Monitoring Technological Activity and Visions:

The case of alternative transport fuels.

FRIDA WAHL
Master Thesis

Environmental System Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
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FRIDA WAHL
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Environmental System Analysis
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
http://www.esa.chalmers.se
Telephone: +46(0)31-772 1000
Fax: +46(0)31-772 2172

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Abstract

Transforming the transport sector towards sustainability requires fundamental changes in fuel use: that is to phase out fossil fuels and to phase in alternative fuels. The situation is called a technical discontinuity, and takes place when new technologies or innovations enter a market to compete with conventional technologies. The initial phase in a technical discontinuity is often characterized by uncertainty and experimentation, a range of new alternatives are developed. This period ends by the emergence of a new dominant design. When this happens other alternatives are locked out. The transport sector is standing on the threshold of a possible regime shift in car engine technology and fuel infrastructure. There are currently a variety of alternative fuels that all require development since they face different barriers. The objective of this paper is to survey the present rate and direction in development of alternative fuels and to survey visions of future fuel markets, in order to discover signs of diversification or concentration. Past global and European trends in research and development of fuels are analyzed and compared with the view of Swedish stakeholders, actors and decision makers, on the present and future fuel situation. The trends were analyzed through patent and article analysis and the visions through a questionnaire. Both the patent and the article analysis show an increased activity in research and development of alternative fuels. The increase does not lead to a focus on any single fuel but to a growing diversity. Swedish research and development activity, which focus on ethanol fuel, differs from other European countries, where ethanol is not a prioritized fuel. A desire of a phase out of conventional fuels is envisioned within the next 50 years. Several niche fuels will satisfy the phase out in the nearby future and hydrogen is the expected energy carrier in the longer run.

Preface

This report is the result of my master thesis, and the final part of the master programme Problem Solving in Science at Göteborg University. When I started the work I knew little about the complex situation of alternative transport fuels, technical discontinuities, article and patent analysis or questionnaires raised. During the time writing my thesis I have higher my level of knowledge and interest in the different areas widely. The work with writing this thesis has in many respects depended on the help and support from many people. The most important person when it comes to my personal academic development was my supervisor Björn Andersson. Björn has been the best supervisor who has guided me through my work with a professional hand. He has been involved in my work and given me constructive help in the whole process. The guidance was invaluable.
I owe special thanks to those who very kindly answered my questionnaire. The number and variation in background of respondents made the investigation interesting and unique. I am grateful for the feedback and the generous and constructive help from the respondents.
There would be no report without Bo Erbymark´s help with my computer. He worked hard with fixing and updating the computers at all times.

My parents Nancy and Martin Wahl who have supported me through my education are the best support a daughter could ever have, especially in the stressing time of a master thesis. I could never have done this without them.
A special thanks to Charlotta Svensson, Elin Löwendahl, Frida Kjellgren and Christina Olsson for being my best friends and support.

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Frida Wahl

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1. Introduction

One step in transforming the transport sector towards sustainability is the phase out of the conventional fuels gasoline and diesel. The phase out requires a range of technological changes in areas connected with the alternative fuels and vehicle technologies. Government energy technology research and development budgets have been declining significantly since the early 1980s in highly industrialized countries. Two reasons are a decreased level of public attention focusing on energy planning after the end of the Cold war and the presently low fossil fuel prices. On the other hand, the domestic and global political challenges are more pressing than ever as investments to develop clean energy technologies are needed, (Kammen and Margolis, 1999). The transport sector is in need of investments in research and development as well and will suffer if affected by a declining budget, as a declining budget results in a decreased research and development activity. The existing variety of alternative fuels that are potential alternatives to the fossil fuels, require development on storage, infrastructure and vehicle technology. There is a technical competition between the alternative fuels as they are all connected with technological uncertainties and experimentation. The technical competition will end with the emergence of one or a number of dominant fuels.

1.1. Objective and scope

The objective of this paper is to make a survey of the present visions of and rate and direction in research and development of alternative fuels. The survey will indicate whether the trend is an increase in diversity of fuel choices or an emergence of a dominant fuel. Global and European trends in rate and directions of different alternative fuels, fuel cells and internal combustion engines are surveyed. Fuel cell technology has the possibility to turn the transport sector to a more efficient and sustainable sector than the conventional motor vehicles can ever manage (Hoed, 2002). It is therefore of great interest to compare the global activity on research and development of the two technologies; fuel cells and internal combustion engine. The direction of development of alternative fuels can be an opportunity for Sweden to gain market shares on the international transport fuel market. A survey of the Swedish research and development activities on different alternative fuels is compared with three European countries. Swedish actors and stakeholders view on potential alternative fuels and visions of the future fuel situation in the transport sector is studied to make a comparison with the former results in research and development trends.

The task was performed by using the two techno-economic indicators; patent and articles, and by a questionnaire. The patent analysis was performed in a global perspective, covering the period 1976-2001, the article analysis in a European perspective of the period 1990-2001, and a questionnaire surveyed Swedish actors´, stakeholders´, decision makers´ and scientists´ view on present and future fuel development in the transport sector. The questionnaire surveyed the respondent's view of driving forces to develop, and barriers to implement alternative fuels.

The analysis is limited to certain alternative fuels based on the European Commission and the Swedish government's view of potential alternative fuels. The fuels studied are ethanol, methanol, biogas, natural gas, hydrogen, DME (Dimethyl Ether), and RME (Rape Methyl Ether), (STEM, 2002). Fischer-Tropsch and other synthetic fuels, such as LPG (Liquid Petroleum Gas) are not included in the analysis. For the survey of European trends in activity of research and development in alternative fuels four countries where chosen; France, Germany, Sweden and the Netherlands. This choice was based on the assumption of the European Commission that investments in bio fuels vary enormously through out Europe. Only six member states make any real contribution to the total European bio fuel production; Austria, France, Germany, Italy, Spain and Sweden. A survey of energy research and development documents found that in 1995, 98 % of all energy research and development was carried out by only 10 of the 22 member countries of the International Energy Agency (IEA), among them were France, Germany and the Netherlands (Kammen and Margolis, 1999). A questionnaire was sent to 68 chosen respondents that represented different parts of the transport and fuel sector. Fuel efficiency, fuel potential, advantages and disadvantages of the different fuels is not within the scope of this report, thus just a short presentation of the different fuels is included in appendix 3.

Chapter two gives a background to the alternative fuel situation to give the reader understanding and interest in the area of research. The chapter includes a short presentation of the driving force and barriers to introduce alternative fuels to the transport sector and a presentation of chosen future scenarios on fuel consumption and fuel choice. Chapter three gives the theoretical framework that explains a technical change. The technical change that will be completed when one or a few dominant designs emergence. The different alternative fuels compete with each other to dominate the substitution of conventional fuels. The theoretical framework also includes a motivation of using patent and articles as techno- economic indicators. Chapter four describes the method and procedure of patent and article analysis and the questionnaire. The methods were used to survey global, European and Swedish research and development trends of different alternative fuels and technologies. The results of the different analysis are presented in chapter five. A discussion of the results and a presentation of the conclusions are made in chapter six.

2. Background

2.1. Alternative fuels

The definition of alternative fuels are, according to the Swedish energy authority, fuels that are produced of renewable resources or residues, and that contributes to decreased production of CO_2 in a system perspective, (Fjällström, 2002). A definition of alternative fuels might include all fuels that are alternatives to the conventional fuels, gasoline and diesel, and includes synthetic fuels, even though they are not renewable. Alternative fuels that are of current interest in the European Union and Sweden is mainly ethanol, methanol, methane, natural gas, biogas, hydrogen, DME (Dimethyl Ether), RME (Rape Methyl Ether), Fischer-Tropsch diesel and FAME (Fatty Acid Methyl Ester, biodiesel), (Eriksson et al, 2002, and

Arcoumanis 2002). A short presentation of the different fuels is made in appendix 3. At present the alternative fuels require development of engine technology, storage and distribution systems. But some of them can at present be used as additives in blends with conventional fuels and do not require any technological, storage or distribution changes (STEM, 2002, Arcoumanis 2000). The connection between origin, production and usage of the different fuels is presented in figure 1.1.

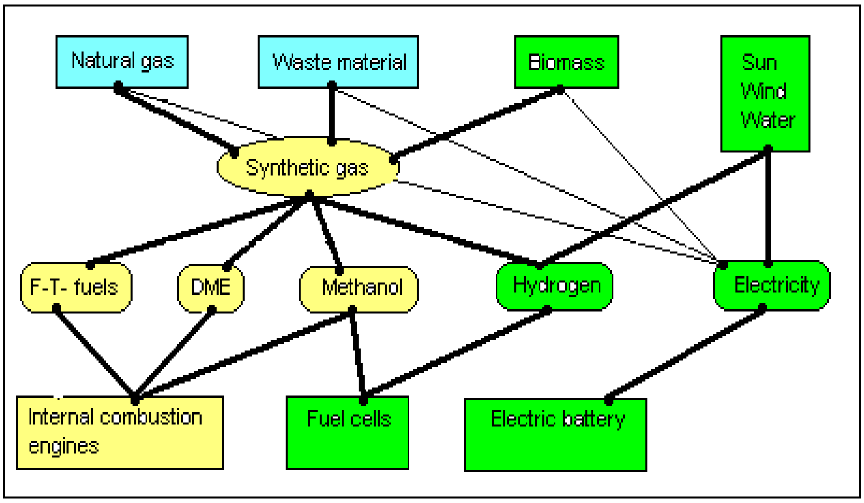

Figure 1.1 *Connection between origin, production and usage of alternative fuels (Eriksson et al, 2002).*

2.2. Driving forces

The driving forces behind substitution of conventional diesel and gasoline have varied over time. The oil crisis during the 1970s caused an increased interest in research and development of methanol, peat and biomass. The driving force was then to secure the domestic supply of transport fuel and reduce the dependency of oil and thereby reduce the dependence on OPEC. (Fjällström, 2002). The environmental and health issues in relation to emissions from fossil fuels became the main issue for finding alternative fuels in the later part of the 1980. (Eriksson et.al, 2002). The knowledge of the anthropogenic impact on the greenhouse effect gives topical interest to the question of developing fuels that are CO_2–neutral. (Liljemark, 2002).

Today the driving force is a combination of the mentioned driving forces. The European commission expresses that alternative fuel technologies must, as a minimum, have to offer a reduction in oil dependency and a reduction in greenhouse gas emissions, compared to the most fuel-efficient vehicles running on conventional fuel (EU Directive 92/81/EEC). The fact that the domestic production of alternative fuels is a way to stimulate export and the employment in sparsely populated areas, is a strong driving force for Sweden.

2.3. Barriers for implementation

The implementation of alternative fuels is connected with many barriers, of technological, economical as well as informational character. A fundamental factor in the implementation process is the availability of the fuel concerned. An increased demand of the fuel will bring pressure on the availability of the fuel. A high demand will also justify the establishing of a fuel supply system, i.e. supporting infrastructure for refueling, recharging, retail supply and maintenance, which is very expensive because of the large area that must be covered. The many possible alternatives and the uncertainty connected with new technologies are fundamental hindrances to an increased demand (EU Directive 92/81/EEC). There are market barriers such as lack of information of the real life performance of new technologies and a lack of confidence among potential users. The lack of confidence can also be found among manufacturers and vehicle and fuel suppliers concerning the viability of markets for new technologies. The Swedish energy authorities´ opinion is that the lack of strong economic actors, who promote the development through investments in new technologies, is at present a major barrier to an implementation of alternative fuels (Liljemark, 2002). The high manufacturing cost before economy of scale is achieved is another barrier (MURRAY,2001). Economical barriers also include higher initial vehicle cost for most vehicles adapted to new fuels, or business risk due to the uncertainty in vehicle lifetime costs. Technical barriers are for example limitation of the vehicles performance such as driving range, heavy and bulky tanks or batteries and long recharging or refueling time.

Political means of control such as tax incentives could provide an effective way to promote the development of alternative fuels and the technology connected with it. Tax schemes can also reduce the differences in production costs between fossil and alternative fuels, which at present is a clear disadvantage for many alternative fuels. Many technical and economical barriers can possibly be reduced by further research and development.

Alternative fuel vehicles faces certain disadvantages compared to conventional fuel vehicles, creating barriers to market entry (Murray, 2001). Government regulation often compels the adoption to standards, some have suggested that governments may employ standards as specific policy instruments capable of erecting barriers to trade (Anderson and Tushman, 1990).

2.4. Future scenarios of alternative fuels in the transport market

A presentation of scenarios of the Swedish government and the European commission, on future fuel consumption is made to compare with the Swedish stakeholders visions , surveyed by the questionnaire.

The European Commission's Green Paper is a programme for introduction of alternative fuels with the goal that they account for 20% of the fuel consumption in 2020 (Arcoumanis, 2000). The alternative fuels, which have high volume potential, are natural gas, hydrogen and bio fuels, i.e. bio diesel, methanol and ethanol, according to the European council. The commission argues that it is unlikely that existing vehicles will be adapted at a large scale to the new technology. This means that the gradual introduction of this alternative fuel will mainly depend on the sale of new adapted vehicles. An optimistic scenario, based on active policy, is 2% in 2010 and 5% in 2015. The commission sees the production capacity as an additional issue for the introduction of hydrogen, which makes it unlikely that a substantial market penetration for this will take place before 2015.

According to a best-case scenario of the transport market in 2019, performed by the European commission, the market will be dominated by gasoline-fueled (59.3%) and diesel vehicles (13%). The remaining (27.7%) is mostly electricity, bio diesel and natural gas driven vehicles (MURRAY, 2001)

The Swedish energy authorities performed an investigation, through a questionnaire to automotive suppliers companies, about the Swedish future transport sector. The result showed an expected major change in the near future. The gasoline consumption was expected to drop from the current 60 % to 44 % in ten years, and be replaced by a multitude of fuels such as ethanol, RME, methane, methanol and hydrogen. The investigation shows that expected future vehicle technologies are 72% conventional, 16% hybrids and 10% fuel cells (Pohl, 2002).

3. Theoretical framework

3.1. Technical discontinuity

The process of replacing the conventional fuels with competing alternative fuels requires technical change. This technical change, when a concurring technology or product is introduced to a market, is generally visualized as in figure 3.1 below and is called a technological discontinuity. A technological discontinuity can be defined as “an innovation that dramatically advance an industry’s price vs. performance frontier” (Anderson and Tushman 1990), or in greater detail as “a substantial change in the set of technologies, in the sense of technological competencies, required to design and produce a product, often resulting in a significant change in the price/performance of a product” (Andersson and Jacobsson, 2000). The technical change is impossible unless the innovation is superior to the existing technology in some way (Johnson and Pettersson, 1997, Anderson and Tushman, 1990).

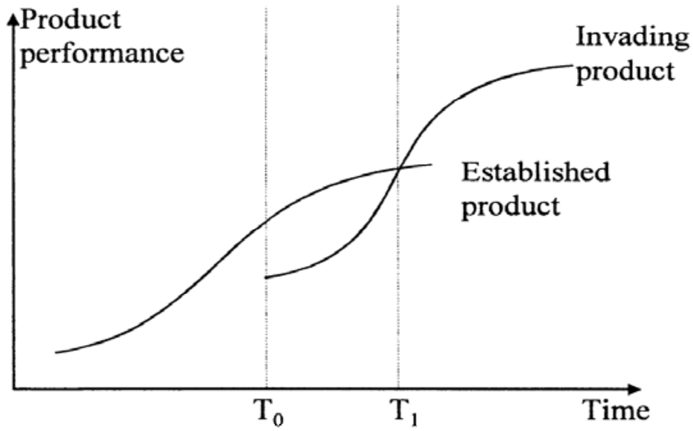

Figure 3.1 *A technical discontinuity; an innovation takes place at T_0, this new and concurring innovation becomes the dominant design at T_1. (Ehrenberg and Jacobsson 1996)*

The initial phase of the discontinuity starts when a new product or technology is invented and enters the market, in the figure at time T_0. This phase is frequently connected with competition between various technologies and standards, indicated by the three smaller curves between, T_0 and T_1 in figure 3.2. The phase is often characterized by a great deal of uncertainty and experimentation with alternative design approaches, (Ehrenberg and Jacobsson 1996). Political actions that stimulate either technical development or the market demand are important factors in this phase as it might function as catalysts for the technical change. Social, political and organizational dynamics select single industry standards or dominant designs from a range of technological opportunities. This is important especially in the absence of pursuit actors (Anderson and Tushman, 1990). The transport sector with the competition between a variety of alternative fuels, that demands further research and development, and the lack of standards for technologies, is presently at this stage of a technical discontinuity.

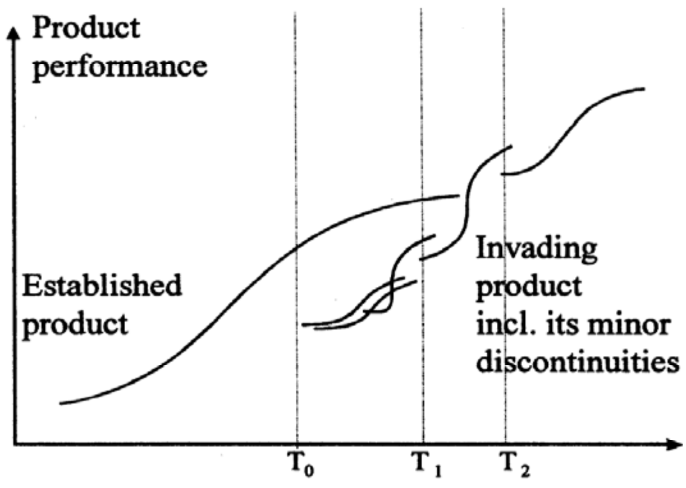

Figure 3.2. *A technical discontinuity including its minor discontinuities, (Ehrenberg and Jacobsson 1996).*

A dominant technology or design may materialize at some point in time, T_1 in figure 3.2. This leads to a domination of one or a few technologies and most likely a shakeout of the rest of the alternative designs. This situation means that uncertainty can be reduced among both suppliers and users as to which competing designs will come to dominate. At this stage research and development can be more focused and production technology can advance, volume advantage can be reaped and price reduced. (Ehrnberg and Jacobsson, 1996). It is of great importance that the adoption of a dominant design does not occur to early though. An example of an early adoption of a technology is the nuclear power technology. Light water is considered inferior to other nuclear power technologies, yet it dominates the market for power reactors. The reason is that the light water technology was developed for the U.S. Navy submarines, and had an advantage over other technologies when a market for civilian power emerged (Cowan 1990).

The process of a technical discontinuity includes many critical points. The first critical point is the selection of a dominant design, which has the effect of, at least temporarily, reducing the variations in the new technology. The second point, and this is seen from a market perspective, lies in the first exploitation of bridging segment. This point is crucial as it may set in motion a process of increasing returns, which again, may reduce variety. The third point occurs when the new technology first begins to exploit mass-market segments. From a technological point of view, reaching bridging or mass-market segments might be associated with the creation of minor discontinuities. (Andersson and Jacobsson, 2000)

The picture of the transport sector being in the initial phase of a technical discontinuity will be used to analyze whether there is an emergence to one or several dominant designs. The analysis is performed through actor and techno-economic indicators and will indicate what fuels that have received the most attention in research and development.

3.2. Techno- economic indicators

Patents and articles are examples of techno-economic indicators, which can be used to assess trends in research and development. Patents and articles represent the codified part of science and technology and indicate the size and orientation of technological activities and may be used to analyze, for example, variation in activity levels of different competing designs (Andersson and Jacobsson, 2000). Figure 3.3 shows a model of the connection between science, technology and innovations. The model visualizes the measurement opportunities of science activity through patent and articles (Grupp, 1996) But the approach by such indicators on certain outputs grasps only parts of the complex and non-linear innovation-oriented process, as can be seen in the figure. Inputs, research and development funding and research infrastructure, and outputs, innovations in new technologies are closely linked (Kammen and Margolis, 1999). A main advantage of using patent and article statistics is the easily accessible information that is available from long periods. This report makes extensive use of patent and article indicators in order to survey the research and development trends of different potential alternative fuels. Even if it does not give a complete picture of the complex innovation-oriented processes, it is at least measurable quantitative indicators on research and development.

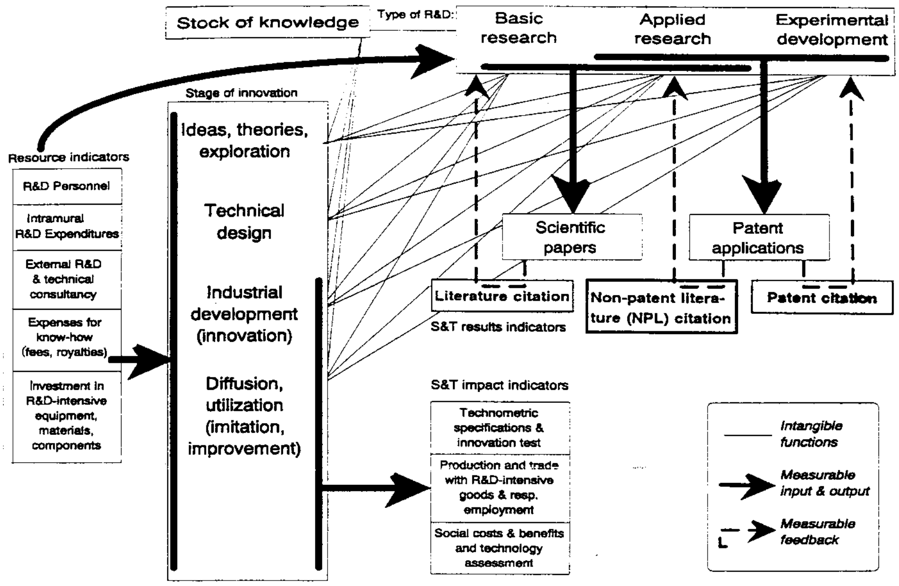

Figure 3.3 *A schematic model of coupled functions of science, technology and innovations, (Grupp, 1994)*

4. Method

4.1. Patent and article analysis

The patent search was performed in the US government patent database, USPTO during October 2002. The patent analysis was performed in order to collect information that reflects historical trends in research and development of the alternative vehicle fuels: ethanol, methanol, DME, natural gas, hydrogen and bio gas. Patents on fuel cells and internal combustion engines were also collected in order to enable a comparison in trends and possible relation between the two in increased or decreased innovations. The analysis considered the period 1976 to 2002 without country specification.

A similar patent analysis was performed in the European patent database esp@cenet, run by the European Patent Organization, in order to investigate the trend differences between different European countries. Swedish patents on ethanol and methanol since 1976 were included. Since the result of this search was not sufficient for any conclusions, the analysis was supplemented with an article analysis performed in the database ISI (Institute for Scientific Information) Web of Science during November 2002. Articles on the different transport fuels ethanol, methanol, DME, RME, biogas, natural gas, hydrogen, diesel and petrol were examined as well as articles on the technologies internal combustion engine and fuel cells. The article analysis considered articles published by French, German, Dutch and Swedish scientists during the period 1990 to 2002.

4.2. Questionnaire

A questionnaire was developed to survey opinions about the current status of alternative fuels and visions of future developments. The method used consists of several steps, the first step being identification and selection of stakeholders involved in research, development and adoption of alternative fuels. Important stakeholders are car manufacturers, oil and energy companies, fuel production companies, politicians, public authorities, researchers and research funders. Final consumers were not included due to the completely different research method that is needed to measure their preferences.

The same questionnaire was presented for the different stakeholders. The actors were asked to score what alternative fuels that the Swedish and European governments and companies respectively, stake in, through research and development, and what fuels that should preferable be invested in. The included fuels were ethanol, methanol, biogas, hydrogen, natural gas, DME, RME and LPG. The questionnaire included ranking of the most important long-term driving force behind a phase in of alternative fuels. The given answer alternatives were to decrease dependency on internationally produced fuels, to decrease emissions of greenhouse gases or other environmental unfriendly substances. In the analysis of future fuel consumption, the fuels mentioned above and the currently dominant conventional fuels were included and divided into the different categories; dominant fuel (>30 %), minor fuel (5-30 %), niche-fuel (1-5 %) and finally negligible fuel (<1% of fuel consumption). The scoring concerned what fuels that are most likely to satisfy the future transport market, in 2010, 2020 and 2050. Finally the actors were asked to score the most important barrier to diffusion of alternative fuels. The alternatives were technical barriers, attitudes among consumers, automobile industry or oil industry or finally lack of adequate policy instruments. The respondents had a possibility to give their own alternatives and comments to all questions. The questionnaire is found in appendix 1.

The first circular was sent November 8 followed by two reminder circulars on November 25 and December 3. Companies, organizations, political parties, researchers and funders that received the questionnaire are found in Appendix 2. The reason for the diversified recipients was to get a picture as complete as possible, of the vision and concentrate among different actors and stakeholders on different alternative fuels in the Swedish transport market.

5. Results

5.1. Patent analysis

The rates of patents on internal combustion engines have almost doubled from the beginning of the 80ies until today with the largest growth from 1995 and onwards, figure 5.1. The amount of patents on fuel cells has increased almost 300 % since 1995. The relative growth of patents is much higher for fuel cells than for internal combustion engines after 1996, figure 5.2.

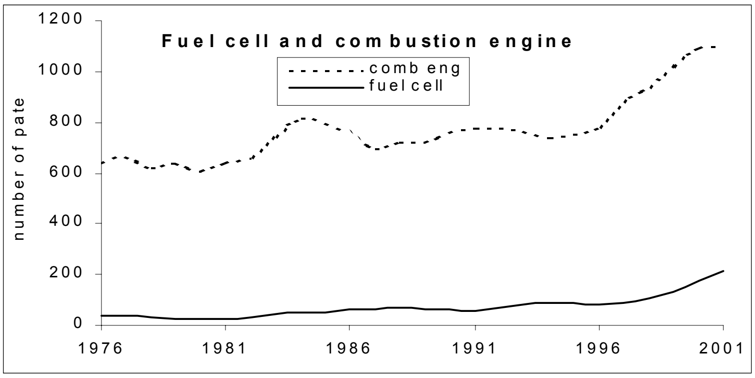

Figure 5.1. *Number of patents of the technologies of fuel cells and internal combustion engines from 1976 to 2001. Three years average, key words are found in appendix 4. (USPTO 2002)*

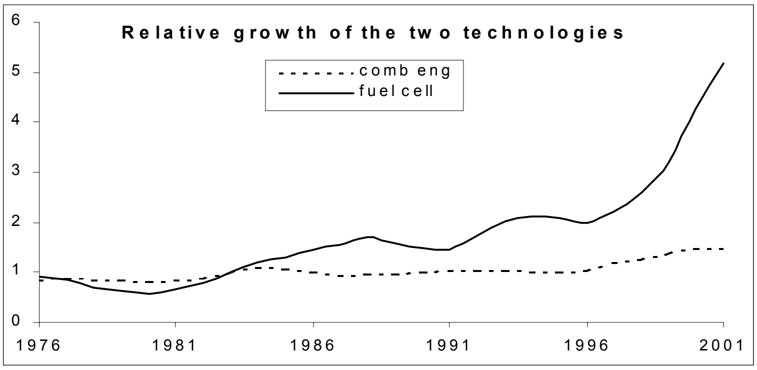

Figure 5.2, *The relative change in patents on fuel cells and internal combustion engine. Three years average, key words are found in appendix 4. (USPTO 2002)*

The general global trend is a steadily growing rate of patents on alternative fuels, since the beginning of the 1990, figure 5.3. The research and development of alternative fuels shows an obvious peak in the beginning of 1980 and a steady increase since 1987.

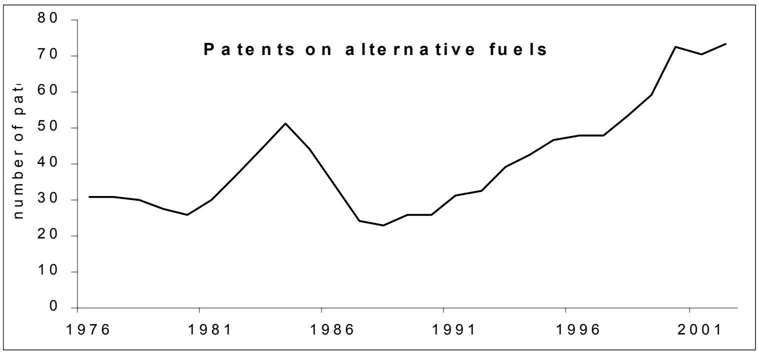

Figure 5.3: *Number of global patents on alternative fuels. Included fuels are ethanol, methanol, DME, natural gas, hydrogen and biogas from 1976 to 2001. Three years average, used source is USPTO and key words are found in appendix 4. (USPTO 2002)*

This picture includes the mentioned alternative fuels and can thus be subdivided into six separate trend curves, figure 5.4 to 5.6. It is of major importance to observe the different scales of the tables. The picture of ethanol and methanol shows that research and development of the fuels have proceeded for many years, figure 5.4. The trends are quite similar over time for the fuels; there is a peak of patents in the beginning of the 80s. Between mid 80s and mid 90s there has been a decreased quantity of patents, but after 1995 the interest increased again. There are now more patents than ever on methanol, but considering ethanol, the number of patents is not as great today as it was 20 years ago.

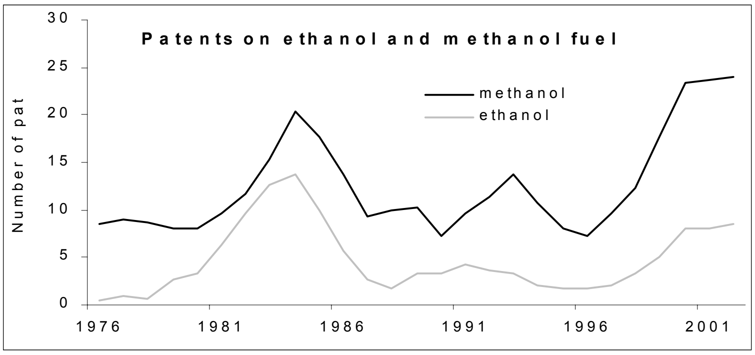

Figure 5.4. *Number of global patents on ethanol and methanol as transport fuels from 1976 to 2001. Three years average, key words are found in appendix 4. (USPTO.gov 2002)*

Research and development on hydrogen as energy carrier has been continuous since 1976; the intensity on research and development has generally increased over time since the late 80s with a maximum the last ten years, figure 5.5. Considering the activity of DME and natural gas, it has never been higher than the last years, figure 5.5 and 5.6. Natural gas is a fuel of stable growing interest. DME is, according to the analysis, a fairly new fuel, with a rapid growth of patents since the late nineties. The search on biogas fuel patents gave five hits, the first one in 1987 and the last one in 1998.

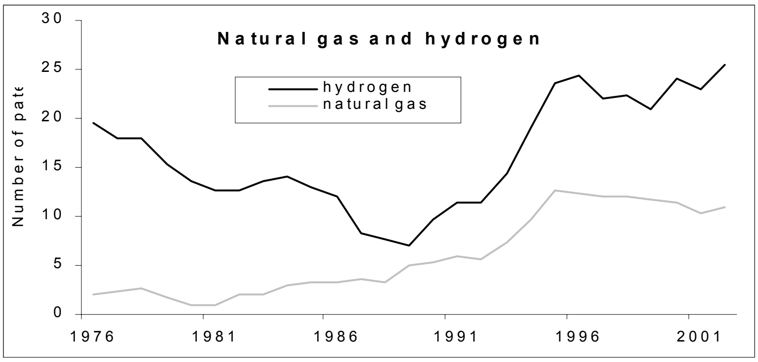

Figure 5.5, *Number of global patents on natural gas and hydrogen as transport fuels and energy carrier. Three years average, used key words are found in appendix 4. (USPTO 2002)*

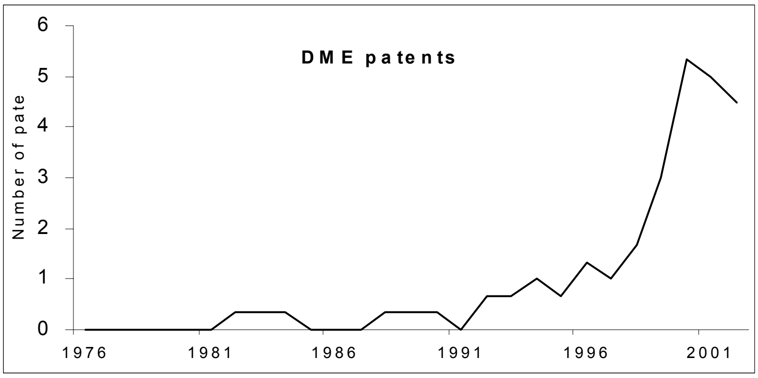

Figure 5.6, *Number of global patents on DME as transport fuels. Three years average, used key words are found in appendix 4. (USPTO 2002)*

5.2. Article analysis

The patent analysis surveyed global trends, whereas the article analysis was performed in order to analyze European academic activity on alternative fuels. The overall trend is increased activities on alternative fuels in all included countries, France, Germany, the Netherlands, and Sweden. This trend generally starts in Germany followed by the other nations, figure 5.7.

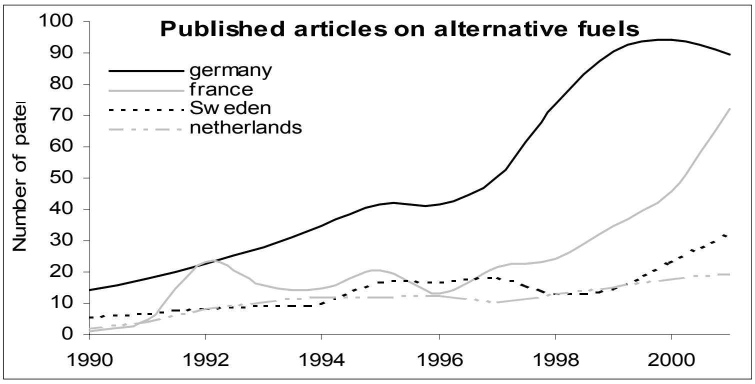

Figure 5.7; *Number of published articles on alternative fuels between 1990-2001, in France, Germany, the Netherlands and Sweden. The included fuels are ethanol, methanol, DME, natural gas, hydrogen, biogas and RME. Three years average, used key words are found in appendix 5. (ISI web of science, 2002)*

The total amount of published articles on different fuels in the four countries is presented in figure 5.8. The overall picture is an increased amount of articles, reflecting an increased R&D activity in all included fuels. Still the increase does not point out any potential dominant fuel among the alternatives to gasoline and diesel since the increased activity is present for all the fuels. Hydrogen, methanol and diesel have the highest level of published articles and also the greatest increase over the last years. Gasoline, ethanol and natural gas have about equal activity. Data on DME, RME and biogas were not sufficient for any conclusions in any country.

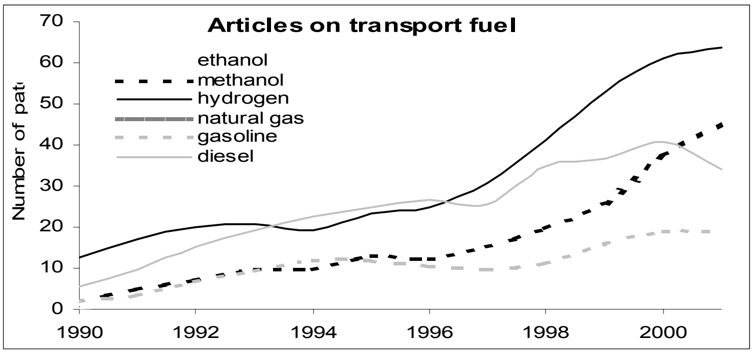

Figure 5.8, *Number of articles published in Europe on different transport fuels between 1990–2001. The European countries included are France, Germany, the Netherlands and Sweden. Three years average, used key words are found in appendix 5. (ISI web of science, 2002)*

Figures 5.7 and 5.8 can be divided into different tables, showing the specific trends of each fuel in the four countries respectively. The result of this is figures showing that the increased activity does not result in a focus of one or a few specific fuels but on a multitude of fuels in all four countries.

The increased activity on hydrogen, ethanol, methanol and gasoline in the last years is noticeable in Sweden, as the domination of diesel in the mid 90s, figure 5.9. The high activity on hydrogen and ethanol can be related to the Swedish actors desired priority of increased concentration in R&D on the mentioned fuels, figure 5.15. The article analysis also shows that the activity on methanol is almost as high as for ethanol; this does not emergence from the questionnaire, as methanol is supposed to be a much less prioritized fuel according to the respondents. No articles on biogas as fuel were published in the period.

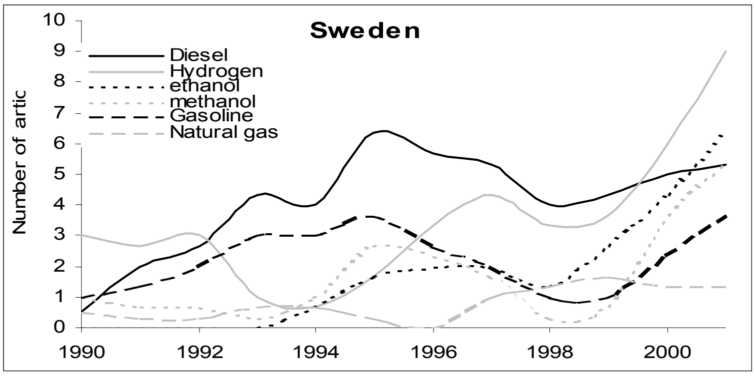

Figure 5.9. *Number of articles on different transport fuels published in Sweden between 1990-2001. Three years average, used key words are found in appendix 5. (ISI web of science, 2002)*

The German R&D focus appears to differ from the Swedish. The increase of activity the last years are not as obvious as in Sweden, but the overall picture is more stable with three main fuels; hydrogen, methanol and diesel, figure 5.10. The steadily increase of published articles on methanol since 1996 is remarkable. Hydrogen has been "the leading academic fuel" during the whole period with a rapid growth of interest from 1996 to 1999. The concentration on hydrogen corresponds to the picture of the European priority on the different fuels according to figure 5.16. As mentioned above, data on biogas, RME and DME are not sufficient for any conclusions.

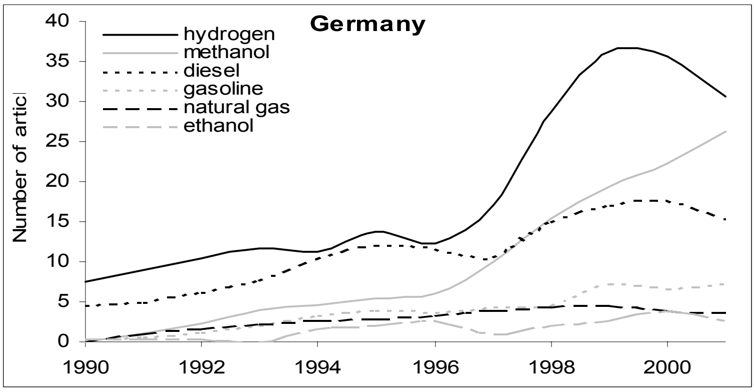

Figure 5.10 *Number of articles on different transport fuels published in Germany between 1990-2001. Three years average, used key words are found in appendix 5. (ISI web of science, 2002)*

France shows an overall and steady increased R&D activity on transport fuels, 5.11. Diesel and hydrogen are given priority and methanol, gasoline and natural gas face a rapid increase in R&D activity since 1997. No articles on biogas were published the period and the data on the fuels RME and DME is not sufficient to construct a trend graph.

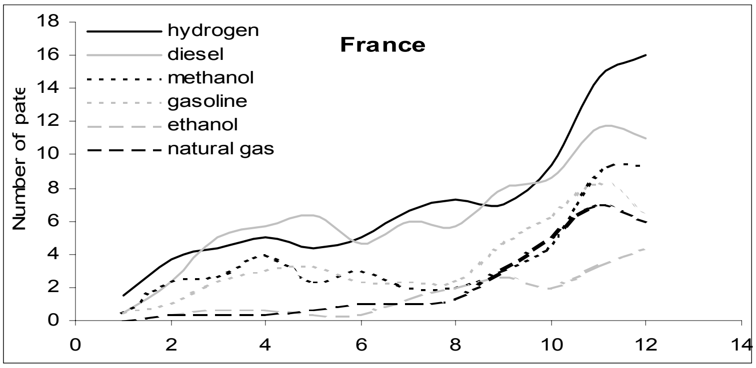

Figure 5.11; *Number of articles on different transport fuels published in France, between 1990-2001. Three years average, used key words are found in appendix 5. (ISI web of science, 2002)*

In the Netherlands hydrogen and natural gas attracted most attention until the mid nineties, when diesel had a strong peak, figure 5.12. Since 1996 the activity on hydrogen and methanol has increased steadily. This complies with the Swedish actors view that natural gas and hydrogen are given priority in Europe. The data on DME, biogas and ethanol are not sufficient for any conclusions.

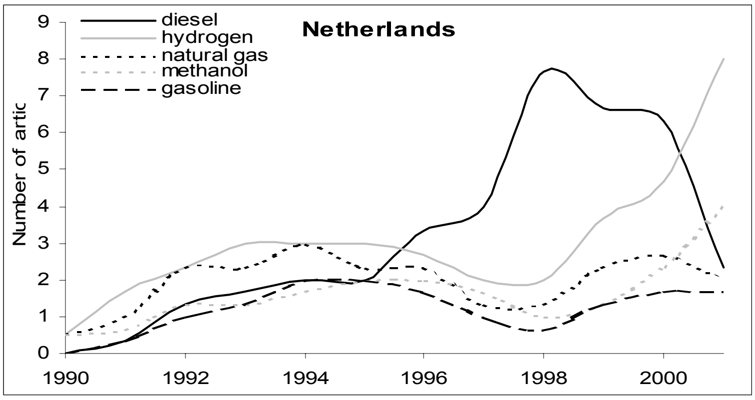

Figure 5.12*; Number of articles on different transport fuels published in the Netherlands, between 1990-2001. Three years average, used key words are found in appendix 5. (ISI web of science, 2002)*

For all countries, with the exception of Sweden, hydrogen diesel and methanol have attracted most attention in total, in that order. In Sweden ethanol has an exceptionally high share. Hydrogen has a stable curve showing an increased activity in all countries. Germany had the largest growth of hydrogen patents between 1996 and 1999, but methanol is at present at about the same level of activity. In Sweden and France, equal amount of articles on hydrogen have been produced, and over the last three years the increase of published articles is most rapid for hydrogen in both countries. This trend is less clear in Germany but in the Netherlands hydrogen is rocketing while diesel is plummeting. Gasoline, natural gas and ethanol are all, in that order, of moderate interest compared to the former fuel. All countries show a growing interest in methanol fuel. Compared to ethanol, methanol shows a more stable growth curve in all countries. Natural gas shows very varying trend curves in the different countries, a steadily increase of articles in Germany, a prominent growth between 1997 and 2000 in France, a quite even interest in the Netherlands and a growing interest in Sweden since 1996. The amount of articles on methanol and natural gas is comparable in the Netherlands, and the amount of articles on natural gas shows a moderate interest for the fuel in all countries. Articles about biogas, RME and DME have been the least frequent among the analyzed fuels.

The comparison between articles published 1990-2002 on internal combustion engines and fuel cells, shows a 10 to 13 times higher rate of articles on fuel cells than on combustion engines in France, Germany and Sweden, countries that all have large car manufacturers, figure 5.13. The comparable rate is 39 times in the Netherlands. The uniform and stable increase of articles on fuels cells can be compared with the varying trend curve of combustion engine articles.

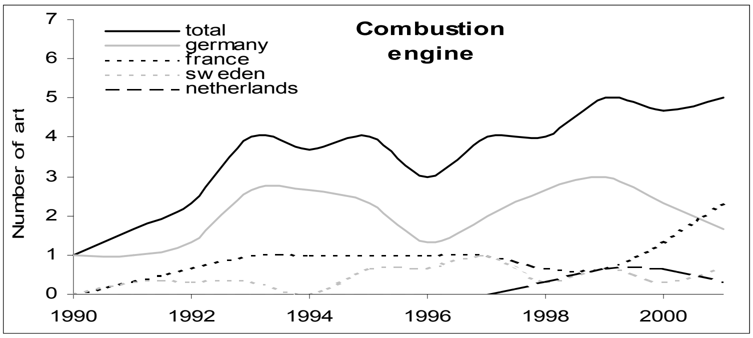

Figure 5.13; *Number of articles published on internal combustion engine technology in France, Germany, the Netherlands and Sweden between 1990-2001. Three years average, used key words are found in appendix 5. (ISI web of science, 2002)*

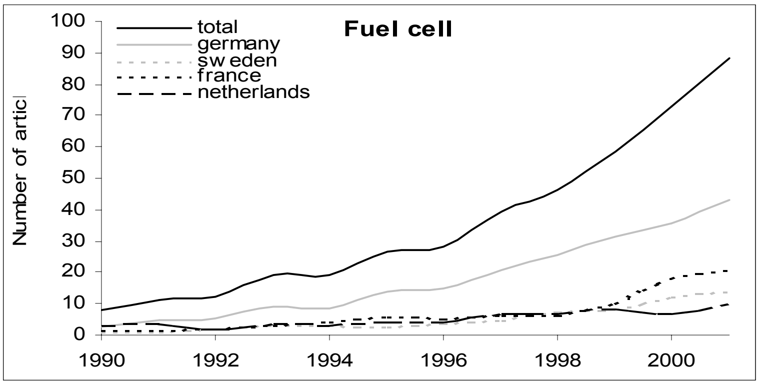

Figure 5.14; *Number of articles published on fuel cells technology in France, Germany, the Netherlands and Sweden between 1990-2001. Three years average, used key words are found in appendix 5. (ISI web of science, 2002)*

5.3. Questionnaire

Out of 68 recipients 32 answered the questionnaire, aimed to survey Swedish stakeholder´s and actor's opinion and vision of potential alternative fuels. The 32 answers came from all included groups; politicians, governmental and private companies, non-governmental organizations, oil industries, Swedish energy corporations, scientists and research financiers. The questionnaire is found in appendix 1.

5.3.1. European and Swedish research and development of alternative fuels

The survey of Swedish governmental, private and science based research and development priorities for different alternative fuels and preferred priorities are presented in figure 5.15. The black bars represent the respondents' opinion on what fuel is prioritized in research and development while the grey bars illustrate the preferable priority. Biogas, ethanol and hydrogen are ranked highest preferred priority. They are also the preferred short- and long-term substitution fuels, see section 5.3.3. This can be put in relation to the fact that hydrogen and ethanol actually corresponds to the most prioritized fuels in R&D in Sweden the last years, figure 5.9. Ethanol is considered to be the highest prioritized fuel and less focus on this fuel is desirable. Methanol, biogas, hydrogen, DME and RME are all considered to be worth more attention, and in particular hydrogen. The fuel that attract least attention is LPG but is considered to be worth even less attention. Also natural gas deserves less attention. Hydrogen corresponds to the largest change as it is considered worth a greater deal of attention than is given today. The overall result shows a desire to increase the concentration on alternative fuels.

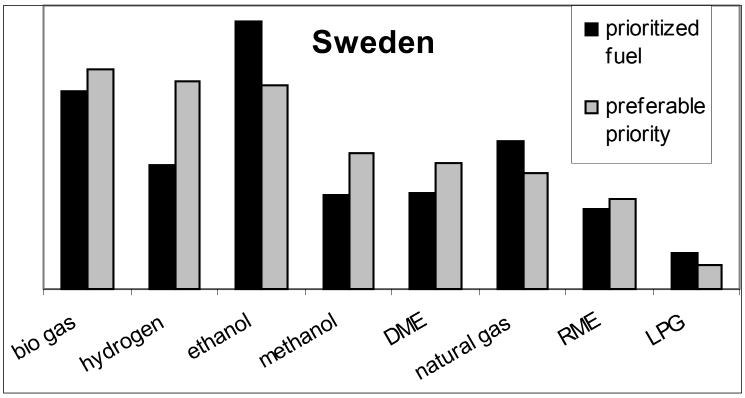

Figure 5.15, *Swedish actors and stakeholders view on activity on different alternative fuels in Sweden. The black bars presents the respondents´ view on fuel priority and the grey bars presents the respondents´ preferable priority of the fuels. (Questionnaire)*

The situation in Europe looks different than the previously presented, as ethanol and biogas are the highest valuated fuels in Sweden and corresponding fuels in the rest of Europe is natural gas hydrogen and ethanol, in that order, figure 5.16. Ethanol, methanol, biogas, hydrogen and DME get too little attention, while natural gas, RME and LPG deserves less attention. Biogas shows the largest difference between assumed and desired effort. A comparison between Sweden and the other European countries shows a good match between desired priorities, with the possible exception of methanol that for the same reason get a higher score for Europe. The fact that biogas, ethanol and hydrogen are preferred highest priority corresponds well to the vision presented in section 5.3.3. The frequency of uncertain answers is slightly higher for Europe than Sweden.

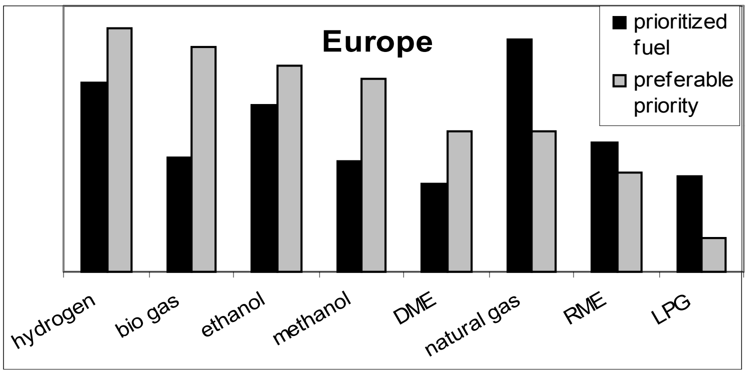

Figure 5.16. *Swedish actors´ and stakeholders´ view on activity on different alternative fuels in Europe. The black bars presents the respondents´ view on fuel priority and the grey bars presents the respondents´ preferable priority of the fuels. (Questionnaire)*

The question whether there is any relation between answer and the respondents background were analysed. For example that a person in the ethanol production business would like to see more activity on ethanol, due to the persons own interest. But no relation between the answers and the different groups of respondents were found.

5.3.2. Driving force to phase in alternative fuels

The driving forces behind long-term substitution of conventional diesel and gasoline have varied over time and an attempt to survey the Swedish actors opinion of the current main driving force was made by the questionnaire. The knowledge of the anthropogenic impact on the greenhouse effect gives topical interest to the question of developing fuels that are CO_2–neutral and is currently the main reason to develop alternative fuels. To secure the domestic supply of transport fuel and reduce the dependency on imported fuel is also a strong reason to develop alternative fuels, figure 5.17. The reduction of emissions of other health and environmentally unfriendly substances is a reason almost as strong as the former mentioned reasons. Other reasons to develop the alternative fuels is that the domestic production of alternative fuels is a way to gain employment in agriculture and in sparsely populated areas and to increase the exports market. The goal to decrease the dependency of the finite resource oil and to improve the security of energy supply is also a driving force.

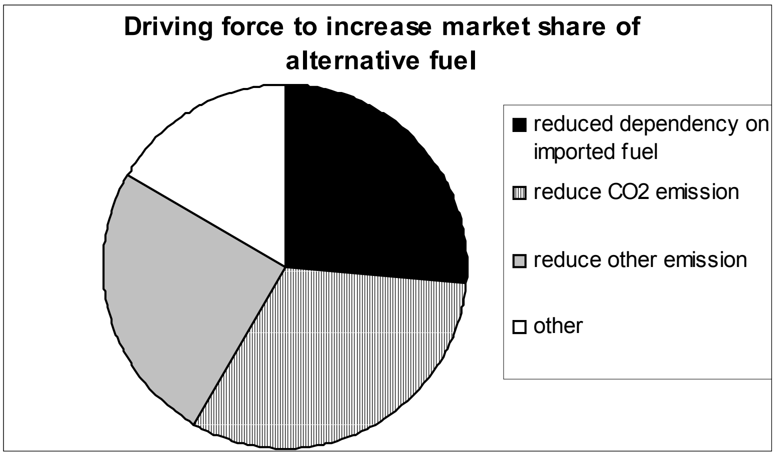

Figure 5.17 *Driving force to increase market share of alternative fuels (questionnaire)*

5.3.3. Future fuel markets

The fuel supply on the future transport market might be satisfied by gasoline, diesel, ethanol, methanol, natural gas, hydrogen, DME, RME or biogas. In the analysis of the future fuel consumption, the fuels were divided into the different categories; dominant fuel corresponds to over 30% of the total fuel consumption, complementary fuel 5-30%, niche-fuel 1-5% and finally negligible fuel <1% of the fuel consumption.

The result of the questionnaire shows that there is a very legible trend in the answers showing that almost all respondents agree that diesel and gasoline are facing an almost complete phase out in the future and that changes are expected to happen in the near future. Diesel and gasoline will still be the dominant fuels in the transport market in 2010. A majority of the respondents consider the conventional fuels to be the dominant fuels

even in 2020, but the thought of the conventional fuels as a minor fuel in 2020 is almost as popular. In 2050 the opinions meet on that the conventional fuels are expected only as complementary fuels.
The short-term substitute fuels are biogas and ethanol and the long-term substitute is hydrogen. These fuels were also those that should be given research and development priority according to fig 5.15 and 5.16.

The predicted fuel consumption in the transport market 2010 is represented in table 5.1. 27 and 25 respectively of 32 respondents consider gasoline and diesel to remain dominant fuels in 2010. Ethanol and biogas are considered to be niche fuels, which is an increase compared to the present consumption of less than one percent of the total fuel consumption in the transport sector. Hydrogen, DME and RME are fuels of negligible size today, a situation that will hold even for 2010 according to a majority of the respondents. Whether methanol is remaining as a negligible fuel even in 2010, or is a niche fuel is not agreed upon, the former opinion owns a small majority of the respondents. The fact that ethanol and biogas is expected as niche fuel in 2010 can be associated with the former result of the fuels that currently attracts most attention.

2010	Dominant fuel	Complementary	Niche fuel	Negligible fuel	Unsure
Petrol	**29**	3	0	0	0
Diesel	**26**	6	0	0	0
Ethanol	0	10	**21**	1	0
Methanol	0	0	**13**	**19**	0
Hydrogen	0	2	6	**24**	0
DME	0	1	9	**19**	3
Bio gas	0	4	**24**	4	0
RME	0	0	9	**22**	1

Table 5.1, *The Swedish transport market in 2010 will be dominated by gasoline and diesel, according to 29 and 26 out of the 32 respondents. Ethanol and biogas has expanded to niche fuels, while methanol is either a niche fuel or a negligible fuel*

The assumed changes until 2020, are not as unanimous as the opinion on the situation in 2010 and the frequency of uncertain answeres is twice as high compared to 2010. The scenario that diesel and gasoline will still be the major fuels even in 2020 is not as obvious; the picture of the fuels being just complementary fuels is nearly as expected. Ethanol and hydrogen is considered to be either complementary fuels or just niche fuels. The expected future of methanol is uncertain; it can either be a complementary fuel, as ethanol and hydrogen, a niche-fuel as DME or a negligible fuel, which does not even account for 1 % of the fuel consumption. The scenario for biogas and RME in 2020 is either complementary fuels or niche- fuels. DME is considered being more of a niche-fuel than a complementary fuel but is most of all expected being a negligible fuel. The picture in 2020 is an overall decrease of gasoline and diesel consumption and an increase in consumption of alternative fuels, but what alternative fuel that will be dominant cannot be predicted. There exist no consensus of a dominant alternative.

2020	Dominant fuel	Complementary	Niche fuel	Negligible fuel	Unsure
Petrol	**17**	12	1	0	2
Diesel	**16**	**13**	1	0	2
Ethanol	1	**14**	**12**	0	3
Methanol	1	**8**	**12**	**8**	3
Hydrogen	2	**10**	**10**	8	2
DME	0	8	**9**	**10**	5
Bio gas	0	**10**	**18**	2	2
RME	0	**3**	**11**	15	3

Table 5.2. *The Swedish transport market in 2020, petrol and diesel have lost market shares to ethanol, methanol, hydrogen and biogas. The picture is not as uniform as the previous for 2010 and the uncertainty has increased. (Questionnaire)*

The scenario of the transport fuel market in 2050 gives a more homogenous picture than the scenario of 2020, even though the frequency of uncertain replies is almost three times the frequency in the scenario for 2010. The majority agrees upon a shift from gasoline and diesel, which has become complementary fuels, to mostly hydrogen that is now a dominant fuel. Ethanol, methanol and biogas are complementary fuels and RME remains a negligible fuel. It seems like the decrease of gasoline and diesel is compensated by not only hydrogen but a variety of alternative fuels. Many respondents believe that the Fischer-Tropsch diesel is a potential future fuel and that it will become a complementary fuel in 2050.

2050	Dominant fuel	Complementary	Niche fuel	Negligible fuel	Unsure
Petrol	2	**16**	5	5	4
Diesel	3	**16**	5	4	4
Ethanol	3	**14**	8	3	4
Methanol	3	**11**	6	6	6
Hydrogen	**16**	7	5	0	4
DME	0	**10**	5	**9**	8
Bio gas	1	**14**	9	4	4
RME	0	4	8	**14**	6

Table 5.3. *The Swedish transport market in 2050, petrol and diesel have lost market shares to above all hydrogen, which is the expected dominant fuel. Petrol, diesel, ethanol, methanol and biogas are all complementary fuels. The picture is more uniform than the previous for 2020.*

The overall trend is an increase of alternative fuels at the expense of the conventional fuels, diesel and petrol. The diversification of fuels increases. Complementary fuels play a more important role in the future and the only expected dominant fuel is hydrogen. Table 5.4 include table 5.1, 5.2 and 5.3 and visualizes the expected development of the fuel consumption in 2010, 2020 and 2050.

2010	Dominant fuel	omplementary fu	Niche fuel	Negligible fuel	unsure
Petrol	**29**	3	0	0	**0**
Diesel	**26**	6	0	0	0
Ethanol	0	10	**21**	1	0
Methanol	0	0	**13**	**19**	0
Hydrogen	0	2	6	**24**	0
DME	0	1	9	**19**	3
Bio gas	0	4	**24**	4	0
RME	0	0	9	**22**	1

2020	Dominant fuel	omplementary fu	Niche fuel	Negligible fuel	unsure
Petrol	**17**	12	1	0	2
Diesel	**16**	**13**	1	0	2
Ethanol	1	**14**	**12**	0	3
Methanol	1	8	**12**	8	3
Hydrogen	2	**10**	**10**	8	2
DME	0	8	**9**	**10**	5
Bio gas	0	10	**18**	2	2
RME	0	3	**11**	**15**	3

2050	Dominant fuel	omplementary fu	Niche fuel	Negligible fuel	unsure
Petrol	2	**16**	5	5	4
Diesel	3	**16**	5	4	4
Ethanol	3	**14**	8	3	4
Methanol	3	**11**	6	6	6
Hydrogen	**16**	7	5	0	4
DME	0	**10**	5	**9**	8
Bio gas	1	**14**	9	4	4
RME	0	4	8	**14**	6

Table 5.4. *Development of the Swedish transport market in the case of fuel consumption from 2010 to 2050.The picture is an increase of the alternative fuels and a decrease of the conventional fuels, diesel and petrol.*

5.3.4. Barriers to implementation of alternative fuels

Despite the common desire to phase out the conventional fuels, the introduction of alternative fuels faces different barriers. The main barrier against an increased share of alternative fuels in the transport market is surveyed through the questionnaire. Figure 5.18 illustrates that the suggested constraints are of almost equal importance. The lack of long-term political means of control is thus a considerable hindrance for industrial investments for both fuel and vehicle production. Commercial actors consider long-term political decisions to be of crucial importance to future development as the required investments in for example infrastructure and vehicle development are long-term. According to one respondent the loss of long-term political visions is due to the desire to retain the governmental income. Many respondents commented that the consumers attitudes and the technological development seem to be the least constrains, while the fact that the production cost of alternative fuel competes with the low production cost of fossil fuels is considered a more important constrain. Politicians consider both consumers and vehicle industry to be essentially positive to alternative fuels but the former are not willing to increase the cost of transport while the latter demand long-term perspective to develop technology and production. An outcome of the questionnaire is that since the turn over period of the car park is slow the availability of alternative fuels is not a current problem.

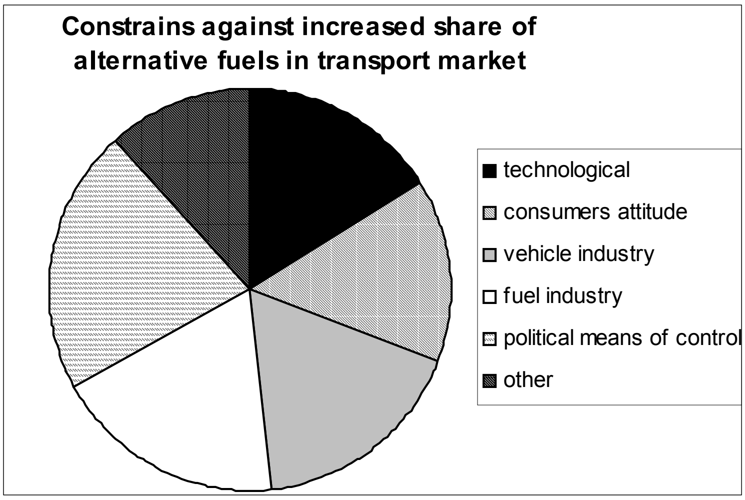

Figure 5.18, *The constraints against an increased share of alternative fuels in the transport market (Questionnaire).*

6. Conclusion and discussion

6.1. Method discussion

The advantage of using patent and article statistics, as a measurement of science activity, is the accessibility of data. A disadvantage of patents is that the willingness to take out patent differs not only between companies but also between countries. This is either a result of a chosen strategy or the high cost associated with patents applications and it makes a comparison between countries´ patent statistics not completely reliable. (Anderson and Tushman, 1990). The patent analysis was thus made on a global perspective and did not compare trends in single countries. The high costs connected to patents lead to a decreased amount of patented innovations, which implies that the actual level of activity is often higher than the measured. As there is no international patent database that offers information of all countries, the American database USPTO has been used. Due to the importance of the American market many international companies make extensive use of the American patent office, while small and medium sized companies abstain.

To measure the rate of science activity through articles has the same advantage as patent statistics. Data are easily accessible over a long period of time. The article analysis that was performed in the ISI web of science is depending of the database's definition of a science journal. If the result of the analysis would be compared to a similar analysis performed in another database the picture would be more complete and would have been preferred. The article analysis is a measurement of science based research activity and does not measure the bulk of the business based research activity. This implies that the article analysis and the questionnaire to some extent measure different things. This is obvious in the case of biogas. Biogas is, according to the respondents of the questionnaire, in research and development activity a prioritized fuel. Whereas published articles on biogas is not enough to measure any trends. The difference is probably due to that research and development activity of biogas is not academically based.

The number (32 out of 68) and area of knowledge of respondents of the questionnaire is sufficient for conclusions. The main discussion is the ranking of question three and five. There is a possibility that the respondent confused the ranking as it was reversed from the other questions. This makes the result for these questions somehow unreliable.

6.2. Discussion and conclusion

Both patent and article analysis show that the global, European and Swedish activity in research and development of alternative fuels in the transport sector have increased significantly in the last eight years, (compare for example article and patent statistics for fuel cells and internal combustion engine figure 5.1 and figure 5.11). The global activity peak during the 1980s, figure 5.2, was mainly due to increased activity in ethanol and methanol fuel. The increased activity was most probably a result of the oil crisis (Fjällström, 2002). The 1988´s California Air

Resource Board (CARB) Zero Emission Vehicle Mandate (ZEV-mandate) was a strong driving force to increase research and development of alternative fuels shortly after its introduction, figure 5.2 (Johnson and Petterson, 1997 and Faber et.al., 2002)

The technical discontinuity of alternative fuels replacing the existing conventional fuels could end with one dominant fuel, but there is also a possibility that many complementary fuels might replace the present dominant fuels, gasoline and diesel. The general increase of activity in research and development of alternative fuels does not focus on any particular fuel but implies an increased diversification. The oil and gas industry express in their response to the European Commission Green paper on the development of alternative fuels, (Europia, 2001), that they support a continuing diversification of the energy choices available to consumers and society, including the development of economically sustainable additional energy sources and user technologies. A diversification of alternative fuels obstructs a too early shakeout of alternative fuels that are potential substitutes. The activity of research and development of all fuels included in the survey increased during the measured period, which implies that a shakeout of any alternative is not expected in the near future. The increased variety is also reflected in the Swedish stakeholders view, that there will be a variety of fuels replacing the conventional fuels in the near future. In the long term, however, hydrogen appears to be the energy carrier that will dominate the transport market.

Many actors in the transport market advocate international standards on technology, for example refuelling equipment standards, in order to facilitate the phase in of the alternative fuels. As mentioned above the Swedish energy authority recognizes a lack of strong economic actors, who can promote the development of alternative fuels through investments in new technologies. This implies the importance of political actions in the transport sector.

Conclusions from the questionnaire are that the driving force behind the Swedish interest in development of alternative fuels is the desire to make the energy sector more sustainable, but also to create a national market and decrease the dependency on fuel supply from other countries. This is in line with the view of the Swedish energy authority's on prevailing driving forces. The development of alternative fuels could also be an opportunity for Sweden to take a leading position on an international fuel market. It is in this perspective interesting to identify if the direction of research and development in Sweden differ from the direction in other countries. The Swedish activity in ethanol differs from other European countries. In Germany and France ethanol has received less interest than all fuels but biogas, DME and RME. In the Netherlands articles on the fuel is not enough for any trend analysis, but in Sweden academic research and development on ethanol is presently ranked second highest next to hydrogen. This direction of development can be an opportunity for Sweden to gain market shares, but it also contains the risk of betting on the wrong horse.

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Appendix 1: Questionnaire

Alternative fuels.

- The Swedish government, municipality and businesses invest in research and development of alternative transport fuels. What alternative fuels do you consider being the most prioritised fuels? Does Sweden prioritise the same fuel as the rest of Europe?
  Rank the alternatives from 0-3 of how you consider the current priority and investment in research and development of the different fuels, 3 corresponds to the highest priority and 0 corresponds to not prioritised at all. Different alternatives receive the same ranking, put the number right after the fuel.

Sweden

- Ethanol
- Methanol
- Bio gas
- Hydrogen
- Natural gas
- DME
- RME
- LPG
- Other alternative:
- Don't know

Europe

- Ethanol
- Methanol
- Bio gas
- Hydrogen
- Natural gas
- DME
- RME
- LPG
- Other alternative:
- Don't know

Comment:

- Would you prefer another priority of research and development alternative fuels?
  Rank the alternatives from 0-3 how you would prefer an investment in research and development of the different fuels, 3 corresponds to the highest priority and 0 corresponds to not prioritised at all. Different alternatives receive the same ranking, put the number right after the fuel.

  Sweden
    - Ethanol
    - Methanol
    - Bio gas
    - Hydrogen
    - Natural gas
    - DME
    - RME
    - LPG
    - Other alternative:
    - Don't know

  Europe
    - Ethanol
    - Methanol
    - Bio gas
    - Hydrogen
    - Natural gas
    - DME
    - RME
    - LPG
    - Other alternative:
    - Don't know

Comment:

- Which are the long term driving forces behind the research and development of the alternative fuels? Rank from 1-4, where 1 is the premiere driving force.

    - To reduce the Swedish dependence of imported transport fuels.
    - To reduce CO_2 emissions.
    - To reduce emissions of other substances.
    - Other alternative:

Comment:

- How will the transport fuel market change in the near future? Mark the probable sale-share of respective fuels in Sweden in 2010. The numbers in parenthesis describe the current sale-share.
    - Petrol (today 60 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Diesel (today 39 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Ethanol (today <1 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Methanol(today <1%):< 1 %, 1-5 %, 5-30 %, > 30 %
    - Hydogen (today 0 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - DME, (today 0 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Bio-, natural-, methane gas (today <1 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - RME/ bio diesel (today <1) < 1 %, 1-5 %, 5-30 %, > 30 %
    - Other alternative < 1 %, 1-5 %, 5-30 %, > 30 %

    If you answered another alternative, what alternative is that?

Comment:

- How will the transport fuel market change in a longer perspective? Mark the probable sale-share of respective fuels in Sweden in 2020. The numbers in parenthesis describes the current sale-share.

    - Petrol (today 60 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Diesel (today 39 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Ethanol (today <1 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Methanol (today <1%):< 1%, 1-5 %, 5-30 %, > 30 %
    - Hydrogen (today 0 %):< 1 %, 1-5 %, 5-30 %, > 30 %
    - DME, (today 0 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Bio-, natural-, methane gas (today <1 %): < 1 %, 1-5 %,
        - 5-30 %, > 30 %
    - RME/ bio diesel (today <1) < 1 %, 1-5 %, 5-30 %, > 30 %
    - Other alternative: < 1 %, 1-5 %, 5-30 %, > 30 %

    If you answered another alternative, what alternative is that?:

Comment:

- What fuel do you consider the most possible fuel in the long run? Mark the probable sale-share of respective fuels in Sweden in 2050. The numbers in parenthesis describes the current sale-share.
    - Petrol (today 60 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Diesel (today 39 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Ethanol (today <1 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Methanol (today <1%):< 1%, 1-5 %, 5-30 %, > 30 %
    - Hydrogen (today 0 %):< 1 %, 1-5 %, 5-30 %, > 30 %
    - DME, (today 0 %): < 1 %, 1-5 %, 5-30 %, > 30 %
    - Bio-, natural-, methane gas (today <1 %): < 1 %, 1-5 %,
        - 5-30 %, > 30 %
    - RME/ bio diesel (today <1) < 1 %, 1-5 %, 5-30 %, > 30 %
    - Other alternative: < 1 %, 1-5 %, 5-30 %, > 30 %

    If you answered another alternative, what alternative is that?:

Comment:

- What are the present hindrances against an implement of alternative fuels? Rank from 1-6, where 1 corresponds to the greatest hindrance.

    - Technological hindrance, ex:
    - Consumers´ attitudes
    - Motor vehicle industry´s attitudes
    - Transport fuel industry´s attitudes
    - Political instruments of control, ex:
    - Other alternative, such as:

Comment:

Thank you!

Appendix 2: Recievers of the questionnaire

Energimyndigheten
Vägverket
NUTEK
VINNOVA
Vetenskapsrådet

Trafikkontoret Göteborg
Sekab
Baff
Cute
Usher
EPAB

Lund tekniska högskola
Chalmers tekniska högskola
Göteborgs universitet
Umeå universitet
Uppsala universitet
Kungliga tekniska högskolan

Folkpartiet
Moderaterna
Socialdemokraterna
Kristdemokraterna
Vänsterpartiet
Miljöpartiet

Shell
Hydro
Statoil
OKQ8
Preem

Sydkraft
Birka energi
Vattenfall

SNF
Motormännen

Appendix 3: Alternative fuels

Ethanol is produced from natural gas, crude oil, biomass surplus or crops (Arcoumanis 2002) and is probably today the most widely used alternative fuel. Ethanol has been used in various mixtures with conventional fuels from 5 % and up to 95 % ethanol in gasoline and diesel. EU-commission allows 5 % ethanol, but in for example Brazil it can be more than 22 %. The high rate blend, such as in E85, which consists of 85 % ethanol, is available in certain places in Sweden and requires special designed vehicles (Flexible Fuel Vehicle), whereas low fuel blends can be used in conventional engines. Its flexible use in fuel blends is to some extent the reason for ethanol being the most widely used alternative fuel. Ethanol cannot compete with the present lower production cost of gasoline and diesel. The disadvantage of ethanol is among others some increased emissions, the requirement of starting aid in cool climate and requirement of adjusted vehicle technology. (Arcoumanis 2002).

Methanol is produced from natural gas or gasified biomass, and most of it used as industry chemical and just a small share as fuel. Methanol can also be produced from methane gas and biogas but with a lower overall efficiency due to the energy loss in the conversion and higher overall CO_2 emission than natural gas (EU Directive 92/81/EEC). Methanol is suitable in fuel blends or as replacement of diesel and petrol, in ordinary combustion engines. Methanol is comparable with ethanol in many cases but the latter offers better promise for reduction of regulated and unregulated pollutants. Methanol is highly corrosive and toxic, affecting both humans and the environment. (Arcoumanis 2002). Because of these properties both vehicles and distribution systems need to be adjusted. Methanol can be used in fuel cells but with lower efficiency than hydrogen. Methanol offers few advantages over natural gas, apart from being a liquid and therefore easier to store in the car (EU Directive 92/81/EEC).

Biogas can be produced from solid wastes, sewage, agro-industrial wastewaters, etc. by microbes during methanogenic anaerobic fermentation. Biogas production has an additional advantage in that it does not compete with human food demands for grain or starch as ethanol production does (Månsson and Foo, 1998). Biogas is not expected to become a generally used automotive fuel, due to lack of both availability and economic viability (Cordis, 1999).

Natural gas can be used directly in compressed or liquefied form but also as methanol or DME. It's main use has until recently been to reduce oil dependency. (Arcoumanis 2002). Natural gas has been used as automotive fuel in many countries as Argentina, Canada, Italy, New Zealand, Russia, Sweden and USA. There are over 380.000 natural gas vehicles in Europe, mostly in Italy. (Murray 2001). Carbon dioxide, NOx and particles emission are lower compared to the corresponding amount of petrol and diesel (Murray, 2002). Disadvantages of natural gas fuel is the transportation difficulties, limited driving range due to low energy content and disadvantages with refueling.

Hydrogen can be produced either directly from sunlight and water by biological organisms and using semiconductor-based systems similar to photovoltaics or indirectly via thermal processing of biomass or fossil fuels. The production technologies have the potential to produce essentially unlimited quantities of hydrogen in a sustainable manner. Hydrogen as energy-carrier has little impact in environmental and health aspects, as water is the only emission from hydrogen when used in fuels cells. Hydrogen can also be used in diesel engine, with low emissions but also with a low efficiency. Hydrogen requires more research and development of production, distribution and vehicles. One of the major problems to solve is the infrastructure of hydrogen, transport, storage and refill stations, although liquid hydrogen storage systems have been used in vehicle demonstrations worldwide. The issues of safety, capacity, and energy consumption have resulted in a broadening of the storage possibilities to include metal hydrides and carbon nanostructures (Elam, 2001).

DME, dimethyl ether, is produced from fossil fuels, such as natural gas and coal, or renewable products such as biomass and waste material. DME is a fairly new but promising alternative fuel as it can be used in diesel engines with corresponding performance as diesel fuel and better performance than the petrol driven otto engine. (Murray, 2001). DME can be used as fuel alone, as additive to bio fuels to improve their ignition characteristics or as source of hydrogen for fuel cells. DME requires development of vehicle and storage technology. FINAL REPORT EU. DME is a gas at ambient temperature but liquefies under the pressure of a few atmospheres (EU Directive 92/81/EEC). Being a diesel fuel, it offers higher efficiency than fuels for gasoline engines, enough in fact to compensate for the energy loss in the conversion process from natural gas, (EU Directive 92/81/EEC). Due to its recent introduction very limited vehicle tests have been performed with DME- fueled engines.

RME, Rape Methyl Ether, is produced from rapeseed oil. RME is a common type of biodiesel and is suitable for use in modern diesel engines. Pure fuel use requires some technical modifications whereas RME used in fuel blends requires no modification of the vehicle technology (BAFBO, 2000). Because of the expensive production cost, a small potential production volume and the negative biological effects of the production, RME is not suitable as clean fuel. But RME can well be used as additive in fuels (Tornevall, 1998). The energy content is approximately the same as in diesel.

Fuel cells: A fuel cell generally uses hydrogen as energy carrier, but other fuels such as natural gas, methanol can be used. However, in most fuel cell types these fuels must first be transformed into hydrogen by means of a reformer or a coal gasifier. The direct outputs from fuel cells are electrical power and heat. The key advantages of fuel cells are the energy efficiency, low emission of pollutants, their multi- fuel capability and quiet operating. Many technical and engineering challenges still remain for fuel cells, which are still too expensive and not reliable enough to face a breakthrough. (http:// europa.eu.int/comm., 2002)

Appendix 4: Patent analysis key words

Key words used in search for patents in the Us government's patent database in the period 1976-2001;

ABST/ **Ethanol**
ABST/ (Ethanol and fuel)
ABST/(Ethanol and (fuel or fuel blend or internal combustion engine or power train or transport or motor vehicle or store*) andnot (power plant)

ABST/ **Methanol**
ABST/ (Methanol and fuel)
ABST/(Methanol and (fuel or fuel blend or internal combustion engine or fuel cell or vehicle or power train or transport or motor vehicle or store*) andnot (power plant or nuclear))

ABST/ (**DME** or dimethyl ether or di methyl ether or di-methyl ether or dimethyl-ether) and (fuel or or fuel blend or internal combustion engine or fuel cells or vehicle or power train or transport or motor vehicle or store* or produc*) andnot (power plant))

ABST/(**bio gas** and (fuel or fuel blend or internal combustion engine or fuel cell or vehicle or power train or transport or motor vehicle or store* or produc*) andnot (power plant or nuclear))

ABST/(**bio fuel** and (fuel blend or internal combustion engine or fuel cell or vehicle or power train or transport or motor vehicle or store* or produc*) andnot (power plant or nuclear))

ABST/(**Natural gas** and (fuel or fuel blend or internal combustion engine or fuel cell or vehicle or power train or transport or motor vehicle or store* or produc*) andnot (power plant or nuclear))

ABST/(**Diesel** and (fuel or fuel blend or internal combustion engine or fuel cell or vehicle or power train or transport or motor vehicle or produc*) andnot (power plant or nuclear))

ABST/(**petrol or gasoline**)
ABST/(Petrol or Gasoline) and (fuel or fuel blend or internal combustion engine or fuel cell or vehicle or power train or transport or motor vehicle or produc*) andnot (power plant or nuclear))

ABST/(**Hydrogen** and (fuel or fuel blend or internal combustion engine or fuel cell or vehicle or power train or transport or motor vehicle or store* or produc*) andnot (power plant or nuclear))

ABST/((**fuel cell**) and (fuel or fuel blend or vehicle or power train or transport or motor vehicle) andnot (power plant or nuclear))

ABST/((**internal combustion engine**) and (fuel or fuel blend or vehicle or power train or motor vehicle or transport) andnot (power plant or nuclear)).

Appendix 5: Article analysis key words

Key words used in search for articles produced in France, Germany, Netherlands and Sweden in the period 1990-2001;

Ethanol and (fuel or (internal combustion engine) or (fuel blend) or (power train) or vehicle),

Methanol and (fuel or (combustion engine) or (fuel cell)) not spectrosc*
Methanol and (fuel or (combustion engine) or (transport vehicle) or (power train) or (battery vehicle) or (electric vehicle)) not chromatography*

(Dimethyl ether or **DME** or Di-methyl-ether or dimethyl-ether) and (fuel or (combustion engine) or (transport vehicle) or (power train) or (battery vehicle) or (electric vehicle)) not chromatography*)

Hydrogen and (fuel or (combustion engine) or (transport vehicle) or (power train) or (battery vehicle) or (electric vehicle) or (motor vehicle) or (fuel cell)) not (chromatography* or nuclear or fusion)

Bio fuel and (fuel or (combustion engine) or (transport vehicle) or (power train) or (battery vehicle) or (electric vehicle)) not (plant*)

(**Natural gas**) and (fuel or (combustion engine) or (transport vehicle) or (power train) or (battery vehicle) or (electric vehicle)) not (plant* or fire*)

(**Bio gas**) and (fuel or (combustion engine) or (transport vehicle) or (power train) or (battery vehicle) or (electric vehicle)) not (plant* or fire*)
(Bio gas) and fuel

(**RME** or Raps methyl ether) and (fuel or combustion engine or vehicle or power train or battery vehicle or electric vehicle) not (plant or heat)

(LPG or liquid petroleum gas) and (fuel or combustion engine or vehicle or power train or battery vehicle or electric vehicle) not (plant or heat)

Diesel and (fuel or combustion engine or vehicle or power train or battery vehicle or electric vehicle) not (plant or heat)

(**Petrol or gasoline**) and (fuel or combustion engine or vehicle or power train or battery vehicle or electric vehicle) not (plant or heat)

Internal combustion engine

(**Fuel cell**) and (fuel or combustion engine or vehicle or power train or battery vehicle or electric vehicle) not (plant or heat)