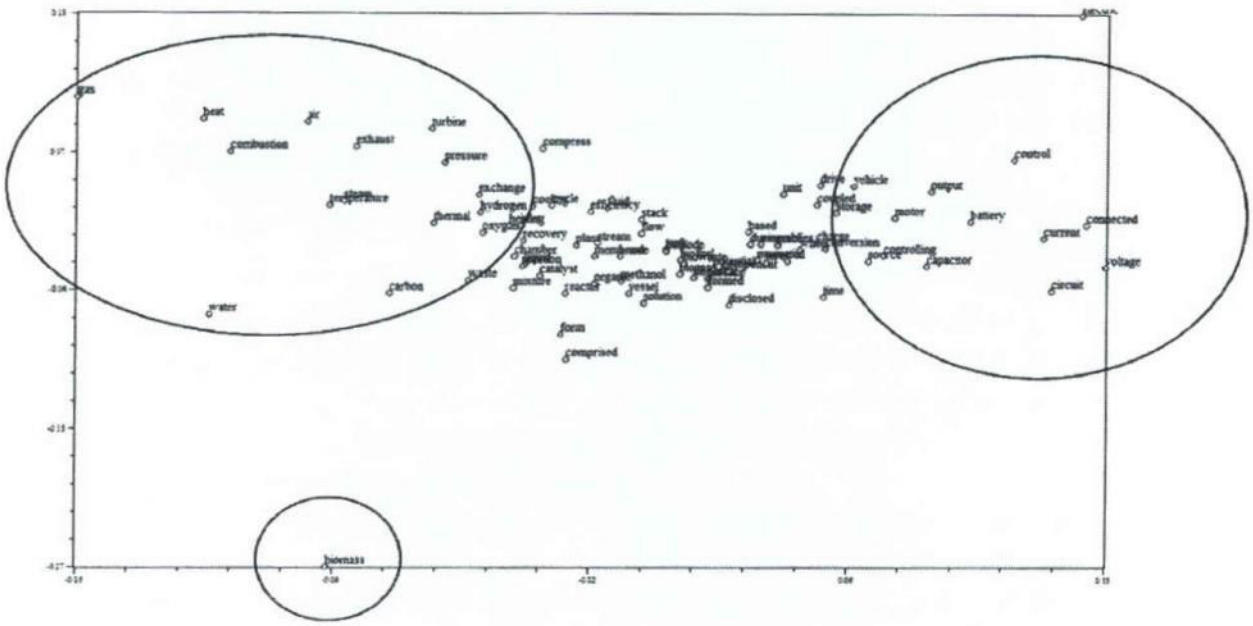

Figure 3. Technological map of energy generation without taking fuel cells into consideration

terms closest to biomass relate to water, carbon, waste, compression, and reactors. Next to the origin point are the terms *biogas, biofuel and biowaste,* but not close enough to biomass to assume a direct link as explained by the map. This could be construed as a normal feature of an expanding technique where efforts are not directed toward specific aspects, but towards isolated or disjointed initiatives. The groups linked to electricity and steam reappear here.

In order to find explanations to what was observed near the origin point, a further map was made (not shown here) in which both trends were absent. There, the groups of words that had appeared since the beginning, corresponding to electricity and steam-based energy generation, remain predominant.

With this methodology two emerging technologies were identified and, as many mature technologies, were also confirmed. One of the detected technologies, biomass-based energy generation, is of a general nature, and the other one, fuel cells, is more specific. The next section shows the results of applying this methodology to patents related to fuel cells.

5. APPLICATION OF THE METHODOLOGY TO FUEL CELL LITERATURE

With the aim of validating the methodology, it was decided to apply it to a set of 171 patents that included the words *fuel and cell* in their abstracts. These patents were granted by the U.S. Patent Office between January 1st, 2000 and 2005.

The five groups described below in table 6 were plotted in Annex 1.

Table 6. Groups of words found during validation process

Group 1	Trends in the applicability of fuel cells in vehicles as a substitute for internal combustion engines as a source of power. Structural design for these vehicles is in study because all of the components of a fuel-powered car are electrical, and this allows designers to place any component anywhere in the vehicle.
Group 2	Describes the functioning of a fuel cell, which is composed of two electrodes kept apart by an electrolyte. When hydrogen is ionized, it yields and electron, and both hydrogen and electron take separate routes toward a second electrode. The hydrogen atom migrates through the electrolyte, while the electron does it via a conductive material. This process will form water, electrical current and utilizable heat. This word group likewise emphasizes the development of cells of direct methanol, which produce a considerable percentage of efficiency. These use a polymer membrane as its electrolyte. They work by pumping a water-methanol mixture toward the cell, which produces carbon dioxide and water. Their working conditions allow them to perform at low ranges of temperature, which makes their application in small devices, like cell phones and laptops, more attractive.
Group 3	Explains the trend towards using direct methanol cells instead of proton exchange cells due to the fact that the former do not use a reformer to obtain the hydrogen that feeds the cell. However, the functioning of the latter is widely developed in systems of vehicle propulsion. For generating utilizable amounts of current, the fuel cells are put to work together in stack. An increase is likewise observed in the use of cogeneration systems based on a PEM fuel cell, which contains a natural gas reformer that converts this fuel into hydrogen to feed the cell, a heat exchanger that reduces the temperature of exit gases, and control systems for monitoring.
Group 4	As a consequence of the commercial applications of fuel cells, based on both proton exchange and direct methanol, a trend is found toward the development of products that improve their efficiency. Such is the case of antifreeze, because water steam is the emission these cells produce, and may become a problem in subzero conditions. Similarly, due to their applicability to automobiles, the development of these products leads to infer that these cell systems may be used in countries with very cold climates. Besides, direct methanol cells have applications in handheld electronic devices, such as cell phones. With a water-methanol mixture they can function like a regular battery, with the added advantage of not needing electricity to recharge.
Group 5	The trend of applying cells for electronics and automobile industry has led to the development of electronic systems (power converters) to control the flow of auxiliary energy in electric cars. This application is ideal for urban areas because a vehicle with an electric engine can have excellent torque.

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Annex 1. Technological map about fuel cells.