

**Paper for the DRUID Winter Conference 2004**

**Stian Nygaard**

**PhD student at Lund Institute of Technology**

**Division of Innovation**

**“Emerging technology and the evolution of industry:**

**The case of Fuel Cell Technology”**

**PhD Research Proposal- Draft of 05.01.04**

## **1. Introduction- topic and problem**

The topic for this thesis is the relationship between emerging technology and the evolution of industry. The relationship between technology and industry was for a long time understood as a linear relationship where the industrial structure affected the technological advancement. Philips in “Technology and Market structure” from 1971 was among the first to suggest that also technology might have an effect on the industry (Nelson 1995:171), and in this thesis a position advocating the co-evolution of technology and industry is defended. The third element is the level between technology and industry: the firm. A related question will therefore be what characterises the relationship between technology, firm and industry, and how can this relationship be explained.

The empirical case is the emerging fuel cell (FC) technology and the evolution of the FC industry. This is a generic technology with application areas for automobiles, laptops and in energy production both for industrial and residential purposes, and due to its emerging character it has not been widely studied. Therefore, to study how FC technology develops, the evolution of the FC industry and the firms within seems as a rewarding approach to follow.

While there is ample literature on the evolution of industries, the emergent phase – or the fluid phase to use Utterback’s terminology – still needs further analysis, especially regarding patterns and reasons for entrance, early strategies, cooperative patterns and co-evolution of technology and industry development. In this thesis we employ a conceptual framework that seeks to explain the evolution of industry based on new emerging technologies. We discuss the different positions on this theme, those advocating a product life cycle process as characterising the evolution of industry (Abernathy and Utterback) and those

who emphasise the design hierarchies (Abernathy and Clark). We also seek to explain how industrial leadership is achieved (Mowery et al). The conceptual framework will be employed on the FC industry, asking how an emerging technology creates an industry.

### **Research Question(s)**

The main research question in this thesis is “How does an emerging technology create an industry and what is the enabling and constraining factors for the evolution of the FC industry? Connected to this is the question of the roles that firms play in this evolution?

In order to answer these questions, we use certain sub-questions:

What is the relationship between the development of technology, firms and the industry? How is competitive advantage achieved – by technological advantages, by alliances, by policy regulation? What kind of market strategies is evident: first mover advantages, fast second mover? (Why are some firms reluctant to be first movers even though they have the technology?) What is the difference/similarity to other new technology driven industries (ICT, Biotech)? When do the technologies reach successful commercialisation- Who is first, and why are they first, due to technology, strategic partnership or something else?

## **2. Fuel Cell technology explained**

The fuel cell was invented in 1839 by the English lawyer William R Grove, but it was not until 1960's that F.T Bacon demonstrated the first effective and useful cell. This cell was an Alkaline electrolyte fuel cell and was exported the NASA and used in their space program. A FC is a technology which in principle works as a battery which enables production of electricity because of a chemical reaction between hydrogen and oxygen. The fuel cell has positive environmental effects since the exhaust from a fuel cell vehicle is pure water i.e. no emissions. The no emission effect occurs when the fuel cell runs on pure hydrogen. Another option is when the fuel cell runs on methanol, which is a rich source for hydrogen, but which involves some emissions of CO<sub>2</sub> and other pollutants. In this phase, there is still testing of different forms of energy sources for the fuel cells going on, ranging from pure hydrogen, to the use of methanol directly in fuel cells and to zinc air fuel cells. The choices are many and no dominant designs exist. There are five different types of fuel cells and they can be classified according to the electrolyte they use and to the operational temperature, i.e. the temperature that is in the cell when they produce electricity.

### **3. Theoretical Framework**

The theoretical framework used in this thesis comes from several strands, but all seeks to explain how industries evolve. Those studying the evolution of industries came first mainly from come from two disciplines: the Industrial organisation economists (Klepper) and those concerned with the Product Life Cycle (PLC) theory (Utterback, Abernathy, Suarez). According to Nelson these two discovered each other around 1993 and “there has been convergence” (Nelson 1995). Lately, the relevance of the PLC theory has been contested by several authors and we present shortly three of them, Nelson that brings institutions into the analysis pf industrial evolution, McGahan which propose a theory based on four basic models and Mytelka’s theory of New Wave Technologies. First we discuss the PLC theory and later present the different oppositions to this perspective by Nelson, McGahan and Mytelka.

#### **3.1 Product life cycle theory (PLC)**

When employing the PLC theory as theoretical framework to explain the evolution of industry, one is met by a broad range of concepts and empirical works. Important concepts are that of a dominant design, of the product lifecycle and of design hierarchies. We will give a presentation of these concepts and relate them to explaining industrial evolution.

Abernathy and Utterback recognised in an early article that industries in the beginning is characterised by a fluid phase with a high variety of technological alternatives and immense product innovation. The concept of a dominant design is important and according to the Abernathy and Utterback model, the dominant design makes the industry shift from product to process innovation and a decline of number of firms will occur. This model is further developed in Utterback (1994). Dominant design is “a specific path along an industry’s design hierarchy, which establishes dominance among competing design paths” (Suarez and Utterback 1995: 416).

Another approach using the PLC theory and focusing on design hierarchies as important for industrial evolution is Abernathy and Clark who introduce the concept of a transilience map and:

*“The transilience map is (thus) much more than a simple categorisation of technical change; it provides a framework within which one can examine the relationships among innovation,*

*competition and the evolution of industries, as well as develop insight about the strategies of specific competitors” (Abernathy and Clark 1985: 13)*

As we can see, this approach focuses more on the shift in innovation from radical to incremental instead of from product to process innovation. Furthermore, also an emphasis on firm strategy is employed.

The Abernathy and Utterback Model is based on an understanding of the product life cycle where the “fluid to specific phase” and “the transition from architectural to regular innovation” is present. These transitions are associated with the emergence of a dominant design in the product (Abernathy and Clark 1985: 13-14). The concepts of architectural and regular innovation were later changed and architectural is now called radical and regular is called incremental (Henderson and Clark 1990: 3). Architectural innovation is now understood as new combinations of existing knowledge i.e. the knowledge is reinforced while the links is changed (Henderson and Clark 1990: 3).

According to Abernathy and Clark, the transition from architectural to regular (or radical to incremental) indicate that also” a shift from innovation meeting emerging needs with new concepts, to refining, improving and strengthening the dominant design and its appeal in the market” (Abernathy and Clark :14) will take place. This means that firms must search for gaining a strategic advantage over its competitors and “exploiting the advantage inherent in a dominant design demands a change in strategic orientation”

We will now present the position of Klepper who comes from the Industrial organisation economist tradition and in “Entry, Exit, Growth and Innovation over the Product Life Cycle” from 1996 found two regularities to entry and exit and that was in accordance with the PLC theory. Klepper states here that:

*“At the beginning of the industry, the number of entrants may rise over time or it may attain a peak at start of the industry and then decline over time, but in most cases the number of entrants eventually becomes small. The numbers of producers grow initially and then reaches a peak, after which it declines steadily despite continued growth in industry output” (Klepper: 1996:564)*

As we can clearly read out of this quote, in the fluid phase there are many new entrants to the infant industry and this number declines as the industry matures. Klepper further recognizes three regularities of technological change based on the case studies to among others;

Abernathy and Utterback (1978) Utterback and Suarez (1993), Andersen and Tushman (1990). These were

1. The diversity of competing versions of the product and the number of major product innovations tend to reach a peak during the growth in the number of producers and then fall over time.
2. Over time, producers devote increasing effort to process relative to product innovation.
3. During the period of growth in the number of producers, the most recent entrants account for a disproportionate share of product innovations” (565)

Klepper’s findings in this article in strengthen the PLC theory as he draws on several sources and confirm the model to Abernathy and Utterback dating back to 1978.

### **3.2 The criticism of PLC**

McGahan states that the product life cycle theory and the five forces to Porter are incomplete as frameworks for explaining how industries evolve. She proposes a theory of industry evolution based on four basic models: receptive, blockbuster, radical organic and intermediating (McGahan 2000)

Richard Nelson in “Co-evolution of technology, Industrial Structure and supporting Institutions” from 1994 argues that technology and industry structure co-evolve, and he connects this with the role of institutions in this process. Following Nelson then, Nations differ in their pace and pattern of institutional response to the birth and development of an industry. Furthermore, “comparative advantage is largely determined by these different kinds of national response” and Nelson, by this, moves the theory of industrial evolution into an institutionalist framework. How does one get competitive advantage? Connect it to your supporting institutions. Nelson states that the concept of dominant design, which is by many viewed as universal, “only fit those industries where the product is a ‘system’ and where customers have similar demands (Nelson 1995: 174). According to Nelson “The development of an effective system of labor training, the establishment of standards, the emergence of standard patterns of interaction between firms, suppliers and customers, and across firms in the industry, involve the creation of a collection informal and formal organizations“and “as

these form, people become conscious that there is a new industry and that it has collective interest and needs” (Nelson 1995: 176)

We now move on to another explanation of industrial evolution which comes from Mytelka (2003) who uses the concept of new wave technologies (NWT). She argues that:

*“whereas models of technological change have traditionally distinguished between innovation in products and in production technologies and generally regarded these as sequential processes, new wave technologies tend to fuse product and process innovation at the experimental stage, that is the laboratory”* (Mytelka 2003: 10).

Following the quote above, Mytelka argues against the PLC theory when it comes to explaining NWT is wrong, since product and process innovation occur at the same time. Mytelka in this article analyses Fuel Cell technology as a new wave technology and her approach is therefore further analysed in the next part, the discussion of sources- innovation studies of FCT. Mytelka state that NWT has 3 characteristics: “A broad knowledge base increasingly anchored in the sciences, new strategies of knowledge generation and appropriation, and system embeddedness in the establishment of a dominant design (Mytelka 2003: 9). section four we present a discussion of the sources.

#### **4. Innovation studies of Fuel Cell technologies**

This section consists of two parts, first the work that has been done on FC related to innovation is presented and latter we identify what is missing and which thus is the perspective for this thesis.

##### **4.1 What have been done in the field: Review of relevant work on FC**

According to Thompson ISI<sup>1</sup>, fuel cell related articles in economics and business was 4, In social sciences 8 and 18 Multidisciplinary articles. After conducting a search on ISI, google and Lovisa at Lund University library pages, we came up with seven relevant articles that dealt with fuel cells and innovation. This is not a large amount of articles compared to the several thousands of articles in engineering and natural science. Due to the small amount of articles, all of them are reviewed briefly here. There is also a book published by BETA

---

<sup>1</sup> <http://www.esi-topics.com/fuelcells/index.html>

researchers in august 2003 and there is an OECD project<sup>2</sup> on energy innovation which also deals with FC innovations. This report will be finished during spring 2004 and will also most likely lead to journal articles on the subject. There is also an unauthorised biography of Ballard, the most successful fuel cell producer in the world, written by Tom Koppel. This book is made on the basis of a large number of interviews conducted by the author who planned to write a “Readers digest” article. He found the Ballard Corporation to be such an interesting topic that he decided to write a book. This was not appreciated by Ballard. There is also a report edited by Wengel and Schirrmeister that deals with fuel cells.

This part will continue with a review on the book from BETA (the relevant chapters) and then continue with the articles.

### **Avadikyan, Cohendet and Heraud, ed. (2003) “The Economic Dynamics of Fuel Cell technologies”**

The most comprehensive study on FC from an economic perspective this far is “The Economic Dynamics of Fuel Cell technologies” from 2003 edited by Avadikyan, Cohendet and Heraud. This compilation is the result of a research contract carried by BETA (bureau d’Economie Théorique et Appliquée, University of Louis Pasteur of Strasbourg and CNRS) for IFE (Institut français de l’Energie) on public-private networks for developing fuel cell technologies at an international level.

The book is separated in two parts, the first dealing with “FCT: Diffusion perspectives and governance of an emerging innovation” and consist of four chapters: a state of the art chapter: diffusion perspectives and barriers, a chapter on the future of FC in a long term inter-technology competition framework, a chapter on rationales for cooperation between firms and states within an emerging radical innovation and finally the potential economic impacts of FCT. The second part deals with FC vehicles and consists also of four chapters analysing the four different, but most important regions, USA, Canada, Japan and EU.

The objective of the book is “understanding the governance of innovation networks in the field of FCT” and “the book aims at providing an overview and an analysis of the modes of governance of the innovation system which has been emerging progressively around FC over the last decade” (Avadikyan et al 2003: 3).

---

<sup>2</sup> I have participated on this projects and was responsible for the patents study and I also wrote a piece on the norwegian FC projects and policy implications of these. This resulted in my master thesis.

This book focuses in great part on the innovations in FC vehicles which they identify as the most radical area, but this is also the area where the technology will last on the market. A weak point is therefore that they don't study innovations that are much closer to commercialisation.

**Hall and Kerr: "Innovation Dynamics and environmental technologies: the emergence of fuel cell technology". Journal of cleaner production 11 (2003) 459-471**

This paper explores the dynamics of environmental innovation using the case of Ballard Power system and their PEM FC technology. The article analyses the value chain and supporting infrastructure for the FC for automobiles through the value added chain model. Is FC a radical technology (competence destroying)?

**Pilkington, A. "Technology portfolio alignment as an indicator of commercialisation: an investigation of fuel cell patenting" Article in press. Technovation 2003.**

- patenting in FC used as indicator of commercialisation

**Mytelka, L. "New wave technologies: their emergence, Diffusion and impact- the case of hydrogen fuel cell technology and the developing world" (2003)**

Mytelka focus on FC as a New wave technologies (NWT) and "new wave technologies tend to fuse product and process innovation at the experimental stage, that is the laboratory" (Mytelka 2003: 10), furthermore, moving an innovation from laboratory to the market, moreover, Mytelka argues, increasingly requires partners and a pattern of precocious partnering for research and development as well as standard setting has developed in industries based on ICT's (Mytelka 2001) and biotechnology (Mytelka 2003). This, in turn, has given rise to changes in competition in the emergent and transitional phases of these technologies. In contrast to arms-length firm to firm competition characteristic of earlier wave of technological change, in industries based on new wave technologies competition takes place among networks of firms bound to each other through a variety of alliances" (Mytelka 2003: 12).

**Clark, W.W., Paolucci, E and Cooper, J. (2002) "Commercial development of energy-environmentally sound technologies for the auto industry: the case of fuel cells" Journal of cleaner production 11 427-437 and Clark, W.W. and Paolucci, E (2001) "Commercial development of environmental technologies for the automotive industry towards a new**

**model of technological innovation” International Journal of Technology Management, Vol.21, No 5/6, 2001**

These two articles discuss Zink-Air FC and the transfer from R&D lab to the mass market and the impact in the automotive industry.

**Schlecht, L. (2003) “Competition and alliances in fuel cell power train development” International Journal of Hydrogen Energy 28, 717-723**

-using game theory to make a basic model to depict the optimal strategy of the automotive industry.

**Bos, P.B. (1996) “Commercialising fuel cells: managing risks” Journal of power sources 61, 21.-31.**

This is an article on commercialising and from that perspective it is already old. This article focus on the financing risks associated with FC commercialisation .

**Wengel, J. and Schirrmeister, E. ed. (2000) “the innovation process from the internal combustion engine to fuel cells. Opportunities and Risks for Baden-Wurttemberg Industry. Final Report**

This report focus on FC for automotive industry in a region in Germany

#### **4.2 What is missing? The approach of this thesis and why this is important**

It is obvious that the previous studies of FCT have not approached the subject from an evolution of industry and emerging technology angle. Most of the studies relate to use of FC in the automotive industry, and from the reviews of the articles we saw that the previous work had focussed on: “commercial development of environmental technologies for the automotive industry” (articles by Woodrow and Clark and the book by Avadikyan, Cohendet and Heraud), on “Competition and alliances in FC power train development” (Schlecht), “Innovation dynamics and environmental technologies: the emergence of FCT” (Hall and Kerr), and “investigation of FC patenting” (Pilkington).

This thesis will as stated earlier focus on the emergence of FCT and the evolution of the FC industry. The FC industry is then understood as those private firms producing FC.

We will focus on what is identified by Avadikyan et al as the key industrial actors in the development of FCT: the FC producers (Avadikyan et al:4) and a global study of this industry using the theoretical framework described in section 2 has not yet been conducted.

## **5. Trends and data collection**

This part consist of a short overview of the countries where FC firms are located and the science and technology indicators of that country in FC. We also give a brief account of the analytical technique that will be employed.

FC consists of different components that are integrated into systems and these components are: fuel cell stacks, anode, catode, converters, fuel supply, fuel reformers, materials, membranes etc. In this thesis the focus is set on producers of fuel cell systems, i.e. firms that are doing R&D or offering products; a fuel cell system to a market (or a potential market). Following this, we define a fuel cell firm as “a firm that is involved in R&D and/or production of fuel cells for a market”. We do not consider component producers, marketing or other related firms as a fuel cell firm. The fuel cell firms constitute the fuel cell industry and we found this to be 150 firms worldwide. The countries that are leading in number of firms, publications and patents were 5: USA, Japan, Germany, Canada and UK. These countries had both most of firms, patents and publications. France, China and Brazil had many firms but few papers and patents. Denmark, Sweden and Italy were strong on science (publications) but had few firms producing fuel cells.

Data collection will consist of two parts:

1. Part: Survey to the 150 FC firms where we will gather information about the firm, innovations made, R&D spending, Products on the market, alliances etc. It might also be good
2. Part. Conduct interview with FC market analysts if this is possible.

PriceWaterhouseCoopers, Fuel Cell today, Frost & Sullivan, and ABI research are following the FC industry closely and publish reports every year (these reports are unfortunately very expensive)

2. Part. Identify the key actors in the FC industry. Size, localisation, and innovativeness, importance for the commercialisation of FC, trace knowledge flows. Then interview a selection of these firms (costly to travel so this has to be considered thoroughly, dependent on finance)

**Geographical delimitation:** Global (but how well is the countries performing? and why (triadic differences?) how is the Nordic countries performing?)

## **6. Timetable for Completion**

1. Literature survey: spring 2004.
2. Survey sample: Spring 2004
3. Survey: 1. survey fall 2004, 2. January 2005.
4. Interview and visit to firms: 2004-2006 → Data collection finished
5. 2005-2007: writing of thesis.

## **7. Literature**

Abernathy and Clark (1985) "Innovation: Mapping the winds of creative destruction"  
Research Policy 14 3-22

Andersen and Tushman (1990) "Technological Discontinuities and dominant designs: A cyclical model of technological change. Administrative Science Quarterly, 35: 604-633

Avadikyan, Cohendet and Heraud, ed. (2003) "The Economic Dynamics of Fuel Cell technologies" Springer Verlag Berlin 2003

Bos, P.B. (1996) "Commercialising fuel cells: managing risks" Journal of power sources 61, 21.-31.

Clark, W.W., Paolucci, E and Cooper, J. (2002) "Commercial development of energy-environmentally sound technologies for the auto industry: the case of fuel cells" Journal of cleaner production 11 427-437

Clark, W.W. and Paolucci, E (2001) "Commercial development of environmental technologies for the automotive industry towards a new model of technological innovation" International Journal of Technology Management, Vol.21, No 5/6, 2001

Hall and Kerr, "Innovation Dynamics and environmental technologies: the emergence of fuel cell technology". Journal of cleaner production 11 (2003) 459-471

Henderson and Clark (1990) "Architectural innovation: The reconfiguration of existing Product technologies and the failure of established firms" Administrative Science Quarterly, 35:9-30

Klepper, S. (1996) "Entry, Exit, Growth and Innovation over the Product Life Cycle" The American Economic Review, vol.86, No. 3 (Jun. 1996) 562-583.

McGahan (2000) "How industries evolve" Business Strategy Review, 2000, Volume 11 Issue 3, pp1-16

Mytelka, L. (2003) "New wave technologies: their emergence, Diffusion and impact- the case of hydrogen fuel cell technology and the developing world", INTECH discussion paper series #2003-3

Nelson, R. (1995) Co-evolution of technology, Industrial Structure and supporting Institutions, and the making of comparative advantage" International Journal of the Economics of Business Vol. 2, No.2

Pilkington, A. "Technology portfolio alignment as an indicator of commercialisation: an investigation of fuel cell patenting"

Suarez and Utterback (1995) "Dominant designs and the survival of firms" Strategic management journal, Volume 16, Issue 6 (sep. 1995), 415-430

Schlecht, L. (2003) "Competition and alliances in fuel cell power train development" International Journal of Hydrogen Energy 28, 717-723

Utterback, J. (1994) "Mastering the dynamics of Innovation" HBS Press.

Wenngel, J. and Schirrmeister, E. ed. (2000) ""the innovation process from the internal combustion engine to fuel cells. Opportunities and Risks for Baden-Wurttemberg Industry. Final Report