Innovation in Fuel Cells and Related Hydrogen Technology in Norway:

Patents and Knowledge Interactions in a System of Innovation

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Thank you Lilja for supporting me and everything else.
Abstract

This thesis is an investigation of innovation in fuel cells and related hydrogen technology in Norway from 1990-2002. The main focus is an analysis of the innovation activities that took place in Norway within the area of fuel cells and related hydrogen technology. Were they a result of cooperation among different actors in sharing and developing knowledge, or rather a result of in-house R&D efforts, conducted independently by the firms?

The point of departure for the thesis was an analysis of patents undertaken by at least one Norwegian inventor in the field of fuel cells and related hydrogen technology in the period 1990-2002 in Norway, EU or USA. This patent analysis resulted in 83 patents and involved by 14 assignees (firms).

The firms were specialised in semi-fuel cells for use in unmanned submarines, fuel cells for heat and energy production, in production of hydrogen, storage of hydrogen in carbon material, and in membranes that can be used in fuel cells. This analysis was supplemented by 14 interviews of key actors identified by the patent analysis.

The analytical framework used in this thesis comes from the Systems of Innovation approaches and we make use of the National innovation systems approach and the technological systems approach as these are complimentary and together provide a good theoretical fundament for the thesis.

The results showed that the patents were a result of cooperation between firms, but in-house R&D was also seen as an important source of knowledge for innovation. The actors were internationally oriented, especially towards EU and the frameworks programmes. Even so, there was still a strong commitment towards building a Norwegian environment through cooperation and national competence building.

Key words: Innovation, Innovation systems, fuel cells, hydrogen, patents
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<th>Description</th>
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<tr>
<td>FC&amp;RHT</td>
<td>Fuel Cells and Related Hydrogen Technology</td>
</tr>
<tr>
<td>SI</td>
<td>System of Innovation</td>
</tr>
<tr>
<td>SIA</td>
<td>System of Innovation Approach</td>
</tr>
<tr>
<td>NIS</td>
<td>National Innovation System</td>
</tr>
<tr>
<td>TS</td>
<td>Technological System</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>SOFC</td>
<td>Solid Oxide Fuel Cell</td>
</tr>
<tr>
<td>PEM</td>
<td>Proton Exchange Membrane Fuel cell (also known as PEFC)</td>
</tr>
<tr>
<td>AFC</td>
<td>Alkaline Fuel cell</td>
</tr>
<tr>
<td>MCFC</td>
<td>Molten Carbonate Fuel Cell</td>
</tr>
<tr>
<td>PAFC</td>
<td>Phosphoric Acid Fuel Cell</td>
</tr>
<tr>
<td>FFI</td>
<td>Norwegian Defence Research Establishment</td>
</tr>
<tr>
<td>IFE</td>
<td>Institute for Energy Technology</td>
</tr>
<tr>
<td>NHD</td>
<td>The Ministry of Trade and Industry</td>
</tr>
<tr>
<td>UFD</td>
<td>The Ministry of Education and Research</td>
</tr>
<tr>
<td>NFR</td>
<td>The Research Council of Norway</td>
</tr>
<tr>
<td>SND</td>
<td>The Norwegian Industrial and Regional Development Fund</td>
</tr>
<tr>
<td>NIFU</td>
<td>Norwegian Institute for Studies in Research and Higher Education</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-governmental Organisation</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>SME</td>
<td>Small and Medium sized Enterprises.</td>
</tr>
<tr>
<td>CMR</td>
<td>Christian Michelsen Research institute</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined Heat and Power Production</td>
</tr>
</tbody>
</table>
1. Introduction

This thesis is an investigation of the innovation system for fuel cells and related hydrogen technology (FC&RHT) in Norway, and is part of a OECD project on innovation FC&RHT, which has been undertaken by NIFU (Norwegian Institute for studies in research and higher education) in a national case study of Norway.

FC&RHT is understood as the basis for the hydrogen society or economy, which has become a common term in politics and media for describing hydrogen as the potential main energy carrier in the future. This is a result of the increasing negative effects that pollution has had on the environment and the ensuing formulation of policy and strategies towards a more sustainable future. The Kyoto agreement on reduction of CO$_2$ requires a shift from fossil fuel containing carbon to less polluting alternatives. As part of fulfilling the Kyoto agreement, California has formulated the Zero Emission Vehicle act, which requires that at least 4% of all vehicles sold as of 2003 must be zero-emission cars. This act had an enormous effect on the development of technology and production of fuel cells, (Palm & Hedsten 2000: 14-15) as this would result in an enormous emerging market. The fuel cells and hydrogen technology community, has experienced increasing focus in the media and several non-governmental organisations (NGO) state that hydrogen is the future energy source that will provide society with clean and safe energy.

In order to obtain an understanding of the innovation processes in FC&RHT, we will in the following employ the system of innovation approach (SIA) as an analytical framework and we make use of two complementary perspectives from the SIA- the National Innovation System approach (NIS) and the Technological Systems approach (TS). The reason for this is that this thesis has a national focus, whilst at the same time, a technological bias.
The NIFU project is the first innovation study of fuel cells and related hydrogen technology in Norway. There are some studies of NGO’s and their role in promoting hydrogen as the future energy carrier\(^1\) and in addition there exists some innovation studies on fuel cells in Norway.

This thesis deals with both fuel cells and related hydrogen technology, as these two technologies are strongly interrelated, hydrogen being the primary energy source for fuel cells. Another reason for analysing fuel cells and hydrogen technology together is that Norway is a major energy-producing nation in the world has a history of hydrogen production.

1.1 Focus of the thesis

The main focus of this thesis can be related to the insight from innovation theory regarding the nature of the innovation process and to what extent this may explain how innovation activities evolve in FC&RHT. A key question pertains to whether the innovation process is a product of deliberate R&D efforts by a firm, or if the innovation process is a systemic phenomenon, a result of interaction between heterogeneous agents operating in a market. This is an important question when employing the systems of innovation approach, since a salient feature of this approach is that innovation happens as a result of knowledge interaction between actors in the ‘innovation system’, i.e. in a country, a region, a sector or a technological field.

When analysing the innovation process for FC&RHT, the point of departure has been a patent analysis, focussing on the actors behind the patent i.e. the inventors and the topic for the patent. This provides an interesting picture of the innovation activities in a country since a patent is a tangible result from an innovation process and patenting involves a complex effort from the inventors and assignees.

\(^1\) For instance there are two ESST theses dealing with Bellona’s role in hydrogen
As a first step, all inventors were identified, and patent citations were analysed to see whether these are mainly citations to national or international actors. Patents also reveal technological field and cooperation between firms.

The next phase of the empirical work was based on interviews with the inventors and the focus was on how the invention was created, on interaction between the actors in the innovation system, the importance of citation to previous patents, what kind of knowledge was used in the patent, project cooperation, and government funding.

As we will see in the following, the results from the analysis show that the patents were a result of cooperation between firms, but in-house R&D was also seen as an important source of knowledge for innovation. The actors were internationally oriented, especially towards EU and the frameworks programmes. Even so, there was still a strong commitment towards building a Norwegian environment through cooperation and national competence building.

1.2 Methodology

The methodology for this thesis was aimed at giving a picture of the innovation system for FC&RHT in Norway. In order to do this we had to consider what kind of data could provide us with some insights in this respect. Patents provide a good account of what is being produced in a scientific field as well as actual inventions. The methodology therefore consists of a patent-analysis, supplemented with information from the actors on their innovation activities, gathered from home pages on the internet. This gives a more complete picture of the innovation activities they have in Norway. During this work the search-engine Google was used in order to search for possible homepages of the assignees. An assignee is the firm that have financed the R&D which lead to the patent and in many cases they own the property rights. A few findings were found here, that were important for the analysis and which were
not evident from the patent analysis in isolation. However, the patent analysis constitutes the quantitative empirical source. This will be supplemented with interviews with key actors identified as the main inventors from the patent analysis and as well as interviews with two scientist that did not have any patents but who where identified as important for the analysis. The interviews will give a more dynamic picture since patenting takes time and the patents analysed here are therefore at least a couple of years old.

1.2.1 The data

The empirical findings in this thesis are based on both qualitative and quantitative methods. First, an analysis of a set of collected data on patents made by Norwegian inventors, which have been applied for either in Norway, EU or the USA where conducted. Therefore, not all patent families were categorised as this fell out of the delineation of the thesis. Citations in patents are a tool for measuring explicit knowledge embodied in inventions or in the Science and Technology field they belong to.

The patent applications have been analysed with regards to what kind of R&D the actors have been undertaking in the Norwegian innovation system, with focus on finding connections between them in form of alliances, project cooperation and more informal networks, and, the importance of these interactions for the innovation process. The data are structured around revealing knowledge flows and networks in the innovation system and that are salient for innovation activities. The next part of the empirical work was the qualitative part and this consisted of interviews with the key actors in the field.

The data sources in this thesis are:

- 83 Patents 1990-2002 filed in EU, USA or Norway
- 14 interviews with key actors in the innovation system (appendix C)
1.2.2 Using patents to analyse Systems of Innovation

In this thesis patents are used to identify innovations and as a measurement of innovation activities, so it is a natural task to explain what patents are and how they can be used to analyse systems of innovation. A patent is a contract between the inventor and society that gives the inventor exclusive rights to use his or her invention commercially for a limited period and the knowledge that lead to the invention is then in return revealed to society. This is supposed to have the effect of encouraging people to invent (gain profit) but also to reveal their knowledge, so that others can use that knowledge as a building block in their R&D efforts. It is not hard to imagine that if inventions where not patented, a lot of firms with big R&D expenditures would be out-competed by firms who would imitate the technology and therefore only have production costs to consider. Hence, “in order to make R&D expenditure pay, and therefore stimulate innovation, inventions are protected from competition by patents” (Stiglitz 1997: 413).

There are three legal requirements a patent must fulfil (Meyer 2000: 413). The first is the legal responsibility of the applicant to describe previous art. This means that “he or she must set out the background in such a way as to show how the claimed invention relates to, but is innovatively different from, what was already public knowledge” (Collins and Wyatt 1988 cited in Meyers 2000: 413). The second requirement is that a patent should have inherent usefulness, or utility. This implies that the invention must have a potential for commercial application. The third requirement is that a patent should have novelty. It is also expected that the potential inherent in the patent will be followed by active development of a product and be non-obvious. According to Iversen, “this contractual relationship relates to the assignee’s basic desire to gain profits from the invention and the system’s basic desire to have details of the invention spread to others so that the system can build on new knowledge. In this sense, the patent-system acts as an incentive-mechanism for the
creation of new economically valuable knowledge and a knowledge-distribution mechanism. As such it is a central element of the knowledge-infrastructure that underlies the innovation system” (Iversen 1999:1-2).

The quote from Iversen tells us that patents are important aspects in an NIS analysis and their importance have grown to become a necessary strategic dimension that firms have to deal with. The type of knowledge that can be identified from patents is “the technical capabilities that are manifested in inventions and which are made visible as utility patents” (Iversen 1999: 1). This refers to the idea that the patents identified in this thesis, can be said to give a picture of the technical capabilities that exist in the SI for FC&RHT in Norway. This is important for an analysis of what kind of technological fields actors are specialised in, or if there exists some division of labour between the firms in the innovation system.

A common method when studying patents is to use citations as indicators of knowledge diffusion. This method is also employed in this thesis and therefore some issues regarding this method are treated. The citations found in the patent are both to previous patents and to scientific articles. In many studies using patents as an indicator, citations to previous patents are said to “open the possibility of tracing multiple links across inventions” (Jaffe and Trajtenberg: 2002:1). This method can be employed because patent applications include rich information about the patent, inventor, assignee etc. and can thus be used for tracing knowledge diffusion and interaction between the actors in the innovation system. Citations to other patents are necessary due to the claim of novelty, “the technological frontier is defined and the invention’s claim’s of novelty is tested” (Iversen and Kaloudis 1999: 23). These citations to previous patents are there for the requirement of explaining novelty i.e. what is new with this invention, what is the previous art (preceding patents)? The citations open up the possibility of tracing knowledge flows between patents, and therefore also
diffusion of knowledge between actors (assignees) in an innovation system, as well as flows between countries.

Another method used in patent analysis is that of tracing citations in patents to scientific articles. This is said to reveal the relation between science and technology because:

“In cases where that which helps define novelty is found not in patented technology but published scientific articles or conference proceedings, there is a strong suggestion that the technology builds directly on the work from the scientific community and thus indicates a close relationship between industry and universities. As a result, the best known technology/science linkage indicators are patent citations of scientific papers” (Iversen and Kaloudis 1999: 23).

The method described by Iversen and Kaloudis in the quote above, of linking science to technology through citations in patents to scientific articles, is also employed by Meyer (2000). He states that the science-to-technology linking in this method necessarily indicates that a linear relationship from science to technology exists. Meyer identifies six motives for citing non-patent literature and only one that can be said to constitute a direct link from science to technology. This motive must be based on the fact that “prior art is not yet documented. Examiner thus relates progress in the examined patent application to a scientific publication” (Meyer 2000: 415). This means that the field is new and that there have been very few if any patents before. This makes it valid to cite articles in some instances and is in accordance with the method proposed by Iversen and Kaloudis.

1.2.3 Limitations of patent analysis

Various limitations of patent analyses exist, the most obvious being that of secret knowledge and tacit knowledge. Secret knowledge indicates that the innovator keeps the process/product
secret and therefore has no need to patent. Tacit knowledge alludes to the fact that a lot of innovation is not replicable. Firms might choose not to patent because of the high costs of doing this, but also because a lot of the firm’s knowledge used in the innovations is tacit knowledge and embodied in the firms workforce. The need to patent is therefore gone, since the crucial knowledge used is ‘sticky’\(^2\) and therefore cannot be transmitted to other firms as information (imitation from competitors is not possible).

Patents can be used as a means for mapping the competence base of firms, a process wrought with several obstacles. Carlsson et al (2002: 241) find three important problems regarding patent analysis of competence bases can be identified. The first problem is when one wants to identify a population on knowledge-based criteria. The US patent classification system is not always structured around specific knowledge areas, but is product based. This means that products based on very different technologies and fields all fall under the same category. The second problem is that patent holding does not necessarily reflect a deep knowledge in a particular field. A separation between those who ‘apply’ a technology and those who ‘develop’ a technology is here in order. Those who apply might not have a large knowledge base of the chosen field since they do not develop the technology. The third problem is that patents reflecting knowledge for developing a technology may be found in many classes and it can be hard to find those that are central. Carlsson et al (2002: 242) suggest that when investigating the different patents that are important for a particular field, such as biomaterials (the example they use), this could involve for instance patents made by already identified actors, combined with different keywords and a look at patent citations (tracing knowledge flows) since these give a picture of what knowledge is used in the process

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of innovation. This should then be supplemented by a qualitative analysis, such as an interview with the assignee or inventor to validate the findings.

1.2.4 Building a patent-database

The patents were gathered from the Delphion database in the period stretching from the second of April to the second of May 2003. The patents were those applied for between 1990-2002 in EU, USA or Norway. Due to time constraints there could also be that some patents have not been included in the database, but that is impossible to avoid in a master thesis. The fact that the search also spans over several technological fields and disciplines also contributes to make this a difficult task. All the important patents are thus present, as the assignees were interviewed in a later phase.

The first search conducted on Delphion had the description “fuel cell*” and country “Norway”- this resulted in 19 patents. Following, a search for “hydrogen technology” and “hydrogen storage” was performed. This resulted in 43 patents all together. The next step was to search for the inventor names and also names from articles on the subject. This resulted in a total of 81 relevant patents. Some of the patents belonged to more basic research such as material science, however, this type of research is actually quite important for improvement of the technologies in question, and several referred to use in fuel cells or in hydrogen technology as area of use for the patent. This gives rise to a question as to where one should draw the line with regards to which patents to include in the analysis. Only patents, which are directly dealing with fuel cells and uses hydrogen as fuel? Or can production and storage of hydrogen be seen as important for improvement in hydrogen technology? What about basic research activities, such as development of new materials or new types of membranes for fuel cells, should they be part of the analysis? When answering these questions experts from the research council of Norway gave valuable assistance and a dialogue with some of the
researchers as to what part (if any) of their work was related to fuel cells and hydrogen technology. The conclusion was that a broad understanding of FC&RHT was employed.

A meeting was also held with the patent board in Norway where the methods used and the technological field discussed. The patent board was hired to conduct a search in their database to see if something relevant was missing. The search was defined as “Fuel cells” and “hydrogen storage”. The patent board found 10 patents and 8 of the 10 patents from the Norwegian database were also registered in Delphion, 2 were not. The total amount of relevant patents was finally 83.

The patents were then separated into different sub-categories according to what kind of technological field they belonged to: fuel cells, hydrogen storage, hydrogen production, membranes, new materials or processes.

The next step was to gather the information from the patents and collect them in a database. While working on this database, a decision had to be made as to what kind of information should be gathered. A patent document often consists of around 30 pages of textual information and clearly not all of this can be put into a database. Some of the information is also quite technical, which could be demanding for a person without a technical education. The elements chosen were firstly, the title of the patent and the date of application. The assignee, i.e. the company or institute the invention is assigned to, which is normally the place where the inventor works. Below are listed those elements which were used in the database:

- Patent number (US, NO or WO)
- Title
- Inventor(s)
- Inventors address
The technical information gathered was ‘abstract’, which gives a short and concise description of the patent, and ‘first claim’, which constitutes the most important feature of the patent. The information from the abstract and first claim was used to identify the technical field that the patent belonged to. Here, we differentiated between fuel cells, hydrogen production, hydrogen storage, membranes, material science and processes. These were the fields we found patents in and that where meaningful to categorise. Inventor and assignee are used for identifying location, and cooperation in the innovation system. Citations are as before mentioned used to trace knowledge flows.

1.2.5 The interview phase

In the second part of the work with the thesis, a selection was made of the most important inventors in the dataset. This was a strategic choice based on the work with the patent database and reflected the purpose of giving an account of the working of the innovation system, understood as knowledge interaction processes. 14 interviews were conducted and 10 were devoted to key inventors. The other 4 were of important actors in the innovation system and two were main actors from the Norcell project and two others have key positions in one

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3 Norcell was the first fuel cell project in Norway and is treated later in the thesis.
of the main actors. The interviews involved 12 major assignees. Several assignees were not
important as they were either small firms abroad or firms owned by inventors who had their
main job other places. These interviews gave important additional information on the
workings of the innovation system and provided some insights into shortcomings that a pure
patent analysis would lead to. The most important assignees and inventors were interviewed
and this provided the thesis with what was experienced as a thorough and adequate data
material for further analysis.

1.3 Research questions

The main research question in this thesis is:

- What kind of innovation processes were evident in FC&RHT in Norway in the period
  from 1990-2002? Were they systemic innovation processes based on knowledge
  interaction among heterogeneous actors or were they based on in-house R&D in
  firms?

In order to answer these questions, a patent study was conducted. The relations between the
actors identified by this study and the knowledge flows between the actors were analysed.
The results from these analyses are presented in a map on page 61 showing patents and the
relations among the actors in the period 1990-2002. The purpose with this map is to present
the patents made in Norway in this period in the field of FC&RHT, i.e. who made them and
what was the important input to the innovation process?

An important question that deals with the process of innovation is whether or not a linear
model or an interactive innovation model can explain the technology which is being studied.
This question is important for the application of the ‘SIA’ approach to the empirical matter.
Thus in the following we will analyse knowledge interactions and focus on whether they are important for innovation or if the innovations are a result of in-house R&D solely.

1.4 **Structure of the thesis**

Chapter 2 provides an explanation of the technologies that are being studied in this thesis, and the last part of the chapter examines some challenges related to these technologies.

In Chapter 3 we take a closer look at the analytical framework, and present here the different understandings of innovation, as well as the SIA. Also the two chosen approaches within the SIA are presented, NIS and TS.

Chapter 4 consisted of an empirical analysis of the innovation system in Norway FC&RHT and it identifies the institutional set-up and analyses the patents.

Chapter 5 analyses different aspects of the innovation system for FC&RHT in Norway with regard to actor relations and knowledge interactions. A map illustrating the patents and the relations among the assignees is presented in this chapter.

Chapter 6 sums up the main findings of the thesis and discusses some policy implications that came to light during this thesis.
2. The technology explained

This part presents the FC&RHT and will first start with the working of the fuel cell (FC), the most important types of fuel cells and their areas of application. In the second part, hydrogen technology will be treated. Finally, the challenges that have to be solved with FC&RHT will be examined.

2.1 Fuel cells and related hydrogen technology

2.1.1 Fuel cells

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 (Thorstensen 2001: 9).

![Figure 1. Taken from New Scientist, 16. August 2003 showing the working of a fuel cell](image)
In short, a FC is a technology, which enables production of electricity because of a chemical reaction between hydrogen and oxygen. In figure 2 the working of the fuel cell is explained and shown graphically and, in principle, the fuel cell works as a battery and when hydrogen and oxygen react together in the fuel cell, they combine and produce electricity with water as the exhaust.

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 CO₂ 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.

In table 1.1 the five types of fuel cells are presented and it also shows their working temperatures, electrolyte and area of application.

<table>
<thead>
<tr>
<th>System</th>
<th>Temperature Range</th>
<th>Cell Total Efficiency</th>
<th>Electrolyte</th>
<th>Area of Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFC</td>
<td>60-90 °C</td>
<td>50-60%</td>
<td>30-50% KOH</td>
<td>Space flight, road vehicles, submarines</td>
</tr>
<tr>
<td>PEFC</td>
<td>50-80 °C</td>
<td>50-60%</td>
<td>Proton conducting polymer membrane (Nafion®)</td>
<td>Space flight, road vehicles, heat/electricity cogeneration plants, submarines</td>
</tr>
<tr>
<td>PAFC</td>
<td>160-220 °C</td>
<td>55%</td>
<td>Concentrated phosphoric acid</td>
<td>Electricity production, heat/electricity cogeneration plants, road vehicles</td>
</tr>
<tr>
<td>MCFC</td>
<td>620-660 °C</td>
<td>60-65%</td>
<td>Molten carbonate K₂CO₃</td>
<td>Electricity production</td>
</tr>
<tr>
<td>SOFC</td>
<td>800-1000 °C</td>
<td>55-65%</td>
<td>Ion-conducting ceramic (yttrium stabilized zircon oxide)</td>
<td>Electricity production</td>
</tr>
</tbody>
</table>

Table 1.1 taken from “fuel cells for vehicle propulsion ZSW” by Jorissen and Garche 2000: 17.
Alkaline fuel cells (AFC) have one advantage and that is that they are relatively cheap. But they have a disadvantage and that is that they need pure hydrogen and are sensitive to CO₂. Therefore they are mainly used in space flight. Phosphoric Acid Fuel Cells (PAFC) use concentrated phosphoric acid as electrolyte and carbon black coated platinum catalysts are used. PAFC use hydrogen from hydrocarbons as fuel and is for the most part used in heat/electric cogeneration, but there have been trials in buses. Solid Oxide Fuel Cells (SOFC) use an electrolyte that consists of an oxygen-ion conducting ceramic and it is typically used in stationary heat/electricity cogeneration plants. There is some ongoing research on using small SOFC in transportation. The high temperature makes it possible to convert hydrocarbons directly. Molten Carbonate Fuel Cells (MCFC) operates at high temperatures and is used in electricity production. Polymer electrolyte membrane fuel cells (PEM, which in table 1-1 is labelled as PEFC) have an electrolyte made of a thin, acidic ion exchanging and this acts as a proton conductor. A key problem with PEM is that the membrane can dry out and this makes water management important. PEM is in large part used in transportation and is by many considered the most successful in that sense.

The separation of fuel cells is normally between high temperature and low temperature fuel cells. This mean that AFC, PEM, PAFC are low temperature, while MCFC and SOFC are high temperature. The areas of application are also different so that the low temperature FC is mainly used for transportation while the high temperature FC is used for electricity production.

### 2.1.2 Hydrogen technology

Hydrogen technology is strongly related to fuel cells, since hydrogen is the crucial energy carrier in fuel cells. When talking about fuel cells and related hydrogen technology, we therefore make use of the acronym FC&RHT. Fuel cells and hydrogen technologies are inter-
related technologies i.e. complementary, and therefore meaningful to analyse together. As an example of this, hydrogen cars are dependent on other technologies for their success. First of all, to produce such a car one needs a fuel cell at a reasonable price so the car can be sold in large scale. Hydrogen must be stored in the car and there are several problems related to this. We also have to consider from where one shall obtain the hydrogen? This reminds us that stations supplying hydrogen are needed, and then again, hydrogen must also be produced at a reasonable price and by processes which involve an environmental benefit compared to regular gasoline. The ongoing research on fuel cells and hydrogen technology in most OECD countries is intense, policy makers in the U.S. and EU are investing heavily in these fields.

According to some, one billion $ in the USA and one billion € in EU is devoted to fuel cells and hydrogen R&D (The Economist 15-21st February 2003).

**Decarbonisation**

According to Ausubel (2002), the trend in energy evolution has been and still is decarbonisation. According to him, this process has continued for over 130 years but it was first commented in the 1980’s. Decarbonisation means a gradual evolution to less carbon based energy sources and this process has happened without anyone pursuing it or even noticing it until 1980’s. This is important for environmental reasons because as Ausubel states, what matters is the rate of carbon to hydrogen, the H:C ratio, on fuels and that this process has happened without anyone noticing⁴ (Ausubel 2002:4)

<table>
<thead>
<tr>
<th></th>
<th>H:C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>0.1:1</td>
</tr>
<tr>
<td>Coal</td>
<td>0.5:1</td>
</tr>
<tr>
<td>Oil</td>
<td>2:1</td>
</tr>
<tr>
<td>Gas</td>
<td>4:1</td>
</tr>
</tbody>
</table>

⁴ A further conclusion he draws from this is that energy policy does not matter because the evolution towards more use of hydrogen is happening anyway (predetermined), still though he leaves room for policy questions such as those regarding CO₂ sequestration.
The carbon to hydrogen ratio means how much CO$_2$ emissions there be will when energy is produced from the energy source. This means that wood is the most polluting and gas the least of the alternatives above. The scenarios of a large-scale shift to Hydrogen as an energy carrier, does not take into the account that we are already in the hydrogen society, we just have to remove the carbon. The energy sources we use today, mainly oil and gas, are hydrocarbons. They are in other words a combination of hydrogen and carbon. The idea of shifting to pure hydrogen in fuel cells or directly in combustion is to strip away the carbons and as a consequence, reduce pollution dramatically. If we look into this issue historically, we can see that each period has its own energy source, and this energy source is being replaced by a more efficient and in environmental terms, superior energy source.

2.2 Challenges of fuel cells and related hydrogen technology

As with all other technologies in the development phase, FC&RHT have serious challenges that must be solved before they can have a real impact on the market. In this thesis a central point is that fuel cells and hydrogen are inter-related technologies, which must be analysed in a systemic manner. When doing this we follow Martin who suggests that when studying energy technologies “one needs to consider technological change as systemic, i.e. beyond the introduction and diffusion of individual technologies” (Martin 1996: 81). To exemplify this I can mention how hydrogen cars are dependant on other technologies, such as fuel cells, membranes, hydrogen storage alternatives etc.

First the challenges with fuel cells are treated, then hydrogen technology.
2.2.1 Fuel cells

The biggest problem for commercialisation of fuel cells is the price. Fuel cells cannot compete in price with other technologies such as the combustible engine in cars. Solutions could be tax reductions and sponsoring of environmental friendly alternatives, but since this is an analysis of technological problems and possible solutions that is excluded from the analysis. The effect of economies of scale, (i.e. prices will fall due to mass production) could be a solution to get lower prices. Fuel cells can then experience increasing returns with adoption. This means that when the technology is adopted by the market, it will experience rapid growth in sales, which gives the producer the ability to lower the prices and this again affects the sales (Arthur 1989: 116-117). This is known as positive feedbacks in the economy. One limitation, which can be experienced so that diminishing returns accompany adoption instead of increasing returns, is when resources become scarce. Arthur uses the example of hydro-electric power which “becomes more costly as dam sites become scarcer and less suitable” (Arthur 1989: 117). This is because the producer can only produce a certain amount of energy from the dam, so when demand rises, the price follows. The same problem is evident with some fuel cells such as PEM and PEFC which have platinum as a key component, a scarce and expensive resource. Increasing returns with adoption will therefore not take place. Innovations in material science are therefore needed to solve this problem and replace platinum as a component with new materials. Another problem, especially with PEM, is that it is vulnerable for impure hydrogen.

2.2.2 Hydrogen technology

There are two aspects with hydrogen technology that are important to solve, namely storage and production of hydrogen.
Storage of hydrogen

One of the major barriers with regard to hydrogen as an energy carrier is the lack of satisfactory storage alternatives. Hydrogen takes up too much space and if hydrogen is to be used in large scale, then basic problems related to storage have to be solved. Several possible solutions to this problem have been proposed. According to a Bellona\(^5\) report there are basically three options (Kruse et al 2002: 26)

- Hydrogen may be compressed and stored in a pressure tank.
- Hydrogen may be cooled to a liquid state and kept cold in a properly insulated tank.
- Hydrogen may be stored in a solid compound, such as in a metal hydride, in carbons, methanol or in gasoline and other hydrocarbons.

When analysing the patents, applications in these fields have been looked into in order to try to find out in what field the Norwegian effort is focusing and if there is some kind of division of labour among the actors in the Norwegian innovation system. Safety concerns about using hydrogen in travel also have to be solved.

Production of Hydrogen

A challenge involved with hydrogen is how one shall obtain it. Hydrogen is the most abundant component in the world, it exists everywhere. The problem is that it does not exist in a pure form; it always combines with other atoms. Therefore, hydrogen must be obtained from somewhere and that involves use of energy. It is therefore important that hydrogen is

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\(^5\) Bellona is a NGO in Norway and has a good knowledge base in hydrogen technology and problems with the technology. They have imported to hydrogen mini buses and are setting up Norway’s first hydrogen filling station in Oslo in August 2003. Homepage: http://www.bellona.no
produced at an acceptable price and that it involves a process that in the end will have positive environmental effect.

The ways hydrogen can be produced are:

- Fossil raw materials, mainly coal or natural gas.
- Electrolysis of water with electricity from renewable sources such as wind and solar energy
- Electrolysis of water with electricity from nuclear power and other sources

The important difference here is between the renewable alternative and the alternative using fossil fuels for production of hydrogen. This difference also separates the EU from the USA in their attitude towards hydrogen production in the future. EU seeks to produce hydrogen from renewable sources, while the US want to use fossil energy sources (The Economist February 15th - 21st 2003: 75). The US alternative still makes the cities cleaner because of zero emission cars.

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6 There’s an ongoing debate whether or not it is an environmental solution to use nuclear energy to produce hydrogen
3. Analytical framework

This chapter outlines a framework of analysis that is going to be applied to this case study of innovation in FC&RHT in Norway in the period 1990-2002.

The chapter is divided in two parts and in the first we present the different models of innovation, and in the second part the Systems of Innovation approach (SIA) is presented.

The outline of this chapter is as following: first we will give an account of the concept of innovation and the different understandings of innovation as either linear or interactive.

The second part of this chapter presents two approaches which can be labelled as belonging to the SIA and that are NIS and TS. Finally we look into some conceptual problems with NIS.

3.1 Models of Innovation

Several different approaches towards innovation exist, and these can be separated in two main categories, the linear understanding of innovation and the interactive understanding of innovation. First we give an account of the linear model of innovation and then move into explaining the interactive model of innovation.

3.1.1 Linear model of innovation

Shortly after and as a result of the radical innovations during the Second World War, such as the atom-bomb, the radar and the jet-plane to mention some, innovation became something that was best interpreted as a linear process which started in basic science. The new knowledge invented in the science lab was then transformed into technology and the technology was introduced to the market. Innovation was, in short, understood as a linear
process and a result of deliberate R&D. A report which contributed significantly to this understanding was Vanevar Bush’s report “Science, the endless frontier” from 1945 to the National Science Foundation in the USA. Science was important during the First World War, but this was strengthened even further during the Second World War, when the Manhattan project and its outcome at Hiroshima impressed people around the world with the power of Big Science.

This linear model of the making of the atom bomb is easy to understand and reductionistic, it sees the innovation process as a result of a ‘science and technology-push’ and from this can one only explain radical innovations as starting in basic science.

Dosi (1982: 147) states that this extreme technology push approach “fails to take into account the importance of economic factors in shaping the direction of technical change” this means that a science and technology push theory, sees the advances in the lab as what drives and constitutes economic change. The social, political or even the market needs are held out of the analysis.

On the opposite end, we find the pure demand pull (market pull) theories which according to Dosi (1982: 149) has as basic argument, “there generally exists a possibility of knowing a priori the direction in which the market is pulling the inventive activity”. This perspective neglects to give an explanation of how the innovations were created and fails to take into account radical innovations. These explanations of the innovation process rely on the idea of a ‘first mover’ (Dosi 1982), in the first case it is science which is the first mover, in
the latter it is the market. In modern innovation theory both of these perspectives are brought

together and one sees the innovation process as a result of both advances science and needs

from the market signalling to the producers which needs exist.

According to Kline and Rosenberg (1985: 286) a weakness of the linear model is that

“there are no feedback paths within the ongoing work of the development processes. Nor are

there feedbacks from sales figures or from individual users.” Their position is that all these

forms of feedback are essential to evaluation of performance and shows the direction further
to chose. So then, is the linear model an outdated mistake proven unworthy by history?

The model is still valid according to some, but only in few instances, and Kline and

Rosenberg also open up for this possibility, for “new science does sometimes make possible
radical innovations. These occurrences are rare, but often mark major changes that create

whole new industries, and they should therefore not be left without consideration. Recent

examples include semiconductors, lasers, atom bombs, and genetic engineering “(Kline and

Rosenberg 1985: 293).

3.1.2 The interactive model of innovation

The interactive model\(^7\) is a more recent understanding of the innovation process than the

linear, and it is based upon the concept of interactive learning, which we can define as “a

process in which agents communicate and even cooperate in the creation and utilisation of

new economically useful knowledge” (Lundvall et al 2002: 226). This indicates that the focus

is on interaction between different actors and this understanding of innovation is strongly

influenced by Schumpeters` broad definition\(^8\) of innovation as “new combinations of existing

pieces of knowledge, whether drawn from science, engineering, market research,

\(^7\) An important predecessor to the interactive model was the chain-linked model to Kline and Rosenberg as

expressed in their article (1985)

\(^8\) As understood by Jan Fagerberg in his article (2001: 8)
organisational experience or other sources, but with a view to commercial application”
(Fagerberg 2001: 8)

Interactive denotes to the fact that the explanation of the direction of innovation is
non-linear. It does not try to explain the innovation as either a result of deliberate R&D in
basic science or as a pure market pull. The innovation can of course be a radical new
innovation produced in a lab, such as a new material for use in computers, but one could also
say that the inventors were looking in that direction (searching). This kind of explanation is
non-linear and feedback is an important aspect of directing the innovation activities. In both
the science push and the market pull theories, the explanation resides on what Dosi (1982)
labelled a ‘first mover’, and this is not the case with the interactive model of innovation. Here
the sources of innovation can come from a broad range of actors, such as users, producers and
manufacturers, and in most cases, the innovation is a result of interaction between several of
the actors. This is compatible with the evolutionary insight, that firms never innovate in
isolation, but interact with other organisations to gain, develop and exchange knowledge,
information and other resources. They interact with firms, but also universities, research
institutes, schools, government ministries and others.

As we can see, this focus on interactive learning points to the fact expressed by
Lundvall (1992: 9) that not all important inputs to the process of innovation come from
science and R&D efforts, but also that a lot of learning takes place in connection with routine
activities in production, distribution and consumption. These learning effects produce
important inputs to the process of innovation. The different ways of learning that we have
presented above go back to several authors. The idea of innovation as a process resulting from
‘learning-by-doing’, can be traced back to Arrow and his paper “The economic implications
of Learning by doing” from 1962, ‘learning-by-doing’ is seen as a source for technological
improvement (innovation) and can “only take place through the attempt to solve a problem and therefore only takes place during activity” (Arrow 1962: 155)

‘Learning-by-using’ can be traced back to Rosenberg’s book “Inside the black box: technology and economics” from 1982. Rosenberg defines ‘learning-by-using’ as “ways of improving the design and operation of new improvement that become apparent only by observing difficulties or opportunities that emerge during the actual operation of the new equipment” (Rosenberg 1994: 196). The quote tells us that the experience from using a technology is seen as a rich source for incremental innovation.

Finally, the contribution in form of ‘learning by interacting’, which involves users and producers in an interaction resulting in product innovations, can be traced back to Lundvall’s article “Innovation as an interactive process: from user-producer interaction to the national systems of innovation”, but maybe first of all back to Von Hippel’s book “The Sources of Innovation from” 1988. In this important work Von Hippel focuses on what he identifies as the different sources of innovation and demonstrates empirically that innovation happens not only as a consequence of R&D, but must be understood as a complicated process of knowledge diffusion between different actors, and that the sources of innovation differ significantly between categories of innovations. He replaces a manufacturer-as-innovator assumption with a view of the innovation process as predictably distributed across users, manufacturers, and suppliers. The innovations functional source stems from users and suppliers, and not only manufacturers (Von Hippel 1988: 44).

As these examples show, the interactive model sees the input on innovations as coming from a broad range of actors and from different sources in different situation. Interaction is an important element in this perspective since it involves knowledge diffusion (learning) which is the most important asset for innovation.

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9 the book was released at the same time as Lundvall’s article, but Lundvall cites Von Hippel’s 1976 article “the dominant role of users in scientific instruments innovation process”. Research policy no.5.
The next part of this chapter is an analysis of the SIA.

3.2 Systems of innovation – National systems and technological systems

SIA addresses firms engaged in innovation and looks at how these interact with each other, and how these are constrained and enabled by the environment, such as policy makers. In the SIA literature there are two different approaches, one that focuses on the geographical determination of the innovation system and the other that sees the technology at hand as determining the innovation system. The geographical approaches study innovation activities in a country or in a region, while the technological oriented approaches study how the development of technologies that are inter-related happens or how innovation occur in a sector. These two different approaches must be seen as complimentary rather than contradictive, it depends on the object of study.

Edquist defines a ‘system of innovation’ as something that pertains to “all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations” (Edquist 1997: 14). The point that the above quote states is that innovation is a process that takes place, not in isolation, but in a network between different actors. This definition is also general for all the different types of SIA.

When using a SIA perspective as analytical framework, it is necessary to explain what a ‘system’ means. We therefore start out by defining a system as “a set or arrangement of things so related or connected as to form a unity or organic whole” and that a system consists of “components, relationships and attributes”(Carlsson et al 2002: 233-34). The components are the actors in the system, relationships are the links between the components in form of feedback (interaction) which makes the system dynamic. The most important relationship is technology transfer. Attributes are the properties of the components (their function) and it is the relationships between them that characterise the system. Since the function of the system
is to generate, diffuse and use technology, the capabilities of the actors to do this, is the main feature in the system.

A central point of this approach is that the behaviour of firms and others engaged in innovation are shaped by institutions that create constraints and incentives for innovation. Those are laws, health regulations, cultural norms, social rules, technical standards etc.

In this thesis the innovation system of Norway in a specific technological field is the object of study and it can thus be concluded that both these approaches are legitimate to use as analytical framework. A NIS analysis always has the Nation as object of study and it is a more macro oriented study than TS which study inter-related technologies. The technological system can be national, regional or trans-national, it is an empirical question. We study innovation in inter-related technologies, FC&RHT, in Norway from 1990-2002, therefore both these approaches are used.

This section is divided in four parts. Firstly, the evolutionary elements of SIA and the aspects of knowledge are treated. Secondly, NIS is treated and then TS, finally we treat some conceptual problems with SIA.

3.2.1 Evolutionary theories of innovation and knowledge

Among the evolutionary influences on SIA, the seminal work by Nelson and Winter in “An evolutionary theory of economic change” from 1982 by far constitutes the most important one. They give a concise critique of the mainstream assumption of innovation and economic growth which the ‘neo-classical’ economists stand for, and introduce ideas taken from biology to economic studies. The idea is that when studying activities in the economy, one should focus on how firm and organisations evolve and change over time. This notion needs a new vocabulary and they use concepts like ‘variation’ and ‘selection’ to accomplish this. An
economy need variation in its stock of firms and they go through a selection process where only the most fitted survive.

Nelson and Winter presented in their book an account of organisational behaviour and its relation to innovation. This was in essence a theory on how firms “think”. Nelson and Winter apply Polanyi’s theory of tacit knowledge to organisational behaviour. Polanyi defined tacit knowledge as “to be able to do something, and at the same time be unable to explain how it is done” (Nelson and Winter 1982: 76). The opposite of tacit knowledge is explicit knowledge and it can easily be codified. In Nelson and Winter’s theory, firms’ behaviour is thought to follow the principle of “bounded” rationality, which they adopt from behaviourism. Bounded rationality means that it is impossible to have perfect knowledge of all alternatives, therefore one cannot make a complete rational decision, in real life, “decision problems are too complex to comprehend and therefore firms cannot maximize over the set of all conceivable alternatives” (Nelson and Winter 1982: 35). Furthermore, the firms are assumed to follow decision rules (routines), and these determine behaviour together with impulses from the environment.

A central point in the evolutionary perspective is that knowledge “is not a general category which can take the form of a free good, (...) it is localised, highly specific and often tacit” (Smith 1991: 261). This means that knowledge cannot simply be taken from one situation and directly used in another situation. Smith goes on to reason that, “to have a particular productive capability involves hierarchies of knowledge, which appears at different levels of abstraction and with different functional characteristics” (Smith 1991: 261). This hierarchical view of knowledge indicates that knowledge can be seen as more or less codifiable, which is relevant for a codification process and the distribution of knowledge. An evolutionary understanding of knowledge creation, regards knowledge as something that is endogenously generated within firms. The capabilities of firms in production and distribution
of knowledge are therefore differing. This creates variation in knowledge bases in firms and therefore also in the economy.

We will now further analyse the characteristics that knowledge can possess. It has already mentioned the view on knowledge as either tacit or codified, whilst presenting Nelson and Winters evolutionary account. Now will the notion that knowledge also can have the property of being either sticky or mobile be added. This distinction has to do with to which degree knowledge can be transferred from person to person through IT systems (mobile), or if it is sticky and therefore highly context-dependent. Mobile knowledge is codified and can be transmitted. Von Hippel introduced the term ‘Sticky data’ which means that, “knowledge does not travel freely” (Cowan et al 1999: 6), and refers to the idea that tacit knowledge is located inside scientists and engineers heads. Therefore R&D investments do not need to be protected with expensive patents and copyrights. The understanding of ‘sticky’ knowledge means that business entities can protect their investment by “a mixture of trade secrecy law and labor law, governing the behavior of current and former employees” (Cowan et al 1999: 7). Therefore knowledge created in small firms can be protected as a consequence of being less mobile and their problem with expenses on patents and copyrights are minimized.

These evolutionary ideas of firm’s behaviour and the different characteristics of knowledge are important for this analysis. We are going to analyse innovation activities in FC&RHT in Norway from 1990-2002 and we will use a patent analysis complemented with interviews to accomplish this. Patents are described in documents and therefore codified knowledge which is freely available. The innovation process also involves more tacit elements, and these can not been written down in patent documents. It is therefore important to supplement the patent analysis with qualitative interviews to try to supplement the patent

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11 It is a fact that patenting is costly and that it is often done by big companies with possibilities of pursuing any violation against their inventions in court. Small firms may not have this opportunity and may chose to keep the knowledge secret.
information with respect to knowledge inputs from persons, inputs from working on projects with other firms or input from articles and previous patents. This methodological approach, patent analysis supplemented with interviews of inventors, will provide a rich source of information of the knowledge input to the innovations.

The next part presents firstly NIS and secondly TS, and thirdly some conceptual problems with the SIA.

### 3.2.2 National Innovation System

The National Innovation System was the first concept that was invented in the SIA and it originates far back in history. In 1841 Friedrich List introduced the concept of ‘national systems of production’\(^{12}\), which took into account a wide set of national institutions such as those related to education and training, as well as networks for transport of people and commodities (Lundvall et al. 2002: 3). List’s system was quite similar to the NIS approach in that it operated on a national level and focused on organisations and institutions as drivers of innovation.

NIS as a concept was introduced by Christopher Freeman in his seminal work “Technology policy and economic performance – lessons from Japan” in 1987, however, Freeman acknowledges Lundvall as the first to coin the expression. There are three paradigmatic publications which made way for the NIS field, and these are the earlier mentioned book by Freeman, and two anthologies – one edited by Bengt-Åke Lundvall (“National systems of innovation: Towards a theory of innovation and interactive learning” from 1992), and the other edited by Richard Nelson (“National systems of innovation” from 1993).

\(^{12}\) Freeman and Soete remarks that he could just as well called it national systems of innovation (Freeman and Soete 1997: 295)
We will now give a definition of NIS and look into some salient features with this approach towards innovation.

NIS is an inter-disciplinary approach, which has been employed in order to describe the network of organisations in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies. Niosi et al gives a striking definition of NIS:

“a national system of innovation is the system of interacting private and public firms (either small or large), universities, and government agencies aiming at the production of science and technology within national borders. Interaction among these units may be technical, commercial, legal, social, and financial, inasmuch as the goal of the interaction is the development, protection, financing, or regulation of new science and technology” (Niosi et al 1993: 212)

As we see, Niosi et al emphasise that interaction between heterogeneous actors\(^\text{13}\) is the focal point in the innovation system. This is known as interactive learning processes whose role is to secure the necessary flow of knowledge between the parts in the system, and knowledge is seen as fundamental to innovation.

Two elements that are crucial in the NIS approach will now be presented, that is ‘interactive learning’ and the role of ‘institutions’ in determining innovation. The micro foundation of NIS rest on the idea of ‘interactive learning’, while the effect on their behaviour are dependent on the role ‘institutions play’. First we give an account of interactive learning, after that we continue with institutions and their role in enabling and constraining innovation.

\(^\text{13}\) heterogeneous mean that the actors are of a different type, i.e. they are not similar
Interactive learning
Interactive learning is an important feature of NIS and it constitutes the micro foundations of the theory. In “National systems of innovation: Towards a theory of innovation and interactive learning”, Lundvall understands learning to be of crucial importance for innovation, for, “in practically all parts of the economy and at all times, we expect to find ongoing processes of learning, searching and exploring, which results in new products, new techniques, new forms of organization and new markets” (Lundvall 1992: 8). Lundvall clearly views learning as being the main component for innovation in a society.

There are different ways of learning and according to Tidd et al (2001: 99) this is:

- Independent R&D
- Reverse engineering
- Licensing
- Hiring employees from innovating firm
- Publications or open technical meetings
- Patent disclosures
- Consultations with employees of the innovating firm

Interactive learning was defined as “a process in which agents communicate and even cooperate in the creation and utilisation of new economically useful knowledge” (Lundvall et al 2002: 226) in part 1 of this chapter, since it is a distinct model of innovation. Interactive model of innovation was a predecessor of the SIA and the learning element is key characteristics of all SIA. Innovation is not a linear process which starts in R&D in science labs, but an interactive process among heterogeneous actors operating in a market.

We will now move on to present the role of institutions in the SIA.
Institutions

‘Institution’ is a concept that is being used in two different ways, the first refer to an institution as a type of organisation, such as a university, research laboratory, or a patent office. This is the narrow definition of institution or ‘formal institution’. The second way an institution is being used is in its ‘sociological’ meaning, which is known as the broad understanding of ‘institution’. Edquist and Johnson make a definition of institutions widely understood as “sets of common habits, routines, established practices, rules or laws that regulate the relations and interactions between individuals and groups” (Edquist and Johnson 1997: 46). This understanding connect the original meaning which they trace back to sociology through the work of the institutional economists (especially Veblen), with interactive learning. So when using the broad concept of ‘institution’ in an SI analysis it is because of the assumption that ‘institutions’ is determining the rate and direction of innovative activities. ‘Institutions’ are then, in an SIA context, understood broadly as norms, habits and rules and narrowly as a type of organisation.

This means that institutions “play a major role in determining how people react to each other and how they learn and use their knowledge” (Lundvall et al 2002: 220). This role of institutions as determining innovation directly, advocates the study of NIS since habits, rules and norms, in large part follow national borders. Lundvall characterises institutions as guideposts for actions in a SI, and since uncertainty always will be an important aspect of economic life, institutions make it possible for economic systems to survive (Lundvall 1992: 10).

A further point that Lundvall makes is “in this context, we may regard technological trajectories and paradigms, which focus the innovative activities of scientists, engineers, and technicians, as one special kind of institution”. Lundvall here make a connection between the SIA and the works of Nelson and Winter (1982), and Dosi (1982).
3.2.3 Technological Systems

As stated earlier in this thesis, there are two major concepts of SIA identified in the literature on innovation and we make use of two of them, NIS and TS. The difference is that NIS focus on the national aspects of innovation, while TS focus on the technological aspects to innovation. Carlsson and Stankiewicz define TS as “a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology” (Carlsson and Stankiewicz 1995: 49). This means that TS study the network of actors that are doing innovation in a certain technological field, and focus’ on the interaction between them and the impact this has on innovation.

A technological system is both disaggregated and dynamic: this means that there are many TS in a country and they evolve and change over time. Put differently, there exist several TS, but only one NIS in a country, so several TS can together constitute a NIS. TS also uses a systemic view towards innovation, but looks more into the development of different technologies than NIS, which has focus on innovation dynamics in a certain country.

According to Carlsson et al (2002: 237) “technological systems involve market and non-market interaction in three types of network: buyer-supplier (input/output) relationships, problem-solving networks, and informal networks”. They further state that it is the problem-solving network that defines both the nature and the boundaries of the system: where do various actors in the system turn for help in solving technical problems? As we see from the quote, TS is more specified to certain technological fields than a NIS analysis. The focus is on solving technical problems. When applying the TS approach in an empirical analysis one has to delineate the system and this may involve different level of analysis. According to Carlsson et al. there are three levels of analysis in an TS: “to a technology in the sense of a knowledge field, to a product or an artefact, or finally to a set of related products and artefacts aimed at
satisfying a particular function, such as health care or transportation” (Carlsson et al. 2002: 217). We will now use this method by applying it to FC&RHT.

The first level of analysis is concerning a technology and this could be analysed in its application or in its use. An example of this could be an analysis of a single fuel cell or maybe a membrane for hydrogen separation. The second level of analysis regards a product, and a product may consist of several technologies. For instance, a fuel cell stack, which consist of several fuel cells, membranes, interconnect and other technologies. The third level of analysis is the multi-product case where the focus is on a set of products which are related by having a common market and, operate under the same institutional arrangement and therefore share a common selection environment. The technological system of FC&RHT belongs to this category. The next part treats some conceptual problems with the SIA.

3.2.4 Conceptual problems with the system of innovation approaches

This part will look into two conceptual problems with the SI approaches. Firstly we discuss the relevance of NIS in a globalising world. Secondly we discuss the conceptual diffuseness of the SIA.

The first thing to consider, is whether or not it is meaningful to use the concept of NIS in an economy characterised by globalisation, i.e. an economy characterised by increased processes of cross-border activity and interdependence of production, and markets for goods and services. These processes clearly make the national aspects less important since both globalisation and also regionalisation are processes that weaken the coherence and importance of national systems. With this in mind Lundvall advocates a position that sees the globalisation trends as making it even more important to understand the role and workings of national innovation systems. This he explains is due to the fact that innovation is an uncertain activity and with a lot of tacit knowledge involved in the process therefore, “when the parties
involved originate in the same national environment-sharing its norms and culturally based system of interpretation, interactive learning and innovation will be easier to develop” (Lundvall 1992: 3-4). A decade later, Niosi comes to the same conclusion and states that: “the less mobile factors of production and the most crucial for innovation are human capital (comment: tacit knowledge), governmental relations, public and semi-public institutions, and natural resources. For all these factors borders and location matter” (Niosi 2002: 292).

As we can see from the quote above, institutions which is a guiding principle for action, follow national borders to a large degree. Therefore this argument for studying NIS is easy to accept.

In a later paper, Lundvall argues the policy dimension of the concept is important and “as long as nation states exist as political entities with their own agendas related to innovation, it is useful to work with national systems as analytical objects” (Lundvall et al. 2002: 215).

Niosi et al (2002: 213) makes a further point in that increasing technical collaborations between universities, corporations and government labs have occurred due to the implementation of EU programmes such as the framework programmes

14. This process is followed by a “harmonisation of technology policies of different countries (2002: 213)” and they ask if these processes have made the way for the birth of a ‘European- system of innovation’ which will be more important than the national ones.

Edquist makes two points about the SIA. First, a problem with the SI approach is that there is no general agreement on what should be considered part of the system, and that there is a vague understanding on the system boundaries. This makes it difficult to determine the system and the concept can be understood as blurry.

A further weak point made visible by Edquist is that there do not exist one common understanding of the SIA. Researchers in the field employ the concept of SIA in varying

14 Norway is part of the EU framework programmes through the EEC agreement.
ways. Because of this diversity Edquist proposes that instead of looking at SIA as a theory, he prefers “to label the systems of innovation approach as a conceptual framework (…) which many scholars and policy-makers consider to be useful for the analysis of innovation” (Edquist 1997: 30).

To sum up this part, we can conclude that a SIA analysis, have to identify the actors in the field and interaction between them. If the national aspects are weak or non-existing, another concept may be preferred than the NIS approach, such as a regional focus or a sectoral focus.

As we have seen, NIS and TS have different focus for studying innovation activities, but they are not contradictory. One could argue for a NIS analysis with a focus on the development of a certain TS in that country. This would necessarily have the country as object of study and the technological system as object of study at the same time. The strongest element in NIS and that a TS analysis lacks or is weak at, is the focus on ‘institutions’ as determining behaviour and innovation in a country. The TS on the other hand, has a focus on interrelated technologies and are stronger at that. Therefore we use elements from both approaches, we see institutions as being nationally strong and important for determining behaviour. We also see technologies as inter-related and to analyse them in relation to each other is fruitful. This constitutes the framework for analysing the FC&RHT system in Norway in the period 1990-2002.

The next chapter provides a mapping of the innovation systems for FC&RHT in Norway. The methodology consists of a patent analysis that is supplemented with interviews of key actors. The analysis focuses on technological field, key actors in the system, institutional set-up as well as patent families.
4. Mapping out the innovation system for fuel cells and related hydrogen technology in Norway

The innovation system consists of institutions and actors, and the interaction between the actors in the system has salience for innovations, since this is how knowledge is transferred. The links between the actors “consist of flows: knowledge, financial, human (people being the bearers of tacit knowledge and know-how), regulatory and commercial” (Niosi 2002: 291).

This chapter gives an account of the actors in the innovation system for FC&RHT in Norway, and we present the formal institutions, such as ministries and governmental institutions that implement innovation policy. These institutions are responsible for the regulatory and some of the financial flows important for the actors in the SI. Actors and institutions are separated into primary and secondary actors.

The first part of this chapter is a presentation of the institutional set-up and the second consist of the analysis of the patents that are grouped after technological field, as well as according to the projects they belonged to. Three such projects where identified in Norway in this period and they were all in the field of fuel cells. These projects will be presented below.

4.1 Institutional set up

This part presents the institutional set-up for the innovation system for FC&RHT in Norway. An important part of empirical analyses of SIA is to define the actors involved and the factors that shape the process of innovation. Following Liu and White (2002: 1094) we separate between primary and secondary actors, as this makes the SIA more rigid. Institutions are used
both in a narrow and a broad sense of the concept. In the following, are the formal institutions (narrow) and their impact in the system and label these the secondary actors.

There are different ways of identifying the actors in the innovation system in a country or in a technological system. We started with a patent-search on FC&RHT and this can be used for tracing networks and interaction between firms/institutes in them. Based on the patent search the most important actors were ranked according to number of patents. Since this is an analysis of the institutional set-up in Norway, we differentiate between the innovators and those that affect innovation in an economy, that is, the government and its instruments. These firms and institutes were defined as the primary actors in the innovation system and these were identified by the patent analysis. The formal institutions constitute the structure of the system, they enable and constrain the possibilities to innovate.

4.1.1 Secondary actors – formal institutions that affect innovation policy

We separate between those that formulate innovation policy and those that implement it. Those that formulate innovation policy are the ministries. The ministries are all involved in funding, but the most important are probably the ministry of education and research (UFD) and the ministry of trade and industry (NHD). The Norwegian policy formulation is based on a ‘sector-principle’, which means that the responsibility for promoting and funding is based on the sector the ministry is responsible for. Even so, UFD has the overall responsibility for the innovation policy and for coordination of the policies of each sector (Ørstavik and Nås 1998: 6), while NHD is responsible for building up and maintaining a competitive business environment.

The formal institutions that implement the innovation policy in Norway are the research council of Norway (NFR) and the Norwegian industrial and regional development fund (SND). NFR was established in 1993 after a merger of the former five research councils.
NFR is the institution that “bears overall responsibility for national research strategy and manages nearly one third of public-sector research funding sector. One of the principal tasks of the Research council is to promote co-operation and co-ordination among the Norwegian research institutes” (Ørstavik and Nås 1998: 8). This means that the power to implement innovation policy as formulated by the ministries, is centralised in one institution, NFR, and they coordinate interaction between the research institutes and organise national R&D projects.

SND is the other formal institution that implements the innovation policy in Norway. Their objective is to fund industrial and regional development in Norway. Their main instruments are “grants for innovation related activities, loans for such activities and for other ‘change generating’ activities like development and acquisition of new capital goods, warranties that enable firms to get loans from private financial institutions, and a general venture fund” (Ørstavik and Nås 1998: 9).

Together these two institutions, NFR and SND, implement the innovation policy in Norway. NFR focuses directly on R&D in firms, research institutions and universities, while SND bear the overall responsibility for promoting start-ups and small and medium sized enterprises (SME).

### 4.1.2 Primary actors - firms and research institutes that undertake fundamental activities

The innovating actors in the SI were identified from the patent analysis and were later interviewed. Below the different assignees are given a presentation and they are grouped into private firms and research institutes.
Private firms

- Kværner
- Statoil
- Hydro
- Prototech
- ABB
- Due miljø AS
- Clean Carbon Energy
- Leiv Eriksen's Nyfotek

Norwegian research institutions

- Institute for energy technology (IFE)
- Norwegian defence research establishment (FFI)
- Sintef

The first observation is that there are no universities among the eleven assignees in the data set. Four of the assignees are large corporations, three are public research institutes, three are SME’s, and one is a venture firm. Hydro and Statoil are the two largest corporations in Norway. Statoil is the public oil and gas company and it is in large part state-owned. Hydro is another giant in Norwegian industry and its main areas are oil and gas, as well as aluminium and fertilizers. Statoil and Hydro are the two Norwegian assignees with most patents granted in the US (Iversen 1999: 8), and they are operating in the energy market, so it is no surprise that they have a dominant position in the data set. Kværner is also a giant in the Norwegian business environment and they operate in the field of oil and gas, engineering and construction, and pulp and paper. ABB is a Swiss-Swedish giant and they are involved in a
range of different businesses, but they are not very active in patenting in this field in Norway. Due miljø AS, Prototech and Clean Carbon Energy are SME’s. The three research institutes all play an important role in Norway.

4.2 Analysis of Norwegian patents on fuel cells and related hydrogen technology

This part is an analysis of patent activities in fuel cells and related hydrogen technology (FC&RHT) in Norway in the period 1990-2002. First, an overview of the patents is given, then they are analysed according to the category they were defined as belonging to. The patents are divided into technological categories:

- Fuel cells
- Hydrogen storage
- Hydrogen production
- Membranes
- New materials
- Processes

The purpose is to give an overview of assignees\(^{15}\) and inventors, the technological field they are patenting in, and the relationship between the identified actors. This will be treated in this chapter. Finally an analysis is also given of patent families that are a commonly used method to trace important patents.

\(^{15}\) Assignee was defined in chapter one as the firm that have financed the R&D which lead to the patent and which in many cases own the property rights to the patent
4.2.1 Overview of patents and assignees in the innovation system

This part gives an overview of the actors and the results of their innovation efforts, interpreted by patent from the period 1990-2002 in Norway. The analysis consisted of a search for patents applied for by at least one Norwegian inventor in the field of FC&RHT. The results were entered in a database and further analysed. In addition an investigation of the links between the assignees and the inventors were also undertaken.

As we can see from table 2.2, 14 firms or institutes have one or more patent related to FC&RHT. Kværner has by far the most patents, 37 in all. The next is FFI with 11 patents and Statoil with 10 patents. Hydro has 4, Sintef has 3 and, IFE, Clean carbon energy and Prototech has 2 patents.

<table>
<thead>
<tr>
<th>Assignee</th>
<th>Fuel cell</th>
<th>H2 storage</th>
<th>H2 prod.</th>
<th>Membrane</th>
<th>Material</th>
<th>Processes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kværner</td>
<td>13</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td>37</td>
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<tr>
<td>Statoil</td>
<td>7</td>
<td>3</td>
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<td>10</td>
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<tr>
<td>Sintef</td>
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<tr>
<td>IFE</td>
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<td>Clean Carbon Energy</td>
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<tr>
<td>Prototech</td>
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<td>2</td>
<td></td>
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<tr>
<td>FFI</td>
<td>11</td>
<td></td>
<td></td>
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<td>11</td>
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<tr>
<td>Norsk Hydro</td>
<td>3</td>
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<td>1</td>
<td></td>
<td></td>
<td>4</td>
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<tr>
<td>M.M.M. S.A.</td>
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<td>Due miljø AS</td>
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<td>L.E. Nyfotek</td>
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<tr>
<td>Siemens, Norway</td>
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<tr>
<td>Donaldson co inc.</td>
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<td>1</td>
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</tr>
<tr>
<td>Private</td>
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<td></td>
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<td>5</td>
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<tr>
<td>ABB</td>
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<td></td>
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<td>1</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31</strong></td>
<td><strong>17</strong></td>
<td><strong>29</strong></td>
<td><strong>4</strong></td>
<td><strong>1</strong></td>
<td><strong>1</strong></td>
<td><strong>83</strong></td>
</tr>
</tbody>
</table>

There are also six firms or institutes with one patent, and five patents are without assignee (private person). Two of the actors with one patent are foreign firms, but with at least one Norwegian co-inventor.
The next step in the analysis was to analyse the different patents according to the technological field they were classified as belonging to and possible links between the assignees were investigated in form of co-patenting, researchers that are registered as inventors for different assignees and citations in patents.

The following section is organised according to the technological categories. In the category of fuel cells, the patents are analysed after the project that they belonged to or as ‘other fuel cell patents’, meaning those that did not belong to one of the big projects. The next is category is hydrogen storage, then hydrogen production, membranes, material science and finally processes. Elements in the analysis are the patent application area, the knowledge sources that were important in the making of the invention and citations in the patents.

In the last part of section 4.2 we analyse patents which are belonging to patent families, this means that the same invention is patented in more than one country. The analysis of patent families say something about the importance of the invention, since patenting in several countries is expensive.

4.2.2 Fuel cells

In the period 1990-2002 there are thirty-seven patents on fuel cells assigned to Norway. They belong to seven firms and five private persons. There were three quite large fuel cells projects in the 1990s in Norway: Norcell, Mjøllner and Hugin. The two latter projects directly resulted in nineteen of the fuel cell patents, but can also be related to three other patents, as the inventors from these projects also patented privately or in other small firms. No patents could be traced directly to the Norcell project that had a Norwegian inventor, but Hydro confirmed in an email that they have partially ownership in four patents assigned by Ceramatec, an US firm.
The fuel cells patents from the Hugin project is presented first, then the Mjøllner patents and then Norcell is treated and there is no patents that can directly be traced to this project in Norway. Then Norsk Hydro’s patents are treated and finally the other ‘fuel cells patents’.

**Hugin**

Hugin is an unmanned underwater vehicle, used for mapping and surveillance of the seabed. The fuel cells used in Hugin are semi-fuel cells, which use hydrogen peroxide and seawater as fuel. This was a joint project between FFI and Statoil, but Siemens was involved in one patent. The knowledge behind the patent was a consequence of problems with hostile submarines that allegedly, were trespassing into the Norwegian coast during the cold war. The Norwegian defence wanted to produce surveillance solutions in form of echo-sound located at the sea bottom. The question was how to supply them with energy! FFI came up with the idea of using sea-water batteries. After the cold war Statoil used the batteries in petroleum production offshore, but their application diminished. Statoil financed these stationary batteries entirely. FFI produced a battery for a submarine that had a long range (1000 hours) and this resulted in the Hugin 3000 submarine which is now licensed to Kongsberg- Simrad and has been commercialised. The battery used in the Hugin 3000 is entirely a FFI patent. The stationary batteries are now in use in the Japanese sea for seismic activity such as earthquakes. The Hugin project is probably the most successful Norwegian project on fuel cells as of today.

FFI has eleven semi-fuel cell patents, and only three refer to previous patents. The patents referred to are in large part patents from the USA, from actors such as Lockhead, US Navy, Globe Union and Westinghouse Electric Corp., but also the military in Canada and Statoil in Norway (co-operation) have been cited. Statoil has two patents that can be traced to the Hugin project, neither of them have any references to previous patents.
Mjøllner

Mjøllner was Statoil’s fuel cell project and ended in 1998. It was a cooperative effort with Prototech and resulted in a 2.5 kW solid oxide fuel cell (SOFC) prototype which was demonstrated in 1997. Six patent applications can be directly linked to the Mjøllner project, and all of them are assigned for by Statoil. One of them, No 964898 “Elektrokjemisk anlegg” was disclosed the 11.02.2000.

Statoil has the patent rights from Mjøllner, but Prototech has the right to develop the technology. Statoil’s R&D department is located in Trondheim, while Prototech is located in Bergen and is connected to Christian Michelsen research institute (CMR) there.

Parts of the laboratory equipment were also taken over by Prototech. Statoil is not involved in R&D on fuel cells any more, but they are involved in an EU project on methanol fuel cells. Statoil has also bought a small Danish heat and power company where they are going to produce small fuel cells. In the Mjøllner project was a prototype was made where Statoil delivered the electrodes and interconnect, while Prototech was responsible for the system aspects of the prototype. Cooperation was also with Sintef and Risøe, a research institute in Denmark.

Several of the employees in Prototech were inventors on Statoil’s patents and had leading roles in the innovation process. Prototech is now using the knowledge from Mjøllner to further develop a SOFC. Prototech has developed the SOFC technology based on own R&D and has now made agreements with several energy producers of delivery for a SOFC to be used in combined heat and power production (CHP) plants. They have got a contract on delivering a SOFC for CHP to BKK, a power production company in the western part of Norway. This task was originally given to Norske Shell that won an innovation award in 2002 for the fuel cell. Norske Shell failed to produce it and Prototech was given the project.

In development projects such as BKK’s project, the knowledge behind the invention is based on Prototech’s own research. Prototech is now cooperating with IFE on developing
components and systems for a SOFC. Prototech and IFE have joint research and they share the patent rights. This cooperation has not yet resulted in patenting, but they expect to patent within four years.

Statoil’s patents from the Mjøllner project referred to patents from different countries. The Patent “Current collecting device for a fuel cell stack” includes citations of Sanyo Electric Co. Ltd. in Osaka in Japan, Westinghouse Electric Corp. in Pittsburgh in the U.S.A. and Dornier GmbH in Germany. The citations are to Solid oxide fuel cells (SOFC). Another of their patents cites Sulzer Hexis AG in Winterthur in Switzerland.

**Norcell**
Norcell was the first fuel cell project in Norway and started in 1984. It involved Hydro, Statoil, Statkraft, and Sintef. The patent rights were sold to the US firm Ceramatek (owned by Elkem), but Hydro has some partial ownership on four patents\(^\text{16}\) that can be labelled as SOFC patents. Two are related to an interconnect\(^\text{17}\), a field Norcell has been known for being good at. In 1989 Statoil broke out of the Norcell project and started its own fuel cells project, Mjøllner.

Norcell 2 was started around 1989 with another industrial firm, Elkem, as project leader and they established contact and cooperation with an US firm, Ceramatek. Norcell presented a SOFC in 1991 in USA. Elkem backed out of Norcell 2 in 1994 and the rights where patented in USA to Ceramatek, but Hydro has some user rights to them. The research

\(^\text{16}\) 1Semi-internally manifolded interconnect stack design (filed 1993-10-06) patent number US5376472
2 Dual column fuel cell module (filed 1994-02-04)
3 Thermally integrated heat exchange system for SOFCs (filed 27.12.1994) US5366819
4 Pin-fin interconnect for planar ceramic electrochemical cells.

\(^\text{17}\) the interconnect is connecting anode and cathode and is a critical area for degradation of the fuel cells.
council in Norway financed Norcell 2 and this was the end of state funding of R&D on fuel cells for the next ten years.

The Norcell project organised researchers several organisations and disciplines. This included researchers from Sintef, and the Centre for material science at the University of Oslo, who had knowledge both on the fundamental issues regarding fuel cells, such as materials under high temperatures and corrosion, but also on aspects with transportation.

This happened at an early stage in the development of fuel cells and the forefront of R&D was in England and USA. Norcell was a joint effort of the leading expertise in Norway to produce a successful fuel cells prototype. The researchers in Norcell used both articles and patents as information sources when they started their own R&D. Some patents by Westinghouse could be labelled as “classics” and there were the “bible” which consisted of four articles\textsuperscript{18}, all from the USA. In these articles all the different fuel cells types were tested and measured.

The knowledge involved in the Norcell project was indirectly transmitted to NorECS and Sintef. NorECS as (Norwegian Electro Ceramics AS) is a company that was started by researchers from Centre for material Science at the University of Oslo and they have a trademark on Probostat, which is a:

“measurement cell for electrical properties and permeability studies at high temperatures and in controlled atmospheres”. (http://www.norecs.com/NORECS_CELL_1.html)

\textsuperscript{18}the most important articles S.S.Penner (ed.), Assessment of Research Needs for Advanced Fuel Cells, Pergamon Press, New York, 1986
The Probostat can be used for testing and building of cells for studies, characterisation and testing of electro ceramics, fuel cell components, membrane materials etc. The inventors are considering patenting the invention.

According to informants, knowledge from Norcell was transmitted to Mjøllner as a consequence of people who worked on Norcell now moved to Mjøllner.

**Norsk Hydro**

Norsk Hydro was involved in the Norcell project but their three patents cannot be related to this project. Two of them are related to large-scale energy production where the carbon dioxide from the hydrocarbons is sequestrated below the surface of the North-Sea and these patents are important in the CO$_2$ Capture Project in Norway. The research is now focusing on membranes for separation of gases, so that the concentration of CO$_2$ will be high enough for sequestration below the surface of the North-Sea.

The knowledge used in this patent was based on knowledge that had been in the company for a long time in the work of improving the ammonia processes and in petrochemical industry.

The last patent application is a metal hydride battery, also a type of fuel cell, but this application was disclosed the 09.07.02. All the references in Hydro patents are to U.S. companies such as General Electrics, Texaco Inc and Jacobs Engineering Limited.

**Other fuel cell patents**

Clean Carbon Energy has two fuel cell patents and is a fairly unknown company. The patent is a Solid Oxide Fuel Cell and of recent date (2002). The inventors are employed by Prototech, and they are building and selling solid oxide fuel cells (SOFC), and were participating in Statoil's Mjøllner project.
ABB has one patent on wireless supply of electric energy to a number of sensors and/or actuators. This patent combines fuel cell technology with blue tooth radio communication for different industrial purposes. The inventors also have one private patent on this technology. This is a patent on an application for fuel cells i.e. it is not a fuel cells patent that has been developed, but in combination with a fuel cell as energy source. This kind of patent is a concept patent, and does not indicate any knowledge in fuel cells production. It is only to be used in combination with a fuel cell.

### 4.2.3 Hydrogen storage

Seventeen of the patents identified can be regarded as pertaining to hydrogen storage. Thirteen are assigned to Kværner, three are assigned to IFE and one belongs to M.M.M. S.A. Two Norwegian assignees have patents related to hydrogen storage- IFE and Kværner. In addition, one group of employees from Kværner has one patent assigned to a foreign firm, M.M.M. S.A from Brussels in Belgium.

When working with "Kværner Carbon Black and Hydrogen Process", Kværner invented special qualities of carbon black that can be used for storage of hydrogen. The inventors responsible were all employees in Kværner’s R&D department in Trondheim, and one of them also published for Sintef, during this period. The knowledge behind the inventions on carbon black was a result of in-house R&D at Kværner's R&D department in Trondheim. The process was first intended for offshore activities as a need for solving an energy problem. When oil is being produced, some gas is left which can not be burnt directly. Kværner wanted to crack the gas into hydrogen and carbon and use the hydrogen as an energy source, while the carbon could be transported onshore. This did not work in practice, but the process gave good qualities of carbon (carbon black). This process produces no emissions, while the traditional process for producing carbon black is extremely polluting. Kværner is
still doing R&D on the carbon black process in their research centre in Trondheim. They cooperated with Sintef (also Trondheim), and IFE, but only marginally in the beginning.

IFE has three patents on hydrogen storage in carbon materials that are similar to the ones by Kværner. The IFE patent “Hydrogen storage in carbon material” has eight references to previous patents. One of them is to the patent by Kværner, “Micro-domain graphitic materials and method for producing the same”, i.e. carbon nano-tubes which can be used for storing hydrogen. The seven other patents they cite are from abroad, six from USA and one from Germany. The other patents by IFE have no references.

IFE is a research institute with a lot of activities both on fuel cells and hydrogen technology. They have been involved in research on hydrogen in 50 years and used the nuclear reactor they possess to identify where the hydrogen is placed in a metal. This is important for R&D on storage alternatives for hydrogen. IFE has a strong advantage in the field of hydrogen storage, they have 50 years of experience to draw on and have good cooperative partners. Their reactor is said to be a key instrument due to this possibility of tracing hydrogen in the materials. This also makes them more attractive as a cooperative partner internationally. Of importance is their program ‘New advanced materials for Hydrogen storage’, which involves storage both in carbon materials and metal hydrides. There is an ongoing cooperation between Kværner and IFE on further development of the carbon black process. IFE, Sintef and Hydro cooperate on a project for building up competence on storage of hydrogen in Norway.

4.2.4 Hydrogen production

Kværner has twenty-four patents on hydrogen production and these are also related to the "Kværner Carbon Black and Hydrogen Process", which involves cracking of natural gas into hydrogen and carbon. The process became a co-production of hydrogen and carbon and a
commercial plant based on this process was built in Canada. Production was started in June of 1999 and the technology was licensed to the factory by Kværner. The factory is now closed. These patents cite US patents such as one from Hydrogen Consultants inc, one from Air Products and Chemicals, Inc, and one from Columbian Chemicals Company. There are also some European references in these patents.

Statoil has access to enormous amounts of natural gas and three patents are related to hydrogen production from natural gas.

Prototech has two patents on hydrogen production. The patent on Hydrogen production is also now in cooperation with IFE. The background for these patents is from R&D on a space travel project in which Prototech was working on recycling of air. Methane gas was separated to carbon and hydrogen.

4.2.5 Membranes

Membranes are generic technologies that can be used both in combination with fuel cells or for gas separation, such as production of hydrogen from natural gas. There are five patents on membranes in the dataset, three belong to Sintef, which is the largest private research institute in Norway and one belongs to Due Miljø, a firm located in Oslo. The inventor on all Sintef’s patents is also inventor on Due Miljø’s patent, so there exist a direct link between the two assignees. Sintef’s three patents are on “a method for manufacturing of a thin metal membrane”, which can be used in fuel cells. Sintef has projects on fuel cells as well as on hydrogen energy systems, but no patents could be found on this. Sintef lead the Norcell project from 87-91

Out of Sintef’s three patents, one has no references to previous patents, while one has a reference to a patent by Ford Global Technologies, Inc., in Dearborn, Michigan in U.S.A. The third patent has several references. Five references are to Bend Research, Inc. in Oregon
USA. concerning “Hydrogen-permeable composite metal membranes”. This patent also refers to two additional US companies, Membrane Technology & Research, Inc and Vapor Technologies Inc. NY, USA. Two Japanese companies located in Tokyo; Anelva Corporation and Orient Watch Company are also referred to and last to ‘Forschungszentrum Julich GmbH’ in Germany. All the references are related to membranes.

### 4.2.6 Material science

Only one patent can be related to material science this Norsk Hydro patent on a glass ceramic material that can be used in fuel cells. The patent is of a generic character. That means, that it can be useful in many different technologies and fuel cells is one of them.

In the patent there are four references to patents by the US firm Corning Incorporated, one reference to the RCA Corporation, which is also a US firm and one reference to Matsushita Electric Industrial Co., Ltd from Japan. All the references are to glass ceramic materials and use of them.

### 4.2.7 Processes

One patent was found on a process regarding FC&RHT and it belonged to a Norwegian firm, Leiv Erikssons Nyfotek. The inventors work for the Norwegian University of Science and Technology (NTNU) in Trondheim. NTNU is also one of the major stockholders together with Sintef. The knowledge behind the patent consisted of three PhD theses on energy optimalisation and is a classic example of in-house R&D. The support to the patenting activities has now been stopped, but the research still results in articles. The researchers were ready for patenting in the US, EU and Japan and view this area as an important one, so they are not pleased that the support for further patents was cancelled. A Dutch research institute is
now patenting in the same field as these patents. They cooperate with Siemens so it is likely that the knowledge went that way.

**Miscellaneous**

Norsk Hydro Electrolysers held one patent on an asbestos free membrane for use in electrolysis of water, but this has expired and could not be found in Delphion. Electrolysis is a process for production of hydrogen from water using electricity. The electricity separates water into hydrogen and oxygen. It is in principle a reverse fuel cell. The company was therefore contacted, and they said that the patent they had on electrolysis was old and had expired. Norsk Hydro Electrolysers is a world leader in water electrolysis and therefore an important actor in this analysis. They delivered the hydrogen filling station with electrolyser to Iceland, which has as goal to be the first hydrogen economy. Norsk Hydro cooperates with several international firms in development of a new efficient electrolyser with pressure, among them the German company GHW. The research is in great part being conducted at the research centre in Porsgrunn Norway, but R&D is also conducted in Germany. It is a network which is coordinated from the Norsk Hydro Electrolysers headquarter in Notodden outside Oslo.

Norsk Hydro also produces large amounts of hydrogen as a bi-product in ammonia production and also in the production of PVC. When the time is right, Hydro may produce hydrogen in large scale.

Norsk Hydro has started an interesting technology development-project at Utsira, a remote island outside Norway. In this project they combine already known technologies from different fields and new technology in an autonomous energy system that will supply electricity to some of the islanders independently of the electricity grid. The system consists of two wind turbines, grid stabilizing equipment, an electrolyser, a hydrogen power gen.set
and a fuel cell system and a system for storage of hydrogen. The wind turbine produces electricity and when it produces more than is actually spent, this additional electricity will be used in the electrolyser to produce hydrogen and oxygen. This additional energy is normally not saved in wind turbines. When the wind is too strong or weak and fails to produce sufficient electricity, the hydrogen is sent to the gen.set and fuel cell where it produces electricity. This system is an interesting solution for providing energy to remote places. This is due to its ability to work as a ‘stand-alone-system’ operating independently of the electricity grid. It could be used in national parks, on mountains, islands etc, where the costs of connecting to the power grid is high and the power lines are not a wanted element in the environment. This technology development project is started to test how all this components work together in a total system and the next phase will be to cut costs. The partner in Utsira is Enercon, a German wind turbine provider. Norsk Hydro has made agreements on grid handling and power supply in case of system failure with the local grid company Haugland kraft

4.2.8 Patent families

A patent family is “a set of patents taken in various countries to protect a single invention” (OECD 2001: 60). Usually it is the triadic patent family that is analysed, meaning a patent granted in EU, Japan and US’ patent systems. The concept of patent families is used by the OECD for two reasons, the first is to more accurately compare patent statistics between countries, and the second is to rank patents. The first refers to the fact that “patent indicators suffer from home advantage bias as a country will take more patents in a domestic country than in another region” and the second refers to the fact that “to create a family, a patent must be filed in several countries. The patentee takes on the additional costs to extend protection to other countries only if it seems worthwhile to do so. Thus, patents that are members of
families will generally be of higher value than those filed in only a single country” (OECD 2001: 60). The latter reason is important in this thesis since it is not a comparison with patents from other countries. It is thus important to see the patents ranked as it can give some clues as to the value seen in the patent. The patents were analysed according to these criterias, i.e. if there were any patents that were related to the same invention and patented in several countries. This study showed that none had patented in Japan, but patents were applied for in Norway, EU and US. Fifteen patent families was identified and below these patent families are treated.

<table>
<thead>
<tr>
<th>Assignee</th>
<th>Fuel cell</th>
<th>H2 storage</th>
<th>H2 prod.</th>
<th>Membrane</th>
<th>Processes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kværner</td>
<td>3</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Statoil</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Sintef</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>IFE</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>FFI</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4</strong></td>
<td><strong>4</strong></td>
<td><strong>5</strong></td>
<td><strong>1</strong></td>
<td><strong>1</strong></td>
<td><strong>14</strong></td>
</tr>
</tbody>
</table>

Kværner has eight patent families, five on hydrogen production and three on hydrogen storage. FFI has three patent families, two are semi-fuel cells and one is a chemical reactor. Statoil has one patent family “Current collecting device for a fuel cell stack” in the field of SOFC. IFE has one patent family on “Hydrogen storage in carbon material”. Sintef has one patent family on “A method of manufacturing thin metal membranes.

This analysis of the patent families shows that it is in the field of hydrogen production and storage, followed by fuel cells, that patenting has been most important. Five assignees have a patent family compared to nine assignees that have a patent in only one country.

The next chapter is an analysis of the innovation system for FC&RHT and here interaction and knowledge flows, and how these have resulted in innovations and patents are analysed.
5. Analysis of the system of innovation

This chapter identifies knowledge interactions between the actors in the SI, based on the patent analysis and involvement in inter-firm research projects, personal connection between inventors, and former employment. Knowledge interaction is an important aspect for diffusion of knowledge in the SIA. This relates to the fact that innovation is seen as an interactive process of learning and diffusion of knowledge and this knowledge constitutes the input to innovation.

5.1 Actor relations and interactions

In Figure 3 on page 61 the relations between the actors that have patented in the period 1990-2002 are shown. The relations are between assignees as these are the actors in the Norwegian innovation system and the analysis is based on the 83 patents in the dataset. The lines show the relations among the actors in the system. The relations between the actors are expressed with thick lines when there was direct co-operation in joint projects resulting in patents, the normal lines are used when there was project cooperation, but not resulting in patenting. The relation expressed in form of the dotted line indicates direct contact between inventors or employment in different firms/institutes.

The results from the analysis showed that the most important interactions were between the actors in the fuel cells projects, and the R&D on hydrogen production and storage. Sintef’s role in the innovation systems is emphasised since this was quite important for innovation in many cases, even though this was not evident in the patents analysis. This is treated later on in this section.

The interactions found in the Hugin and Mjøllner project are expressed in figure 1 with thick lines. The Norcell project did not involve any patenting in Norway, therefore it is
expressed by a normal line, between Hydro, Sintef and Statoil which cooperated on this project.

The Mjøllner project cooperation that resulted in patents for Statoil and which Prototech has the rights to use, is also expressed by a thick line. The inventor from Prototech’s patents is also inventor for Clean Carbon Energy, so here a relation to the Mjøllner project could also be observed. This relation is indirect, so it is expressed by a dotted line.

In The Hugin project, Statoil, FFI, and Siemens (1 patent) cooperated and this resulted in many patents. These relations are expressed by thick lines, and the last box, with no name in it expresses a patent by the inventors on Hugin, where no assignee was connected to the patent.

The relation between Kværner and IFE is in form of cooperation on R&D on hydrogen storage, but they have not patented together. IFE also cites Kværner’s patent and not the other way around. The inventors on the MMM patent are also inventors for Kværner and since this relation is indirect, it is expressed by a dotted line. The same people figure behind the patent, but there is no project cooperation between the assignees. The relation between Kværner and Sintef is that an employee in Kværner co-authored an article with people from Sintef.

Leiv Eirikssons Nyfotek is connected to Sintef and Hydro in form of cooperation between employees. It is therefore expressed by a dotted line.

An important new cooperation is Fun-Mat, a National Consortium for Research within Functional Materials and Nanotechnology. FunMat is a collaboration of four important research institutes in Norway; IFE, Centre for Material Science at the University of Oslo, Sintef material technology, and NTNU. They are joining their forces together and are
applying to the framework programmes in EU in a joint effort. University, institute and industrial research is here combined and one of the tasks is on hydrogen energy.

**The role of Sintef**

Sintef is the largest research institute in Norway, but only has three patents, in this data set. A reason to this is that Sintef in many cases develops technology for other corporations. This is evident in the membrane they produced for Hydro. They lead the Norcell project from 84-89, and they cooperate on Statoil’s projects, with Kværner and IFE on hydrogen storage and with Hydro on Utsira. Sintef and Hydro participated in the work with the membranes for Norsk Hydro electrolysers.

The lines in figure 1 show a relation to Kværner (co-authorship. Cooperation on R&D), to IFE (cooperate on R&D on H2 storage), and Statoil. Sintef is currently part of a project, “the carbon capture project”, where seven oil companies are involved, among them Hydro and Statoil. It is financed by the EU and Sintef has in this project given away some rights to their patents.

All of the above leads to the conclusion that Sintef is a much more important actor in the innovation system than the patent analysis indicates. Sintef diffuses a lot of knowledge in Norway due to its position as a leading R&D organisation, but this is not evident in patent analysis in FC&RHT.
Figure 3: Patents and relations in Norway 1990-2002
5.2 Location of the actors in the system and University-Industry interaction

When analysing a SI, it is important to identify geographical location of the actors, what types of actors that are found and whether or not they cooperate. This part looks at the location of actors in Norway and they were identified as located around three cities. The actors are analysed by regarding the relationship between university and industry in that region. This is due to the location being centred in the university cities of Oslo, Bergen and Trondheim.

When talking about location, a concept that is much used is that of clusters, however clusters denote to the fact that there is some specialisation that the firms in the area are strong at, and this was not evident here. Following Porter (1998: 78) a cluster necessarily involves “unusual competitive success in particular fields” and this was not the case in either of these locations. In Norway the specialisation does not follow the geographical lines in that sense that we can talk about clusters, but there is some specialisation. The location of firms and research institutes were in:

1. The Oslo area where the University of Oslo, Norsk Hydro, Sintef, IFE, FFI, and Due Miljø are located. The competence here is in many fields, hydrogen storage, membranes, semi fuel cells and material science.

2. The Bergen area, with Prototech, Clean Carbon energy and the University of Bergen. Specialisation here is on production of SOFC fuel cells.

3. The Trondheim area where the Technical University of Norway (NTNU) located together with Sintef. Furthermore Kværner has their research lab for carbon black and hydrogen. L.E Nyfotek. Statoil’s research department is also located here. In Trondheim there is also a broad range of activities, fuel cells testing, and optimalisation processes (NTNU), hydrogen storage and hydrogen production (Kværner).
The universities in Norway have no patents assigned to them. This is due to the patent culture where universities do not take out patents, but leave this to the researchers. Two professors had patents in the data presented here, but knowledge from university goes to the private sector. This can be in form of cooperation on projects, or professor 2\textsuperscript{19}'s that are also employed in the industry. This provides interaction processes between university and the industry and at least two of the inventors from Statoil also have professor 2 positions at NTNU (the technical university of Norway) in Trondheim. Statoil’s research department is located in Trondheim as well. So there is strong interaction between Sintef, NTNU and Statoil in development of technology there. Students working on the energy optimisation project at NTNU and that were patented by Leiv Eirikssons Nyfotek are now working in Statkraft (Norway’s national energy company) and IFE. This also indicates that knowledge was diffused from NTNU.

In Bergen there is a close relationship between the University and Prototech (and Christian Michelsen research which owns Prototech).

In Oslo there is a large cluster of different firms that cooperate to a certain degree with the university. The centre for material science is located at the research park in Oslo and has as a task to help new establishment of firms.

### 5.3 Knowledge flows and knowledge interaction

There is a common method of tracing knowledge flows from patent applications and in the patent documents we can look at either citation to other patents or to science articles. The knowledge flows are in form of codified knowledge, as this is knowledge on how the patent was made and what kind of inputs that were important in the process. Codified knowledge such as patents and scientific articles can be important input in an innovation process, but tacit

\textsuperscript{19} Professor 2 is a 20% position at a University and is being used extensively in Norway
knowledge that is a result of in-house R&D and in cooperation between firms is also an important aspect. This will also be treated below.

First the patent citations are treated, after that the non-patent citations are treated. Finally, knowledge interaction and learning in the innovation system is treated.

5.3.1 Knowledge flows in patent citations

This part examines the patent citations that were found in the relevant patents in the period from 1990-2002. These can provide insights into the knowledge flows between the actors as well as where important patents come from. First, a short overview of the patent citations will be given, thereafter some points regarding these will be reviewed.

The data-material that was gathered in the work with this thesis consisted of 83 patents and the results showed that knowledge flows in form of citations between patents were used in about half of the patents. These were mainly to foreign patents (USA, Japan, and EU). The only exception is between Statoil and FFI (joint project) and between Kværner and IFE (IFE cites Kværner’s patents).

Statoil’s patents from the Mjøllner project referred to patents from Japan, U.S.A. and Germany. The citations are to SOFC. FFI has eleven patents and only three refer to previous patents. The patents referred to are patents from the USA and Canada. Also Statoil in Norway (co-operation) have been cited. Norsk Hydro’s patents cited only U.S. companies such as General Electrics, Texaco inc and Jacobs Engineering Limited. The IFE patent “Hydrogen storage in carbon material” has eight references to previous patents. One of them is to the patent by Kværner on carbon nano-tubes which can be used for storing hydrogen. The seven other patents they cite are from abroad, six from the U.S. and one from Germany. Kværner’s patents cite US patents, such as one from Hydrogen Consultants inc, one from Air Products
and Chemicals, Inc, and one from Columbian Chemicals Company. There are also some European references in these patents.

The knowledge flows found in these patents are citations mainly to foreign patents (in USA, Japan and EU. This may lead to the conclusion that knowledge flows in FC&RHT is more oriented towards international actors, than national actors. The only exception is between IFE and Kværner and FFI and Statoil. Does this mean that the notion of a national innovation system for FC&RHT in Norway is weak due to lack of a national technological foundation? or is it only due to an aspect of the patent citations and that these are not salient features to the innovation process? We will now analyse what patent citations can mean for innovation the process.

Citations in patents are necessary due to the requirement that the patent must in the application state novelty and previous art. When a patent application is filed in an area where many have patented before, the document will be more complex due to the requirement of prior art and novelty, while if there is a new area, the patent will be broader and less documented. Using patent citations as indicators of knowledge flows is not uncomplicated. One inventor told us that: “especially the patent office in USA brings up old patents from the 60’s and say that this invention is already patented. And it is not even close to our patent. The citations are there, due to necessity, and not because they provided some profound insight for the patent”. Still though, patents are used by many when they venture into a new field for keeping oneself updated in the technological area. So it is legitimate to use patent indicators as a form of knowledge flow, but they must be looked upon with precaution since some use them quite opportunistically. Many also stated that a patent profile was used when trying to solve problems, and some stated that patenting provides you and your invention with attention and may be viewed upon as a form of marketing of an invention.
The fact that most patents in Norway cite patents from USA may partially be explained by the fact that they are patented there and constitute an answer to demands by the US patent office, but also due to the fact that most of the R&D in the fields have been conducted by USA, European, and Japanese firms. It also became clear that the focus among the Norwegian actors in FC&RHT were internationally focused.

The next part analyses the non-patent citation, as this can provide answers other than patent citations, namely that of the science to technology linkage.

5.3.2 Non-patent citations

Citations in patents to science articles are said to be a direct link from science to technology and are used in several surveys. This method is contested by some researchers such as Meyer, and his position was presented at page 7. According to Meyer, certain criteria for a science to technology link must be evident, and that is when “prior art is not yet documented. Examiner thus relates progress in the examined patent application to a scientific publication” (Meyer 2000: 415). This will be treated in the following.

Literature references were found only in two patents, one by IFE, and one by Kværner. Again, IFE cites an article by Kværner employees in addition to five US articles. The Kværner article is a conference article regarding their work on carbon black. Two of the US articles are from the highly prestigious magazine Nature and are on “Hydrogen Storage in Graphite Nanofibers” and “Graphitic cones and the nucleation of curved carbon surfaces”. This is a field which at the time was quite new and Kværner patented intensively here. The two other US articles that were referred to appeared in three different magazines in the fields of physics and chemistry.

The patents above that cite scientific articles also cite previous patents, we may therefore conclude that, in this case, there was no direct link from science to technology as...
indicated by Meyer. Meyer opens up for two other instances where a direct science-technology link may be apparent, that is either “citations of non patentable research results (e.g. formulae, hypotheses, discoveries, etc.) or “only non patent publications are available due to rapid development in a particular technical field” (Meyers 2000: 415).

Both the Kværner and IFE patents were in a field with rapid advances at that time, but both cite previous patents, IFE cites eight and Kværner cites seven. So, none of these qualify for being a direct science to technology link according to Meyer’s motive 1.20

5.3.3 Knowledge interaction and learning in the innovation system

In the previous section it was evident that both previous patents and articles were important inputs to the innovation process that can lead to a patent. We will now focus on knowledge interaction and interactive learning which is crucial for innovation in a SIA context. This part will analyse the different forms of learning and the knowledge interactions that are evident from this patents.

The starting point is the different ways of learning that Tidd et al21 (2001: 99) emphasised and this taxonomy, as repeated below, will be tested on the empirical material:

- Independent R&D
- Reverse engineering
- Licensing
- Hiring employees from innovating firm
- Publications or open technical meetings
- Patent disclosures
- Consultations with employees of the innovating firm

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20 Presented in section 1.2.2 on page 7
21 Presented in section 3.2.3 on page 33
In this thesis it was clear that independent R&D was seen as very important by all the actors, but none stated that this alone was sufficient for innovation. Reverse engineering was not an issue since this is not an accepted method. Licensing was mentioned once by an actor who had licensed from a firm, and two had licensed their technology to other firms.

Some scientists also worked in several firms, and on different projects, thus cooperation and interaction between people is an important knowledge source for innovation. In these interaction processes, knowledge is also shared and diffused. The distinction between tacit and codified knowledge is relevant here, since tacit knowledge can only be transferred through interaction. This means that patents are codified and easily accessible, while working in projects or hiring people means gaining access to and transmission of tacit knowledge (another popular term is intellectual capital). This indicates how important cooperation can be for knowledge transfer and innovation.

On the Mjøllner project knowledge interaction between Statoil and Prototech occurred, both directly and indirectly through inventors and key personnel working together. Another transfer of tacit knowledge is found in the Norcell project. Even though the patent rights were sold to the US firm Ceramatek (now SOFCo) who was partner in Norcell 2 from about 1990, knowledge was diffused to Norwegian firms. This occurred because knowledge that was built up in the Norcell project can be traced to Ceranor, a firm that stems out of the environment at the centre for material science at the University of Oslo, and to Sintef’s work with membranes. This knowledge is tacit and follows the people who worked there.

Publications as a learning process were evident in the starting phase of Norcell, where the articles from studies that tested the different types of fuel cells and their characteristics were used. This is explained in 4.2.2.

Patent disclosures were evident for several actors. Patent profiles could be made in a problem area or in a new area of interest. It is thus clear that reading patents in its own is not
sufficient, and must be supplied by own R&D (regarded as the most important). Many inventors stated that the innovation was a result of our own R&D, “we built up our own competence. You identify what you think is a market. It is not based on patents. It’s not good enough because you need to do your own research”.

5.4 Policy implications

In this part two policy aspects regarding analysis of the innovation system are treated. The first is related to technological projects that require great resources over a long period of time in a small country, such as Norway. The second aspect is related to the first, and is concerned with whether it is EU or Norway that is an important input to the SI. This relates to the point of using NIS as an analytical approach instead of a supra-national one.

A question that rises out of this analysis is how many different projects there have to be in a NIS for securing sufficient competition? Applying this to a small country such as Norway is something different than applying it to a big economy such as USA, Japan or France. One might ask whether it is reasonable to have several big projects going on at the same time (variation) or whether it is better to have one project with all the available resources put into that project. This also relates to the distinction between normal competition and system failure, where the system fails to secure sufficient interaction between the actors and the result is that several projects do the same kind of R&D. These aspects will now be discussed in relation to the empirical material and we focus on the two competing projects on fuel cells in Norway, Norcell and Mjøllner. Were these a result of system failure or did they constitute normal competition that a country should have?

These two competing projects resulted in a situation where there in Norway, which is a small country, was two projects working on development of a SOFC, which is a both technologically advanced but also financially large project. Several persons feel that it was a
wrong decision by Statoil to go out of the project to start their own. The outcome of Norcell 2, which was that the NFR cancelled all the support to R&D on fuel cells, was not good since knowledge built up over six years then vanished. At the same time the competence base and the patent rights were lost to USA. One informant said that, “the problem with Norcell was that, first there was all this effort and competence building, but then there was no support and the knowledge disappeared. This is not good use of invested money on knowledge”. Several informants stated that the above problem regarding Norcell and Mjøllner was a great disaster for a large Norwegian fuel cell program. One might ask whether this is normal competition or whether it is a form of system failure where policy makers should try to create more interaction between the actors and secure that the project will have sufficient with resources?

Technological knowledge is generic and may be important in many not foreseen contexts, this makes having the ability to operate with a broad perspective when doing R&D especially important. Related to this is the fact that many informants viewed the projects established by the research council to be too narrow in scope. This makes the arguments presented above seem tautological. First, we say that it might not be good to have two competing large R&D programmes in a small country. Now we say that it does not provide variation since they are working on the same technological alternative and that this is also not good. This latter point reflects that one should reason for different projects and secure variation and not have two projects doing R&D on the same technological alternative. Such a position would mean that the policy was oriented toward one project developing SOFC and another one developing PEM fuel cells. If this had been the case, Norway would have possessed a broader knowledge in production of fuel cells today.

The next part looks into the notion of an emerging European Innovation System as important for the actors in the analysis.
Niosi proposed that maybe a European system of innovation was in progress of being born and during the work with the thesis, this question came to mind as relevant also for the SI for FC&RHT in Norway. This is due to the fact that there are several EU programs that Norwegian actors are participating in which are viewed as being very important. Almost all the interviewed actors stated that the EU framework programmes were very important for them. The programmes were both seen as an important source for finance but also important for meeting researchers in the field and acquire contact with interesting partners in EU.

A recognised problem for constellations such as FunMat and other Norwegian researchers when applying to the EU programmes was that of finance. In EU 50% is financed by the project and the rest come from the resident country. In Norway the state funds only 3%. That leaves a residual of 47% that the research institute must find finance for or finance itself. This has the effect that the project sometimes may be cancelled due to lack of finance, while in other cases the research institute may go to the industrial sector in Norway and find finance on something that the industrial partner finds necessary. This may not be the best option when dealing with R&D in fields with a very uncertain future.

The policy implications extracted from this thesis, make it clear that Norway has several strong research environments with an international focus, which are focused on building and maintaining competence in Norway and that can develop FC&RHT further. It should also be stated in the innovation policy whether Norway wants to use the natural gas in Norway or export it as is done today. If there is a wish to use the gas in Norway, there should be a stronger focus on supporting technological innovation in FC&RHT. Ideally, support to the Norwegian actors for participating in the EU framework programmes would provide a good opportunity to develop technological capabilities and gaining access to a broad range of technological alternatives. Innovation in such a big and uncertain field as FC&RHT requires supra-national efforts and EU projects are an excellent choice for Norway to be part of.
It is therefore likely that the NIS for FC&RHT in Norway will be evident also in the future and with a European bias. A problem that must be solved is that of coordinating project funding so that it corresponds with the EU programmes that are important for the Norwegian actors and further innovation in the field. It is also clear that large technological programmes seldom can be undertaken by small countries alone. The EU focus therefore seems to be an optimal solution for the actors to engage in stimulating innovation projects and may help Norway to attain strong national environments in several areas in FC&RHT, it will also avoid the problems a small country might have in development of technologies that require large programmes.

Many informants view Norway’s position as good for obtaining a key role in providing the future market with hydrogen. This is due to the fact that Norway has immense resources of natural gas that can be used in hydrogen production and due to the fact that hydrogen has been produced in several other industries as a bi-product, such as ammonia and pvc production. Policy makers must consider whether Norway shall be a provider of gas to hydrogen production or also produce the technologies, because then the framework programmes are a good opportunity, since these technologies are too big for Norway alone. Norway possess a good research environment in these fields with a strong international network.
6. Concluding remarks

This chapter to sum up the main findings in the thesis and provide some concluding remarks on this. The main objective in this thesis has been to investigate the kinds of innovation processes that were evident in FC&RHT in Norway in the period from 1990-2002. We asked whether the innovation processes were based on knowledge interaction among heterogeneous actors in-house R&D in firms that were important for the innovations.

The empirical evidence has shown that knowledge interactions were an important factor for explaining the innovations identified in this thesis. All of the actors co-operate with other firms in one way or the other. This was also evident in the map on page 61 illustrating the patents and the relations among the actors behind these patents. Most of the informants stated that in-house R&D constituted an important factor for the patent, but they also stated that project cooperation was an important knowledge input.

The analysis presented in this thesis has shown that the national innovation system for FC&RHT in Norway is dominated by large energy companies such as Hydro, Statoil and Kværner. In addition there are a few small ones, Prototech, clean carbon energy and Due miljø AS, however, these three are all connected to the research organisation Sintef and CMR. The latter is owned by the University of Bergen. The research organisations Sintef, IFE, and FFI are also important actors in the innovation system.

If we focus on the technological capabilities that the firms have gained in form of their technological specialisation, we find that they are oriented towards energy production and towards use in automobiles or in laptops. The fuel cells are in the field SOFC and semi-fuel cells. SOFC is preferred for energy production and for combined heat and power production (CHP). They are fairly big and not suited for transportation. This specialisation is evident both from the patent analysis which showed that all of the patents, except the semi-fuel cells for
submarines, were on SOFC. There is some experimentation and testing on PEM fuel cells, but it is not likely that anyone will start manufacturing them. PEM are the most used fuel cells for use in cars and in portable devices. A switch to manufacturing of fuel cells for use in cars and portable devices is not likely to take place since this has not been a field of focus. The exception regarding fuel cells is FFI who has found a niche in R&D on batteries for submarines. This technology is highly successful and has been licensed to production. They have a lot of knowledge in the field and continue along the trajectory they have developed over several decades.

If we look at the patent families that have been made in the field, there is a focus on fuel cells (3 semi-fuel cells and 1 SOFC), Hydrogen storage in carbon material (4) and hydrogen production (4). This also further indicates that Norway is putting their efforts in fields related to energy production. A conclusion of this can be that Norway has its strength in the technological fields directly connected to production and use of hydrogen in the energy sector. Norsk Hydro Electrolysers are producing equipment for hydrogen production globally through electrolysis and they are a world leader in this field. In hydrogen storage both Kværner and IFE have a strong fundament in this field.

An interesting observation is that several of the patents come from a different context than they were originally developed for. This was evident in Prototech’s patent which was developed for a space travel project, Kværner’s offshore patent which become the CB process, and FFI’s semi-fuel cells which were intended for surveillance of submarines during the cold war, now licensed and used in other areas. This tells us something about the problems in advance of managing innovation processes. It also tells us that knowledge invented in one sector may be salient for advances in another field. Technological knowledge is generic and may be important in many not foreseen contexts. This makes the ability to operate with a
broad perspective when doing R&D especially important. Related to this is the fact that many informants viewed the projects established by the research council to be too narrow in scope.

We have seen that the Norwegian actors had an international focus, as they co-operated with foreign firms on projects, participated in international seminars and the patents citations were mainly to foreign firms. Still due to this international focus, a strong tendency was evident towards caring for the building of a national knowledge base and secure interaction and co-operation between the actors in NIS in Norway.

A conclusion is that Norway is an energy producer and this has had strong effects on technological choices that have been made. This is evident in the fuel cells types that are produced and in the strong focus and competence in hydrogen production and storage. This makes it possible to conclude that the NIS for FC&RHT has a strong fundament, and seen as a positive outcome among the actors.

Further Research

Two topics for further research became evident during the working with this thesis, the first is the notion of a European innovation system for FC&RHT, and the second is more methodological and related to use of patent citations as knowledge flows. The first topic, of a common European innovation system can be analysed from a more macro-oriented perspective than this thesis and focus on actors and their networks and not so much on their results. The question of the role patent citations has on the actual patent is not a straightforward question. In this thesis the inventors stated differently on this question: some stated that the citations to patents was important for the process behind the invention, other stated it was merely a claim from the patent office, while other used it more opportunistic and stated that it was decided after the invention was made. These different answers show that using patent citations as evidence of knowledge flows, could be misleading in some cases.
References


Jorissen and Garche (2000) “fuel cells for vehicle propulsion”


New Scientist nr.16 August 2003.


OECD (2001) STI scoreboard 2001


load operation” Journal of Power Sources 92 (2001) 9-16


Ørstavik, F and Nås, S.O (1998) “Institutional mapping of the Norwegian national system of
innovation” STEP working paper A-01. 1998
Appendix A Interview guide

(Translated from Norwegian)

1. Can you tell me about your invention? (This is an open question and the informants can then focus on the aspects that they think were important)

2. Why did you choose to patent the invention?

3. Did you cooperate with someone on the patent and do you cooperate with someone today?

4. What type of knowledge was used when the invention was developed? (articles, patents, own R&D?)

5. Do you think that you can elaborate some niches? Do you think niches are important for innovation in FC&RHT?

6. How do you look at the possibility for finding solutions on the problems related to FC&RHT? (Who and how?)

7. What’s your relation with foreign researchers/firms? (Where do your most important influences come from?)

8. What do you think about the government’s role in the development of FC&RHT?
Appendix B Patents in the dataset

Norwegian patents about fuel cells and related hydrogen technology 1990-2002 (N=83)

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Appendix C List of interviewees

- Dr. Scient Rune Bredesen, Chief Scientist, Head of group-Ceramics, Sintef Materials Technology, Oslo
- Øystein Hasvold, Researcher, Norwegian Defence Research Establishment (FFI), Oslo
- Ragne Hildrum, Project Manager, Statkraft, (former employee in Kvaerner Technology, Trondheim)
- Kjetil Hox, Kvaerner Technology, Trondheim
- Professor Signe Kjelstrup, Dep. Of Chemistry, NTNU, Trondheim
- Snorre Kjesbu, ABB Corporate Research, Oslo
- Kåre Kløv, R&D Project Manager Energy, Statoil AS, Trondheim
- Dr. Vera Ingunn Moe, Manager Business Development, Renewables and Hydrogen, Norsk Hydro ASA, Oslo
- Dr. Helle B. Mostad, Director Hydrogen Research and Technology, Norsk Hydro Energy, Oslo
- Henning Reier Nilsen, Vice President Technology, Norsk Hydro Petrochemicals division, Oslo
- Professor Truls Norby, Centre for Material Science, University of Oslo
- Professor Arne T. Skjeltorp, Head of Department- Physics, IFE, Oslo
- Dr. Ing. Bernt Thorstensen, Managing Director, Keranor, Oslo
- Arild Vik, Head of Technology, Prototech AS, Bergen