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Key Inventors and Key Firms in Fuel Cell Development: A Patent Analysis

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ABSTRACT *This paper summarises a piece of work undertaken a few years ago which employed patent data to investigate the development of the fuel cell. The paper's main aim is to record the investigation and method used and explore whether patent data could be employed to determine the main players, both inventors and firms, in fuel cell innovation. The original work using 2001 data has been utilised in a number of further studies (Pilkington, 2004; Pilkington and Liston-Heyes, 2004; Pilkington and Dyerson, 2001b; Dyerson and Pilkington, 2002, 2004), but its main findings in terms of classifying the main contributors to fuel cell development was never really fully explored. Updating the study and extending the analysis of the groups of inventors and firms to isolate differences, is the starting point for a new piece of work which is just being planned.*

KEYWORDS: Fuel Cell, Patent, Inventor, Innovation.

Introduction

In this paper, US patenting activity in the development of fuel cell technology is used to analyse the flow of information and individuals at a time when this technology was seen as a key response to regulatory and environmental pressures. Such regulation is stimulating incumbent firms to change their approaches to product development from the traditionally exclusive to a more inclusive orientation through the development of knowledge networks. Technology research in other sectors suggests that the development of these knowledge networks may be highly dependent upon key individuals or gatekeepers within firms. This paper tests that proposition through analysis of the patenting activity of firms in contrast to that of individuals engaged in fuel cell development. Using American patent data, indexes of patent quality and activity are constructed and assessed in order to explore who the key firms and individuals are in fuel cell development. In addition we explore the data to present a picture of the movement of individuals between the leading firms in the field and try and assess the impact of these movements on technological transfer.

The Rise of Alternative Fuel Technology

Changing regulatory environments suggest a change in the hitherto comparatively mature technology environment of automotive manufacturers and energy producers. That is, a shift from the proven set of sustaining technologies to an unproven set of disruptive and at times competing technologies (Henderson and Clarke, 1990; Bowyer and Christensen, 1995). With comparatively little experience of the power systems needed to develop the sustainable technologies, the

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traditional car makers and power generators have had to enlist the support of many external firms, outside the boundaries of the traditional supply environments as they look towards fuel cell commercialisation. We have a long interest in examining the technological development of fuel cell technology, and in particular the interrelationships between firms and individuals at the invention stage (Pilkington, 1998), and see this case as suitable exploring the hypotheses identified above (Dyerson and Pilkington, 2004).

Patent Studies

Patent data represent a valuable source of information relating to technological development (Albert, Narin and McAllister, 1990; Brockhoff, 1992; Narin and Olivastro, 1988). Some debate exists in the literature regarding possible problems with using patent data as a proxy for innovation (Girliches, 1998), but these largely rest on using data to examine R&D and economic growth at a national level (Pavitt, 1983; Soete and Wyatt, 1983), or in identifying complete ranges of skills at the firm level (Pavitt, 1985). Here the important differences between home country applications and those from foreign firms become inescapable (Basberg, 1987; Watanabe, Tsuji and Griffy-Brown, 2001). For example, Watanabe *et al* explore the development of technological portfolios within Japanese firms and conclude that applications to the US Patent and Trademark Office (USPTO) is probably the ideal measure of these activities over and above entries into the Japanese system and patents actually granted by the USPTO. They continue that the data from granted US patents does represent a close proxy to the status of a technological field as a whole, capturing not only all the US contributions but also the significant advances from overseas as well. The argument is essentially that inventors use home country protection for almost every invention, and foreign inventors also use US protection for those innovations which they feel represent a significant technological advance or have commercial value. A similar conclusion was reached by Grupp and Schmooh (1999) who praised the notion of a “triad patent”, one which is lodged in all of the US, Japanese and European patent systems. Their argument is that these represent the patents held in the highest regard by the inventors and so represent the key aspects of knowledge and technique in a particular field.

Whilst we acknowledge the general concerns regarding the possible incompleteness of patent data, the attention of this paper on the evolution of an entire technological field instead of the actions of a single firm, the literature reviewed above gives us confidence that using USPTO granted patents certainly contains the significant contributions from the players within the field, be they American or from abroad. Also, our subsequent methodology, and its focus on those who make the largest contributions, specifically excludes the noise generated by less important US patenters who have a greater tendency to patent with the USPTO than non-important developers from elsewhere. Our methodology builds on that of Ernst (1999) who identified and investigated the role of individuals within the innovation portfolios of firms. These individuals can be seen as primary sources or more particularly gatekeepers of emerging technologies. He argues that that the technological performance of inventors tends to be highly concentrated, making particular inventors highly influential in technology development (Teichert and Ernst, 1999). At a time of changing technological know-how however, this potentially exposes incumbent firms to dependence on outside experts and gatekeepers.

Adapting our own modification of Ernst’s methodology we developed patent portfolios on a firm-by-firm and inventor basis and constructed indexes of patent quality and activity (Dyerson and Pilkington, 2000a). These form the basis of our investigation of the impact of movements of individuals on the innovation process resulting from such technology transfer.

Method and Analysis

In February 2001, we identified 6,272 patents in the US Patent and trademark Office (USPTO) that contained the term “fuel cell” in the full text on the front page. This data set included most patents granted between 1975 to the beginning of 2000, but excludes some from the late 1990s which although they had been applied for, had not been formally granted. This application process can take two years, but today applications yet to be granted can also be analysed owing to a change in the system from March 2002. The bibliographic details of the available patents were downloaded from the Delphion service (formerly the IBM Intellectual Property web site) and relevant information extracted using the Patent Lab II software, which is available from Delphion and analysed using both the Excel and SPSS packages. On coding, some 5,998 patents were usable owing to missing data mainly resulting from lapsed older patents that were no longer maintained in full in the data base. The data were standardised by hand to correct multiple spelling of names and changing firm names.

In order to capture as fully as possible all technological developments relevant to fuel cell technology, we chose the free text search in favour of using the IPC or US patent classification systems. Prior work by the authors has shown the limitations of using patent classifications to identify developments pertaining to a particular product as often future key inventions encompass technologies from neighbouring fields and there is pressure on inventors to generalise applications for their technologies as wide as possible to maximise potential returns (Pilkington and Dyerson, 2001). As the fuel cell represents a particular technology, rather than product or usage of certain groups of technologies, we feel confident that we have captured the main areas of development.

An initial test of the rates of entry and exit shown in the data confirmed our expected view that the fuel cell field was one of growing invention and dawning commercialisation. Following the lead of Melera and Orsenigo (1999), we broke our sample into groups and examined the number of firms which did not appear in the later patents but were assignees for the earlier group and *vice versa.* We found that 280 firms had effectively left the field whilst 788 had entered the latter half. This represents a growth index of 2.8, which we contest represents a turbulent and expanding field of technological emergence. Also, given the nature and uses of patents themselves, this also suggests that fuel cell commercialisation is expected within the next few decades at most. As a patent has a limited life - nominally a maximum of 25 years in US – this interest represents a growing anxiety for inventors and firms to claim their ideas and ring fence their future products. This has been observed in other fields, where the rate of patenting reaches a peek at commercialisation rather than its early development stages or after the technology has become widespread (Basberg, 1982).

Key Inventors and Key Firms

Ernst’s methodology (1999) to identify and investigate the role of key individuals, which he contests act as primary sources or more particularly gatekeepers of emerging technologies, suggests that the technological performance of inventors is typically highly concentrated with just a few inventors having highly influential roles in technology development. Ernst’s “key inventors" are characterised by high patenting activity and also a high patent quality rating. In our study we identified key inventors as having a higher than average output productivity of others in the data set whilst also having a citation ratio of their patents twice the average for fuel cell inventors. We could not use Ernst's exact measure of quality which, as well as citations, included the proportion of patent applications granted and also the number of patents applied for abroad, as this information is unavailable for US patents. However, citation rates alone have long been an established method of gauging the quality of scientific publication (Culnan, 1986; Sharplin and Mabry, 1985) and the same technique is equally successful as a rank of patent quality (Basberg, 1987).

We are further encouraged that our measures are robust as there exists a strong correlation between productivity and quality (R = 0.728, significant at the 0.01 level (2-tailed). Similarly, the results of the regression model to predict inventor citations shows that the number of patents an inventor has is the biggest contributor to estimating the citations. The results of the regression are summarised in Table I.

Table I. Results for the Regression of Number of Citations per Inventor

Variable	**Standardised beta coefficients (*t* value)**
Number of patents	0.695* (72.541)
Number of companies worked for	0.061* (6.333)
R^2	0.533
Adj. R^2	0.532
F	4134.87
N	7263

* $p < 0.01$

Figure 1. shows the breakdown of our data to give the 8.5% key inventors. This again suggests that the fuel cell field is emerging as Ernst found only 6.9% of inventors were key in his study of German patenting activity in the more mature fields of mechanical and electrical inventions. The identification of 8.5% of inventors as key inventors shows the concentration of important activity within a limited number of inventors and is similar to the concentrations found in similar areas such as scientific research (Seglen, 1992).

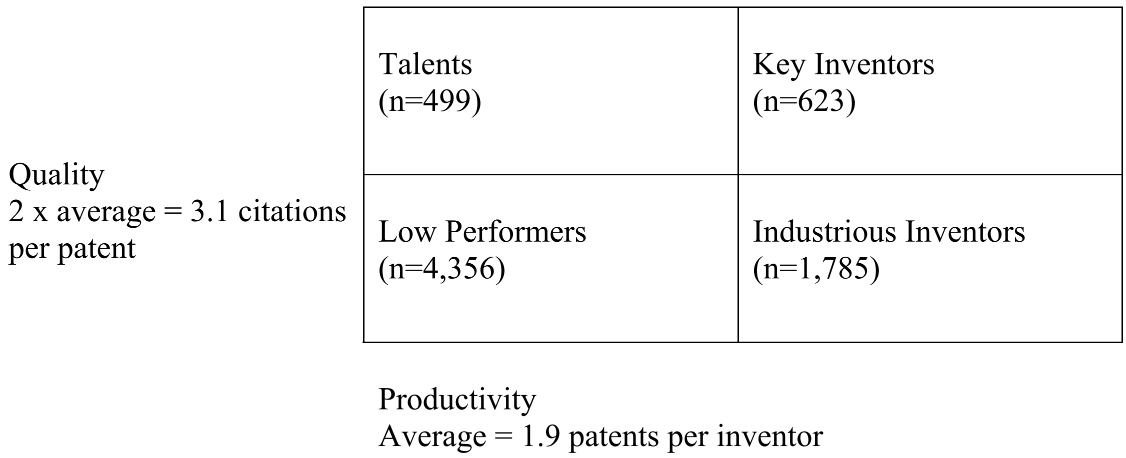

Figure 1: Fuel Cell Key Inventors

Table II, previously published in Dyerson and Pilkington (2004), shows those inventors with outstanding ratings against both quantity and quality measures – the top 20 by citation ratio for inventors within the top 100 patent producers.

Table II: Leading Fuel Cell Inventors

Inventor	**No. of Patents**	**Citations per Patent**
Isenberg; Arnold O.; (US)	26	16
Reichner; Philip; (US)	10	14
Reiser; Carl; (US)	16	11
Baker; Bernard S.; (US)	15	11
Watkins; David S.; (Ca)	14	9
Ruka; Roswell J.; (US)	24	9
Maricle; Donald L.; (US)	14	9
Maru; Hansraj C.; (US)	12	9
Marianowski, Leonard G.; (US)	24	9
Schroll; Craig R.; (US)	12	8
Breault; Richard D.; (US)	38	8
Cable; Thomas L.; (US)	11	8
Dempsey; Russell M.; (US)	11	8
Hsu; Michael S.; (US)	24	7
Iacovangelo; Charles D.; (US)	11	7
Mcelroy; James F.; (US)	12	7
Bloomfield; David P.; (US)	17	7
Bushnell; Calvin L.; (US)	10	7
Buswell; Richard F.; (US)	13	7
Tamura; Kohki; (Jp)	14	7

In order to examine the firms working in the fuel cell area, we extended the key inventor approach to allow the identification of key firms. Again the measures used to identify key firms were based on quantity (>average number of patents per firm) and quality (>twice the average citations per patent per firm). Figure 2 and Table III (previously published elsewhere: Pilkington and Dyerson, 2004) show the results of this analysis. It is interesting to note that while Americans dominate the inventor list, there is a more international spread of firms engaged in patenting fuel cell technology.

Table III: Key Fuel Cell Patenting Firms

Key Firm (>twice average citation ratio and > average no patents)	**No. of Patents**
United Technologies Corporation	216
International Fuel Cells	187
Westinghouse Electric Corp.	155
United States Department Of Energy	142
General Electric Company	128
The Dow Chemical Company	94
Hitachi, Ltd.	80
E. I. Du Pont De Nemours And Company	76
Mitsubishi Denki Kabushiki Kaisha	63
Ballard Power Systems Inc.	62
NGK Insulators, Ltd.	59
Energy Research Corporation	58
Fuji Electric Co., Ltd.	56
Institute Of Gas Technology	52
Diamond Shamrock Corporation	41
Engelhard Corporation	39
The Regents Of The University Of California	38
Daimler-Benz Ag	35
Allied Signal Inc.	33
Gas Research Institute	32
Matsushita Electric Industrial	31
Massachusetts Institute Of Technology	28
Ishikawajima-Harima Heavy Industries	27
Union Carbide Corporation	23
Osaka Gas Co., Ltd.	22
Prototech Company; The Standard Oil Company	21
Tanaka Kikinzoku Kogyo K.K.	20
Lynntech, Inc.	19
Ceramatec, Inc.; Asahi Glass Company Ltd.	18
Watanabe; H Power Corporation; Plug Power, L.L.C.; Rockwell International Corporation	17
Stonehart Associates Inc.	16
Sri International; Dornier Gmbh; Electrochemische Energieconversie N.V.; Ztek Corporation	13
W. L. Gore & Associates, Inc.; M-C Power Corporation	12
Occidental Chemical Corporation; Yamaha Hatsudoki Kabushiki Kaisha	11
Asea Brown Boveri Ltd.; Haldor Topsoe A/S; Energy Conversion Devices, Inc.	10
Communication Satellite Corporation; Leesona Corporation; Degussa Aktiengesellschaft; Tokyo Shibaura Denki Kabushiki Kaisha	8

Quality
2 x average = 0.23
citations per patent per
firm

Talented Firms (n=134)	Key Firms (n=64)
Low Performing Firms (n=915)	Industrious Firms (n=107)

Productivity
Average = 5.09 patents per firm

Figure 2: Key Firms

For the use of patent data to be proved as a means of investigating technological evolution, Table III should represent the firms that are leading the development of fuel cell technology. The authors' own experiences and the help of several outside fuel cell experts drawn from US and UK universities, has satisfied us that we have captured a highly representative list of the firms involved in the rush to commercialise the fuel cell. An area of further work we are exploring is to develop a survey methodology to show this alignment in a statistically reliable manner.

Now we have described our data and explored the evidence that it represents a technology of growing significance and emerging commercialisation, we would like to focus on what it tells us about effective knowledge transfer processes.

Knowledge Transfer as a Key Innovation Process

Patent data allows the determination of the company each inventor worked for when the patent application was made and so it is possible to explore the patterns of individuals and companies in the network of innovation for fuel cells and also the relative movements of individuals between firms. The first observation we should make is that there is a strong alignment of the key inventors and key firms, with 74% of the key inventors having produced patents for at least one key firm. This suggests that any effective mechanism for invention in our sample, whilst being visible at the firm level, is actually generated at the individual level. Further investigation of this relationship between key inventors and key firms was performed by examining simultaneously the nature of the inventor, key inventor or not, and the firm, a key firm or not. The results are presented in the form of a contingency table (Table IV) which can be used to test the hypothesis that there is more tendency for key inventors to be part of a key firm. The null hypothesis is that there is no difference between the number of patents by key inventors whether or not they are in a key firm. The χ^2 statistic calculated form the contingency table was 13.98 and this far exceeds the critical value of 3.84 (one tail, p=0.05), and so the null hypothesis has to be rejected, supporting the argument that key inventors tend to work for key firms.

Table IV. Contingency Table of the Percentage of Patents by Key Inventor and Key Firm.

	Key Firm	Not Key Firm	Total
Key Inventor	15.8	5.7	21.5
Not Key Inventor	22.8	55.7	78.5
Total	38.6	61.4	100

We were also interested in what differences existed between the key inventors and industrious inventors in respect to their movement between organisations and whether there was any significance to the number of moves made by the inventors in relation to the quality of their resulting patents. We calculated the number of different companies each inventor was shown to be working with in the data set and examined if there were any differences in our classifications. The average number of companies for the key inventors was 1.6 whilst the industrious inventors had an average of 1.3. A simple *t*-test (assuming independent variances) found that the difference between the mean numbers of companies given was statistically significant. The *t*-statistic was 7.786, which is significant at the 0.1% level.

In order to explore the relationship between the movement of key inventors and the transfer of knowledge as a result, it was necessary to plot the firms to which the inventors moved. We limited ourselves to the movements of the key inventors and constructed a list of the firms for which they had worked. An index of firm attraction was made by looking at the patents for an inventor chronologically and picking out the instances where they showed a change in firm through their patenting career. Where an inventor left a firm, the organisation was given a mark of -1, with an associated +1 being given to the organisation they joined. These scores which represent the relative attraction of the firm in our data set were summed for each assignee and the extreme results are summarised in Table V.

Table V needs to be treated with care as there are several things which require interpretation or extra commentary. For example, the scores of the United Aircraft Corp, United Technologies and International Fuel Cells are related as in effect they represent the evolution of a research unit in a firm which changed its name and then established a spin off organisation. However, even when this is taken into consideration, it suggests that International Fuel Cells was still a net attractor of key inventors. Inspection of the raw data itself confirms this transition and also highlights several other interesting changes. In particular, the movement of a fuel cell group from Westinghouse to Siemens and the commercialisation of the inventors in Canadian Government labs into Ballard appear to be major changes in the structure of the industry’s knowledge base. A similar case is evident in the movement of US Department of Energy personnel to International Fuel Cells and several other commercial organisations. Again this suggests a technology evolving from a period of basic research to near commercialisation or possibly a change in public funding strategy. This is also an encouraging finding adding weight to our belief that we have been successful in capturing the emergence of fuel cell technology.

Table V. Organisations Showing Net Gains or Losses of Key Inventors.

Assignee of Patent	Sum of Attraction Index
INTERNATIONAL FUEL CELLS	37
SIEMENS AKTIENGESELLSCHAFT	7
BALLARD POWER SYSTEMS INC.	5
ELECTRIC POWER RESEARCH INSTITUTE, INC.	4
ELTECH SYSTEMS CORPORATION	4
ENERGY PARTNERS, INC.	4
KABUSHIKI KAISHA TOSHIBA	4
ALLIED SIGNAL INC.	3
ORONZIO DE NORA IMPIANTI ELETTROCHIMICI S.P.A.	3
H POWER CORPORATION	2
UNIVERSITY OF CHICAGO	2
CERAMATEC, INC.	-2
COMMUNICATION SATELLITE CORPORATION	-2
ENGELHARD CORPORATION	-2
LEESONA CORPORATION	-2
SOUTHERN COUNTIES GAS	-2
THE OHIO STATE UNIVERSITY	-2
UNITED STATES DEPARTMENT OF ENERGY	-2
WESTINGHOUSE ELECTRIC CORP.	-2
UOP INC.	-3
CANADA MINISTER OF NATIONAL DEFENCE	-4
INSTITUTE OF GAS TECHNOLOGY	-4
PERRY OCEANOGRAPHICS, INC.	-4
TOKYO SHIBAURA DENKI KABUSHIKI KAISHA	-4
DIAMOND SHAMROCK CORPORATION	-5
GENERAL ELECTRIC COMPANY	-8
UNITED TECHNOLOGIES CORPORATION	-20
UNITED AIRCRAFT CORPORATION	-22

Concerns about the data in the table which we need to stress include the influence of our sampling criteria which arrived at this list through key inventors, many of whom appear repeatedly for a small number of organisations. This suggests that these inventors could be working on development projects in joint ventures or on some form of contracted basis - their resulting patents being assigned to whichever organisation sponsored that particular piece of a larger project and yet the inventor has not changed organisation. Similarly, inventors may not have been active for the whole period under investigation, and also only register a change when they issue a patent. There may be many inventors which are elevated into management positions either in their existing organisations or by headhunting, and yet as they themselves do no further patenting we miss these career moves.

What the data does suggest is that IFC, Siemens, Ballard, EPRI, and Toshiba are attracting the key inventors whilst Diamond Shamrock and General Electric and some public funded bodies seem to be loosing their established knowledge creators. It is difficult to test this reliably as we have no measures of the effectiveness of the R&D activities of these firms, but when we examine their patenting outputs in the area of fuel cells chronologically, we do find a similar pattern. Table VI shows the amount of activity measured by the number of patents over the period of our data. There may be a pattern observable but we feel this evidence is inconclusive and further work using other data sources is required.

Table VI. Number of Fuel Cell Patents per Year at Selected Firms.

Company	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000
International Fuel Cells	0	0	0	84	52	51
Siemens Aktiengesellschaft	30	30	8	3	6	36
Ballard Power Systems Inc.	0	0	0	0	19	43
Kabushiki Kaisha Toshiba	0	0	1	14	18	12
Epri	0	2	6	5	5	5
General Electric Company	42	25	31	11	11	8
Diamond Shamrock	0	10	31	0	0	0

Results

The above shows the use of patent data to plot the identification of key players in developing that technology. We have identified that the development of fuel cell technology, as embodied in the patent data, shows a concentrated effort in a limited number of firms. This concentration was expected – the processes which lead to successful technology transfer are based on tacit knowledge and require repetition for their success which in turn leads to concentrations of advancement in those firms which are able to successfully practice the process.

When we extended the study to examine if there was a similar grouping of individuals, we found that key inventors also exhibit a similar level of concentration. Indeed there was a significant tendency of key inventors to be working with or in key firms. This supports our view that the significant knowledge itself is located within individuals at the first instance and not within the firm. If knowledge was gleaned and leveraged by firms rather than individuals, then we would expect to see the concentrations of firms above but no similar grouping when we use the individual as our level of analysis. However, the key individuals are largely located within a limited number of key firms and so there appears to be a strong message for a view that the generation of ideas is by individuals and these are then exploited by firms.

We also found that key inventors have more companies in their career histories than the equally productive, but less cited, industrious inventors. This clearly has great bearing on ideas relating to technology transfer and the role of the movement of individuals as the most effective mechanism for such transfers. However, we must be careful to consider the causality involved here: do the key inventors move more because they are better inventors and so have a higher worth, or does more moving lead the key inventors to better quality patents? Investigation of this aspect is an area of on going work. As a next step we propose to sample both the key inventors and industrious inventors in order to explore more fully their career paths and the subsequent impact on their firms.

We also expected to see that the companies which attract key inventors should benefit as a result, but our data is inconclusive. We can see that there are certain firms which attract more key inventors than they loose and that these firms appear to be better positioned to become the leaders in the field. However, there is much more work which needs to be completed to examine if and in what way these firms benefit from attracting key inventors and whether or how those which loose them suffer as a direct result.

Conclusions and Future Work

There have been conflicting views as to the role of individuals and firms in innovation networks with a range of opinions presented about the whether it is the structure and processes within the firms which lead to successful innovation or whether the process is itself one focussed on the tacit knowledge represented by the activities of individuals. We have found that there does appear to be a close link between the individuals and the organisation, but that the invention itself seems to happen at the individual level, with firms providing the structure for such development. When maps of significant inventors are overlaid onto maps of the significant companies within a field, we find a very close match. Similarly, there is evidence that the movement of individuals within the firms aligns with the inventive abilities of the firms, supporting the ideas of the valuable tacit knowledge being transferred by the movement of individuals and highlighting the need for firms to manage their human inventive resources closely.

This study has shown that patent data can identify the key contributors to the emergence of a particular technology and also play a part in exploring the relationships between different roles of individuals and firms in that development. The data can be used to determine the criteria for sampling firms and inventors for further investigation. Such work could allow an investigation of the factors which lead to identifying performance in terms of productivity and quality and whether these are embodied at the inventor or firm levels, or indeed whether both are necessary or sufficient.

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