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SOCIO-ECONOMIC CONDITIONS FOR FUEL CELL AND HYDROGEN TECHNOLOGY DEVELOPMENT

Prepared by:

Coretech, ECN, TNO, VOLVO

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The European Commission is supporting the Coordination Action "HyLights" and the Integrated Project "Roads2HyCom" in the field of Hydrogen and Fuel Cells. The two projects support the Commission in the monitoring and coordination of ongoing activities of the HFP, and provide input to the HFP for the planning and preparation of future research and demonstration activities within an integrated EU strategy.

The two projects are complementary and are working in close coordination. HyLights focuses on the preparation of the large scale demonstration for transport applications, while Roads2HyCom focuses on identifying opportunities for research activities relative to the needs of industrial stakeholders and Hydrogen Communities that could contribute to the early adoption of hydrogen as a universal energy vector.

Further information on the projects and their partners is available on the project web-sites www.roads2hy.com and www.hylights.org

SOCIO-ECONOMIC CONDITIONS FOR FUEL CELL AND HYDROGEN TECHNOLOGY DEVELOPMENT

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1. Introduction

This report is a deliverable of the Roads2HyCom project, a partnership of 29 stakeholder organisations supported by the European Commission Framework Six programme. The project is studying technical and socio-economic issues associated with the use of Fuel Cells and Hydrogen in a sustainable energy economy. Within the project, several studies have been made related to the question of socio-economics.

The aim of this report is to list and analyse socio-economic and financial barriers identified with respect to the transition towards a sustainable energy economy based on Hydrogen and Fuel Cells. Fuel cell (FC) and hydrogen (H2) technologies have the potential to become the main energy conversion device and a complementary energy carrier to electricity. These technologies can be an important part of a sustainable energy system (HFP, 2006). However, there are still many technical and non-technical barriers to overcome before widespread commercial availability is possible.

Addressing these barriers should facilitate and accelerate the development and deployment of cost-competitive, world-class European hydrogen and fuel cell technologies. These technologies would find use in transport, stationary and portable power in the next ten years. This report provides an overview with respect to financing, techno-economic factors, public acceptance, regulation, codes and standards, and education and training.

Basic and applied research is necessary to commercialize fuel cell and hydrogen technologies. The necessity to also remove non-technical barriers might seem not as obvious, but is a necessary prerequisite in order to pass all stages of the innovation cycle. The management of reducing non-technical barriers need to go hand in hand with support of research (COM(2003)226). In this report some selected non-technical barriers with relevance for the development of fuel cell and hydrogen will be discussed. The focus of this report is to discuss the most relevant challenges regarding the selected barriers.

This report complements studies undertaken in the project's Work Package 7, reported in document R2H7007PU, "Policies and Socio-Economic Aspects towards further dissemination of Hydrogen Communities in the EU".

2. Finance and business development

The finance industry is heterogeneous, with numerous diverse participants with varying motivations, occupying distinct niches within the so-called financial intermediation chain. The finance industry incorporates the interactions of people wishing to save (i.e. defer spending) to those planning to consume and/or invest today. The price charged to the recipient of the finance by the provider is either an interest rate, in the case of a loan, or an equity stake in the company, in this case a direct investment. There is an almost infinite variety of ways of 'structuring' the transaction. However, in the interest of clarity, in discussing finance we restrict our discussion to simple debt and equity transactions. Further, we limit ourselves to those individuals and institutions involved in the development of hydrogen and fuel cell (H2&FC) technologies.

The providers of finance to the H2&FC industry include private individuals and business angels, venture capitalists and banks as well as the public sector including the European Union.[1]

The hydrogen and fuel cell industry is widely regarded as embracing a diverse set of technologies, which include the traditional (oil & gas) and emerging (renewable) energy industries, as well as conventional (thermal) and innovative (fuel Cell) energy conversion devices. Thus, the 'Hydrogen Economy' includes technologies that display disruptive characteristics (e.g. fuel cells) and others that exhibit incremental characteristics (e.g. heat engines). Some are associated with indivisibilities or scale effects (e.g. fuelling infrastructure) while others face no such barriers (e.g. components).

The fuel cell sub-sector addresses an unparalleled range of applications, from consumer and defence electronics to residential, commercial and industrial stationary uses and a plethora of transport applications. Given this backdrop, these technologies are being pursued by a wide range of developers, from well-established, economically successful multinationals and SMEs, including many of the world's major chemical and precious metals companies and all major auto manufacturers, to a surfeit of micro companies focused exclusively on the H2&FC industry to numerous universities and research institutes. This chapter attempts to examine the structure of the European H2&FC industry as identified by the EU-sponsored Roads2HyCom (R2H) project[2] acting within the Framework Six programme, and to highlight the financing conditions faced by the constituent parts. We begin by clarifying the term finance.

The term 'finance' is all encompassing and open to interpretation. As such it is consistently misused by those outside the finance industry, which can lead to communication issues and valuable time wasted. Thus, when addressing a general audience, it should be made clear how the term is being used.

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1 See 'Financing and Business Development for Hydrogen Communities', Roads2HyCom June 2007: Ch 3 Financial Instruments. Document Number: R2H7001PU.2 (www.roads2hy.com/WP7.html).

2 R2H is a three-year project tasked with assessing and monitoring Hydrogen and Fuel Cell technologies for stationary and mobile energy applications. www.roads2hy.com.

As a noun the term 'finance' refers to the management of money, i.e. how money is used or allocated. When used in the plural, finances, the term refers to the (cash) resources of a government, company or even an individual. As a verb the sense of the term is often more difficult to determine, with its meaning being a function of the context in which the word is applied. In the context of the development of the hydrogen and fuel cell industry, finance means radically different things to different stakeholders, be they seed or well-established companies, operators of demonstration projects, financial investors or even policy makers.

To the project manager in a university of research institute 'finance' may mean a government or EU grant. To R&D managers in economically successful corporations 'finance' could mean the departmental annual budget and/or Framework grants. To the independent micro developer in all probability it means mortgaging his/her own house, raising funds from friends & family, business angels or venture capitalists via the sale of shares in the company. In summary, where the term 'finance' is being used it is important to understand the position of the individual using the term as well as the context in which the term is being applied.

The following graph not only highlights the type of technology developer active in Europe, but also their diversity. The underlying data derives from Roads2HyCom Work Package 1, which, with the aid of a web-based questionnaire, surveyed the European H2&FC industry.

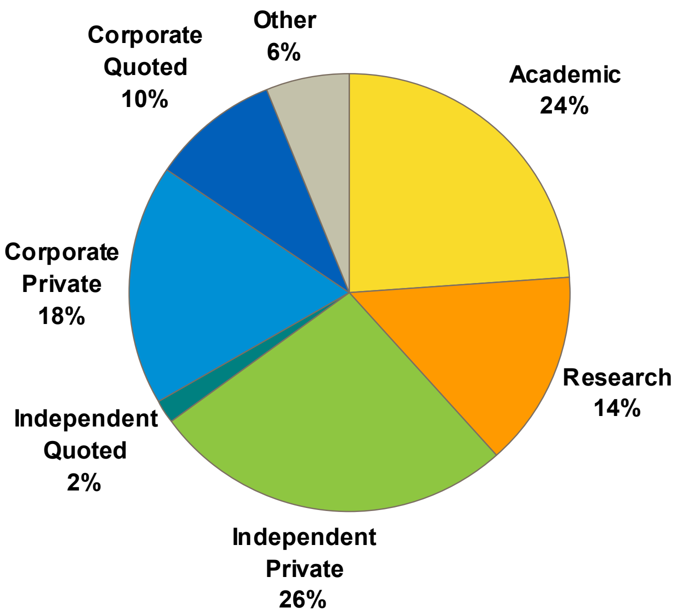

Figure 2.1: ***The Structure of the European H2&FC Industry***

Source: "A map of Hydrogen and Fuel Cell Research and Technology Development Activity in Europe", April 2008, Roads2HyCom Report R2H1015PU.2

Organisation Types are defined a follows: "Academic" means an academic institution or university, "Research" means a national or government research laboratory, "Independent" means a company whose main business is hydrogen or fuel cell technology, "Corporate" means an economically successful corporation whose principal business is not hydrogen or fuel cell technology, "Private" means a company that is not floated on the stock market, "Quoted" means a company that is listed on a stock market Other refers to consultants and other service providers

With the exception of “Other” (6%), the data in Figure 2.1 are based on the number of ‘entities’, both private and public, actively developing hardware, systems and services applicable to the H2&FC industry. It could be argued that a more useful description of the structure of the European fuel cell industry would be to measure the size of the respective players. In this event, the corporate sector would obviously dominate, while the position of the universities and research institutes would be unclear. However, there are a number of reasons for not ordering the industry according to company size or even according to committed investments. On the one hand, it is all but practically impossible to extract a consistent data base from corporate entities for which hydrogen & fuel cell activities constitute an almost insignificant component of their overall activities. On the other, from a financing and business development perspective it is the independent hydrogen and fuel cell developers who suffer disproportionately when it comes to attracting finance for R&D and product development, particularly when compared with the corporate sector in general and North American independent developers in particular. This problem extends to the university and research institutes as and when they spin technology out into an independent company given their research funding is no longer applicable.

Thus, finance to these differing entities must be seen in the context of their ability to access the various types of finance available to them specifically for the development of their technology. The following graphic matches the type of H2&FC developer as defined above, with the sources of finance its organisational type is most likely to be able to source.

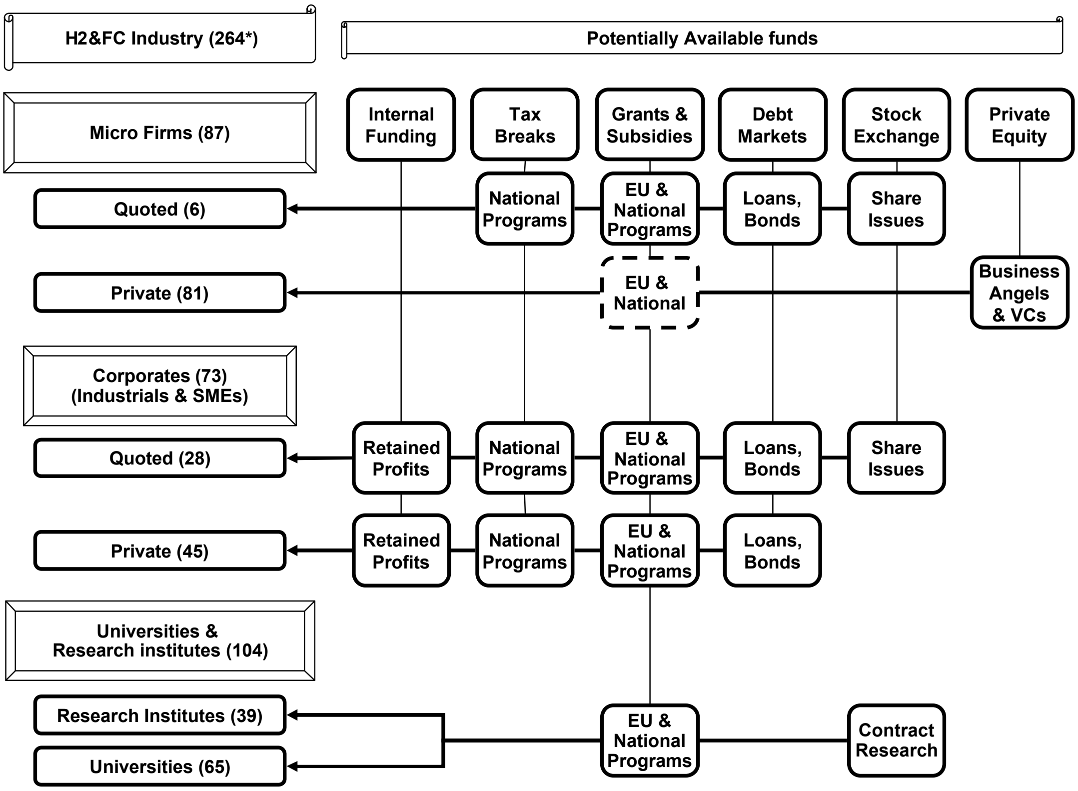

Figure 2.2: ***H2&FC Market Structure and Potential Financing***

Source: Graphic CoreTec Ventures based on WP1 Survey Data.

Academic and Research Institutes, which make up some 38% of the sample, can finance some of their activities through the use of government and EU funding programmes. Indeed such institutions often receive 100% of their funding requirement from official funding programmes. These players also pursue their technology interests by collaborating with industry within the framework of joint research projects or via contract research activities.

Economically successful corporations, which make up a combined 28% of the data collected and include chemical and automotive multinationals and SMEs, are able to finance their activities from a wide array of sources. Stock market listed corporates (10%) can raise funds from financial investors via the issuance of new shares (i.e. equity), or debt (i.e. bonds / bank loans) and have access to internal resources (i.e. retained profits). They can also make use of EU grants (e.g. Framework grants) and national subsidies (e.g. tax breaks). Economically successful privately-owned corporates (18%) can make use of all the above funding sources with the exception of issuing new shares, as their company equity is not publicly traded.

Publicly traded H2&FC micro companies, which comprise around 2% of the WP1 survey, in theory can issue debt, raise equity, use tax breaks and grants to finance their development. However, given the nascent state of the H2&FC industry it is unlikely that these companies are currently able to deploy retained income as none have as yet managed to report profits.

Privately owned H2&FC micro developers, which account for 26% of the survey, are essentially limited to raising capital from family and friends, business angels and venture capitalists. This group of developers not only have the greatest degree of difficulty in raising finances, they are also the most disadvantaged when it comes to making use of government grants and subsidies. On the one hand, R&D grants to companies invariably only cover a proportion of a project's total costs, thus requiring the company to at least match the portion not covered by the grant. Where finances are limited it is virtually impossible to take advantage of such schemes. Even in the case where a micro developer can find the resources to match the grant it is often the case that the company does not have the human resource needed to dedicate to the significant task of making an application. On the other hand, few if any of these micro developers are currently making revenues, much less profits. Thus they cannot make use of any tax breaks relating to income, unlike an economically successful corporation.

On a wider note, given the long-term effects from the credit crisis, which originated in the US housing market in mid 2007, raising investment funds has become increasingly difficult for most companies. With so-called second-round effects now taking hold, where banks are lending less and charging more for their loans to corporates and private individuals alike global economic activity appears to be slowing. Indeed, some financial market commentators are forecasting no recovery before 2010. The overall result is that both corporates and financial investors are less receptive to risky projects. Consequently, it is unlikely that quoted micro developers will be capable of raising more finance on the stock market, that further H2&FC IPOs will be possible, while private independent developers will find it more difficult than ever to raise investment funds.

In summary, given these varying types of developer acting in vastly differing 'financial' environments, from under-capitalised micro developers to well-capitalised public and private SMEs and multinationals to the academic research environment it comes as no surprise that finance means different things to these disparate H2&FC players.

2.1 Public Private Partnerships: Public, Industrial & Financial Investors

At the most general level, sources of finance are often divided into public and private, which can result in considerable confusion within the H2&FC community. It should be noted that private finance can mean either investments on the part of corporations or investments made by financial investors. The distinction lies in their motivation. The corporate is pursuing company goals, which may or may not include short- to medium-term cash return on the investment. The financial investor is almost exclusively motivated by short to medium-term cash return on his or her investment.

Within the public sector, 'private finance' is often referred to in terms of Public Private Partnerships (PPPs) where the authorities seek to collaborate with the private sector. A PPP is a venture which is funded and operated through a partnership of the public sector and one or more private sector companies and banks. These partnerships take many forms. In some PPPs governments provide the finance to be invested in the project, the operation of which is managed either in collaboration with the private sector or under contract. In others, the financial capital is provided by the private sector in return for a contract with government to provide agreed services from which revenues are derived. The salient point is that in the conventional sense of the term PPP, corporations and financial investors collaborate with governments in order to generate business, i.e. revenues and profits. As such, financial investors play a role in these projects, often providing some or all of the investment capital.

We have not been able to identify any H2&FC Public Private Partnerships or technology demonstration programmes (e.g. Cute, Virtual Fuel Cell Power Plant - VfcPP) that generate revenues and profits. While these projects are undertaken with industrials such as Daimler (Cute) and E.on, Vaillant (VfcPP) we have not been able to identify the presence of 'financial investors'. Thus when the term private finance is used by the 'authorities' in conjunction with the development of H2&FC it is unlikely to mean financial investors and as such cannot be regarded as a support mechanism for micro companies active in the H2&FC sector or indeed technology demonstration projects that have no clearly identifiable future cash flows.

It is worth considering the motivations of the various investor types. The public sector pursues economic growth; the private sector (corporate and financial) pursues profits. Thus, in the absence of revenues and profits it is unlikely that H2&FC PPPs will attract purely financial investors. The point to note is that in this case attracting 'private finance' effectively translates into inducing economically successful companies to provide a portion of the financial and physical assets required to execute a technology demonstration. It is not a mechanism for inducing financial investors to support fledgling companies or technology demonstrations.

2.2 Public Sector, Industrial and Financial Investors

Generally speaking the private sector includes the industrial and the financial sectors, while the public sector comprises central and local government authorities and, in the present context, the European Union. Industrial investors are most commonly associated with companies making investments in physical assets such as plant and machinery while financial investors for the most part invest in the shares of a company, or provide debt. Public sector investments by contrast are designed to promote economic growth, and generally take the form of (development) grants and (various tax) subsidies. While industrial and financial investors are both motivated by the need to make a profit from their activities, industrial investors are further motivated by the need to participate in innovation to survive in a world of technical advances and an ever changing regulatory landscape. The public sector is motivated by the need to maintain and promote the welfare of its citizens. As such the public sector is concerned with avoiding 'market failure' by ensuring that the research that underpins per capita economic growth is undertaken, which the private sector may be unwilling to undertake in the absence of public support.

2.3 Investment Horizons (the Investment Holding Period)

Clearly, the maximum period of time over which any given investor either considers the future or expects to remain committed to an investment differs depending on the motivations of the investor, a point often not fully appreciated by technology developers. Broadly speaking, it can be argued that the public sector is a 'long-term' investor, where the investment takes the form of industry support; industrial investors are medium-to-long-term investors while financial investors are short-to-medium-term investors.

Long-term is generally understood to be a period longer than 10 years. Indeed governments regularly issue debt that will not be paid back for periods considerably longer than 10 years. Typically, institutions investing over the long-term include the public sector and those involved in large infrastructure projects (e.g. nuclear power plants). Short-term normally refers to periods of less than one year while medium-term lies between the long- and short-term. Most financial investors invest in the short to medium term.

2.4 Financial Instruments & the Structure of the European Fuel Cell Industry

The majority of financial instruments currently available for the development of European H2&FC technologies favour an industry based on economically successful companies, capable of matching government and EU grants and able to offset H2&FC-related losses against profits and/or against any available tax breaks[3]. As noted above, the European Landscape as identified in the WP1 industry survey reveals an industry numerically dominated by poorly capitalised micro entities, the majority of which are dependent on their owners' financial resources, the support of family and friends, business angels and/ or venture capitalists.

Studies in Work Package 1 of Roads2HyCom (Document R2H1015PU.2, "A map of Hydrogen and Fuel Cell Research and Technology Development activity in Europe") illustrate this issue in greater detail.

From a financing perspective, it would be instructive to identify the structure of the industry according to nature of the innovation being pursued, e.g. radical/disruptive versus incremental. An understanding of this would provide valuable input with respect to how best to meet the specific financial needs of the varying developer types. However, such an investigation is beyond the scope of this work.

2.4.1 Financing the Corporate and Academic Sectors

European corporates, both quoted and privately-owned, as identified by the R2H Survey active, in the H2&FC industry comprise economically successful companies with access to the full spectrum of financial instruments outlined above. Universities and research institutes rely predominantly on the public sector for their financing. Hence, the corporate and academic sectors will not be further discussed in this section.

[3] See Roads2HyCom report "Financing and Business Development for Hydrogen Communities" (R2H7001PU.2), Table 3.1, p29 for an overview of financial instruments and p47/8 for an overview of EU public funding (www.roads2hy.com/WP7.html)

2.4.2 Financing the Independent Sector

The independent sector includes privately owned developers (26% of the total) and a small number of companies (2%) that have succeeded in raising finance from financial investors by listing, principally on London's Alternative Investment Market (AIM). While this development is to be welcomed, it should be noted that owing to current stock market conditions, dominated by the unfolding credit crisis and the 'flight to quality', whereby financial investors minimise their exposure to risk by focusing on well-established, blue chip corporations, it is unlikely that many more will be able to use the stock market as a source of funds for the foreseeable future.

In order to gain an impression of the relative importance of the stock market to European independent developers we investigated the US$ R&D expenditure, numbers of employees and the total amount of equity raised to date by Independent Quoted H2&FC companies in North America, Europe and Australia.

A total of 23 companies were identified as being independent quoted H2&FC developers, 16 of which are North American, accounting for 70% of the universe, 6 are European accounting for a quarter of the population and one is Australian. No independent quoted H2&FC developers were identified in Japan.[4]

Table 2.1 summarises the main findings, which shows North American companies dominating the independent quoted developers of H2&FC technologies in terms of R&D spend, numbers of employees and amount of private investor funding.

Table 2.1: ***R&D Expenditures, Employees and Total Equity Raised***

Independent Quoted H2&FC Companies	R&D Spend FY Latest US$ m [% of total]	R&D Spend FY Previous US$ m [% of total]	Employees FY Latest [% of total]	Equity Raised to end last FY US$ m [% of total]	Number of Companies
North America	$176.107 (91%)	$194.598 (92.2%)	2,132 (91.9%)	$3,360.679 (92.6%)	16
Europe	$9.525 (4.9%)	$7.185 (3.4%)	89 (3.8%)	$131.414 (3.6%)	6
Australia	$7.904 (4.1%)	$9.272 (4.4%)	100 (4.3%)	$136.303 (3.8%)	1
Total	**$193.535**	**$211.056**	**2,321**	**$3,628.396**	**23**

Source CoreTec Ventures

As can be seen above North American independent quoted companies account for more than 90% of the R&D expenditure of this sector, spending some 20 times per annum more on R&D than their European counterparts. While the absolute levels of employment remain low in the independent quoted sector at just 2,321, North

[4] The absence of Japanese independent quoted H2&FC companies reflects the fact that Japan has one of the lowest levels of venture capital investment as a proportion of GDP in the OECD, which in turn can be seen as an indicator of the corporate nature of the Japanese economy. See The Economist, Special Report BUSINESS IN JAPAN: **Not invented here,** Nov 29th 2007, available at http://www.economist.com/surveys/displaystory.cfm?story_id=10169932

American companies employ more than 90% of those currently employed in the independent sector, indicating that this region is probably gaining ground in the important area of technical development and additional expertise in the field of system integration installation and maintenance [5]. This conclusion is supported by the 2005 PricewaterhouseCoopers Fuel Cell Industry Survey, which reported that “70% of respondents [180] reported headquarters of fuel cell activities in North America” (Page 3 PWC Worldwide Fuel Cell Industry Survey 2006).

The total amount of funding these companies have collectively raised from private sector investors reached some US$3.63bn by the end of 2005, with the North American companies accounting for more than 92% of total monies raised or US$3.4bn. Europe by contrast has raised just US$131.4m.

The equity data in Table 2.1 clearly reflects the benefits enjoyed by emerging North American technology companies over their European competitors, who face fragmented financial markets, (at least informal) limitations on the movement of labour and capital, and a culturally defined high degree of risk aversion.

Turning to the situation in the private equity markets (i.e. business angel & venture capital financing) Europe appears weak compared with North American private equity. This in part reflects the fact that financial investors require a clear ‘exit’ from their investments. In other words venture capital activity is heavily dependent on the ability to sell their stakes, which typically takes the form of a public listing or a trade sale. In this respect, the US provides a much more accommodating environment for early stage financial investors than Europe. That’s largely because the US public equity market accounts for around 50% of the value of all publicly listed companies worldwide, making it approximately twice the size of the combined value of all EU quoted companies. It also helps that the US financial system functions under a single regulatory regime and has a largely homogenous culture with a greater tolerance for risk-taking. Thus given the relative paucity of H2&FC listings it is no surprise that the venture capital market is weak specifically in this area. Europe’s VC industry is around five times smaller than its US counterpart, and displays significantly greater variation in its sources of funding, a clear sign of its relative immaturity [6].

2.5 Non- financial issues

In our experience we have found, that at worst, European technology developers are unaware of the importance of finance to their companies’ development, and, at best, recognise the importance of financial capital in the development of the company, but have little idea about how to access such capital or how the financial world functions. The same cannot be generally said of North American technology developers, who not only understand the implications of attracting financial capital for themselves and

[5] Roads2HyCom research has identified approximately 250 fuel cell units have been installed in Europe over the last decade, representing around 12.5MW of stationary fuel cell capacity. This number compares with the 40MW installed in the US according to a Core Technology Ventures presentation held at the Eighth Grove Fuel Cell Symposium “Building Fuel Cell Industries”, London, 24 - 26 September 2003. Available at http://www.coretecventures.com/presentations/grove03.pdf

[6] See: L Bottazzi and M Da Rin 2002 Venture capital in Europe and the financing of innovative companies in *Economic Policy* **17** 229, and B S Black and R J Gilson 1998 Venture capital and the structure of capital markets: banks versus stock markets in *Journal of Financial Economics* **47**243.

their companies, but also show a good understanding of the needs of capital providers. Further, North American developers show an awareness of how diverse the financial sector is and as such know what type of investor to target given their stage of technical development, thus saving valuable company resources.

Given the importance of this issue we surveyed (December 2007) 7 investors representing a cross section of well-respected professionals with experience of investing in both EU and US early-stage technology companies. They comprised:

- The UK's most active venture capital investor in early stage technology companies
- A leading European private equity investor
- Two business angels
- A leading investor in university intellectual property
- A leading UK venture capital fund
- A former venture capitalist now operating as a CEO of a technology developer in which he had previously invested

We asked each individual whether they felt European technology developers lacked the financial and investment literacy of their US counterparts. Further, we also asked a number of other questions to enable respondents to give fuller details of where specifically they felt European developers ranked versus North American developers.

The complete set of questions posed is as follows:

Table 2.2: Results from survey of seven investors

Questions		Yes	No
	In your professional experience do EU technology developers[7] …		
Q1	... lack the financial /investment literacy of US tech developers	**6**	1
Q 2	... produce appropriate business plans and related documents	**4**	2
Q3	...produce appropriate presentation materials	1	**5**
Q4	...have appropriate staffing	**4**	2
Q5	Are they aware of investment processes	3	3
Q6	Do they have realistic management expectations in terms of on-going roles	3	3
Q7	Do they understand the benefits of having a VC partner	3	3
Q8	Do they understand the implications for their company of having a VC investment partner in terms of transparency and reporting	2	**4**
Q9	Do they understand the personal implications of having a VC investment partner	2	**4**
Q10	Are they cognisant of the available exit options	3	3

Source: Core Tec Ventures

As can be seen above, the majority were of the opinion that, in general, EU technology developers lacked the financial and investment literacy of their US counterparts. On specific issues the majority felt that EU developers tended to produce adequate business plans, but clearly fail to take account of appropriate presentation materials. Staffing was not seen as a significant shortcoming. Half of those surveyed said that EU players were unaware of the investment process, failed to grasp the implications of the company's development for their own future roles, did not understand the benefits of having a VC partner, and did not consider the need for the investor to be able to sell (exit) their holdings at some point in the future. Finally, the majority surveyed noted that EU developers did not understand the implications for their company or themselves of having a VC investor.

We asked respondents to comment on the effects of any failings highlighted. The main points made were:

- The deal process is slower in Europe
- Fewer companies get funded
- More EU companies fail or do not meet expectations

[7] Of the seven investors questioned, one answered the first question only.

In conclusion European developers would appear to be disadvantaged when dealing with financial matters relative to their US counterparts.

2.6 Conclusions

The EU H2&FC industry has a strong presence of well-financed, economically successful multinationals and SMEs (corporates): auto, chemical, materials, precious metals and energy companies are very much in evidence. However, the emerging industry is numerically dominated by independent micro companies, universities and research institutes.

In addition to their own internal resources the corporates have access to many external sources of capital to finance their H2&FC activities, including government and EU subsidies. The academic sector acquires most of its funding from public authorities and to varying degrees from contract research activities.

The major finance problems lie with the independent developers, which for the most part rely on their own resources, family and friends and/or venture capitalists. However, relative to the US, the European venture capital market is less dynamic and considerably smaller. Indeed, Europe is institutionally fragmented in terms of finance market regulation, national tax regimes, has a high degree of cultural and linguistic barriers, and is characterised by a relatively high level of risk aversion. In addition, independent European technology developers appear to be relatively unaware as to how, and from whom they could most efficiently seek financial support. In short, they appear to be less financially literate compared with their North American competitors, which may in part help explain the huge discrepancy noted above between the funding raised by European and North American independent developers.

Finally, when considering the following recommendations it is important to bear in mind that much H2&FC innovation displays disruptive characteristics, defined as an innovation once commercially successful leads to fundamental changes in the way goods and services are both produced and consumed. Further, the development of H2&FC technologies, particularly components, are not burdened by scale effects, as witnessed by the plethora of capital poor micro independent developers and academics.

Given these considerations, combined with, in some cases obstacles unique to Europe, we propose the following recommendations be considered to maximise Europe’s chances of becoming a major developer and producer of H2&FC technologies.

2.7 Recommendations

1. EU Provision of Equity: A European Trust Fund for Future Generations

In an effort to address the critical shortage of equity finance the Commission should investigate the feasibility of establishing a European Trust Fund, along the lines of the Carbon Trust[8] established by the UK government, thereby leveraging investment in emerging companies whilst at the same time leaving the lead investment and technology decisions to the market. Where national governments seek to leverage their own investments in new companies, they act on the basis of promoting national and not European interests and as such do not necessarily promote the best European technology.

2. Favourable tax legislation to enhance investment in high risk enterprises

The UK, widely regarded as the 'best practitioner' in finance matters provides both income tax and capital gains tax relief to private individuals investing in UK-based smaller "high risk" companies. Meanwhile, in 2007 the French government introduced wealth tax relief allowing investors to offset their tax liability when investing in early-stage companies anywhere in Europe. While we recognise that the EU cannot legislate for Member State tax arrangements, the EU should proactively support the deployment of such schemes in all member countries.

3. Easier access to non-equity funding

While many countries and regions provide a variety of grants and subsidies to companies within their own jurisdictions, we were unable to identify any specifically allowing the funding to be used for bilateral projects between companies and/or research institutes/universities outside of their jurisdictions. Thus we recommend that both member states and regions investigate methods of extending financial support schemes to small bilateral R&DD partnerships. At the same time, effort should be dedicated to lowering the administrative burden faced by particularly smaller, micro companies when applying for government / EU support programmes. In short, the burden should be proportionate to the nature and size of the applicants.

4. Joining up the policy dots

The commission is often unfairly accused of being unaware of the financing difficulties faced by corporate and small private companies alike. However, the EU is well aware that European fragmentation negatively affects investment and fundraising[9]. Nevertheless, it is widely held that finance

[8] The Carbon Trust was set up, and is financed by, the UK Government in 2001 as an independent company with the aim of accelerating "the move to a low carbon economy by working with organisations to reduce carbon emissions and develop commercial low carbon technologies." To this end the Carbon Trust also act as a co-investor in early stage companies including independent H2&FC developers, managing both venture capital and seed funds. See http://www.carbontrust.co.uk/investments.

[9] See presentation given by Per-Ove Engelbrecht, Head of Unit Financing Innovations and SMEs, at the EASY Summit, London, 26 June 2008

initiatives relevant to innovation are not communicated across all necessary departments, which in turn conveys the impression of fragmentation with the Commission itself. Hence the oft repeated appeal for “more joined up thinking”. Specifically, the Commission should seek to improve communications between directorates with the aim of ensuring for example financial issues and opportunities, above and beyond framework grants are given more prominence in R&DD events and its literature. The JTI for its part should also consider this recommendation, not least in order to avoid similar criticisms in the future.

5. Education and Training

We may not be able to address the cultural issue of relatively high levels of European risk aversion amongst European investors and entrepreneurs alike. Nor can we resolve the problems of institutional fragmentation. But we could address the lack of awareness European H2&FC developers exhibit in the area of finance:

– Promote practical financial courses with credits specifically for scientists from undergraduate level through to PhD. Such courses could specifically deal with issues in finance related to company building and technology development, (rather than the basics of micro and macro economics). Europe’s science & technology students could be academically rewarded for taking such financial courses.

– Promote similar (free or at least low-cost) courses for independent H2&FC developers.

6. Increased and sustained public procurement programmes

At the outset we propose that the EU investigate the feasibility of establishing a European Public Procurement Agency for promising near-commercial technologies. There are many calls within the H2&FC industry for a clear policy of public procurement, not least to compete with the effective H2&FC procurement programmes of the US DoD and DoE. Indeed, in the case of hydrogen and fuel cells, the EU could take the lead by installing H2&FC equipment in high profile locations in Brussels and Strasbourg. The following list offers some of the more pertinent reasons for the EU, member states and the regions to introduce such programmes:

– To bridge the gap between R&D and demonstration on the one hand, and full scale commercialisation on the other

– To facilitate the acquisition within local markets of the skills and expertise required of integrators, installers, maintenance personnel, distributors and recyclers. Fostering ‘home grown’ expertise will not only lead to enhancing local employment opportunities, but will render obsolete the need to import such skills once the technology has become more globally established. Currently the US has a fuel cell installed base estimated at two to three times larger than Europe. This in turn indicates that the US is acquiring the new skills demanded by the technology more rapidly than Europe. European and member state public procurement, widely used in the US, would go some way to redress this imbalance.

– To leverage industry investment in the new technologies, and at the same time assist industry in utilising existing facilities and provide a degree of product visibility.

3. Techno-economic factors

The introduction of hydrogen as a new energy vector for stationary and transport applications not only requires progress in technology development, but also depends greatly on incentives. In principal, incentives should be considered in a broad sense, encompassing policy incentives as well as incentives at the end-user level (i.e. consumer preferences and social acceptance). The transition does not only include technology, but also the interaction of technology with society. Socio-economic aspects in a transition process include cost of technology as well as profits, availability of resources (energy prices, security of supply), public acceptance (see separate chapter), and many other topics. This chapter gives an overview of what research has been done and what further research needs to be carried out to facilitate a successful transition towards hydrogen.

3.1 Cost and technological learning

The introduction of hydrogen into the energy system faces major barriers when looking at cost for both the end-use application as well as the development of the hydrogen infrastructure (including production) (HyWays, 2007a). Reduction in the cost of hydrogen technologies is one of the preconditions before hydrogen and fuel cells can be introduced. Cost of technology can be reduced in several ways. Firstly, cost can be reduced due to advances in technology efficiency or reduction of costly materials. By conducting R&D (learning by searching) advances in technology development and thereby cost reductions can be made. As outlined in the Roads2HyCom 'Political Will' report (Lako, 2007), R&D investments for hydrogen and fuel cells are increasing, but supporting R&D is by itself insufficient to enable an autonomous transition towards hydrogen.

Demonstration of the technology (learning by doing) is also important and a second way to reduce cost. It is essential to demonstrate and test hydrogen technologies under real life conditions in order to see whether a technology reached the end-users requirements. Due to economies of scale in the production process, costs of the technology can go fast. Technological learning is often described by a learning curve (or progress ratio). A learning curve describes technological progress as a function of accumulating experience with a specific technology. Technological progress analysed within a learning curve is parameterised as a cost reduction due to an increase in the accumulated production. Such an estimate is based on historical statistics in the cumulative output. The essential parameter to be estimated in this formalism is the so-called progress ratio (PR). For example, a technology with a progress ratio of 0.8 will see that the unit price will be reduced by 20 percent with each doubling of the cumulative output. The progress ratio is estimated from available historical data or can be derived from the statistics on learning curves of related technologies. Despite that fact that the cost reduction is modelled as a function of (cumulative) deployment, also R&D (in fact: R&D intensity) does play a major role.

Optimising the balance between learning by doing and learning by searching is a key factor in order to ensure that the break even point is reached at minimum costs and as early as possible. However, little studies have addressed this issue yet, partly due to the fact that on a more fundamental level the (empirical part of the) balance between learning by doing and learning by searching still has a substantial 'black box' character. It is important to note that learning curves do not represent a physical law. They are an empirical phenomenon with significant uncertainties surrounding both the estimation of specific progress ratios and their extrapolation for long-term forecasts of the cost reduction of technologies.

Both the impacts of R&D as well as deployment are incorporated in the learning curve since both reduce the cost of a technology. By applying (additional) R&D cost can be brought down even without further deployment. In order to conceptualise this, a so-called two factor learning curve approach has been developed where the R&D expenditures and deployment effects are taken into account as independent factors. For the analysis of hydrogen and fuel cell systems the learning curves for production technologies, distribution, as well as the costs for the different end use technologies (PEMFC, SOFC, etc.), have to reviewed individually.

Within the (EC co-funded) Sapientia project two-factor learning curves have been studied and developed for hydrogen technologies (Martinus et al., 2005). The two-factor learning curve is a concept of high interests, since theoretically it provides the answer on how to shape innovation policy. However, the empirical justification of the theoretical concept is yet weak. By using this approach the optimal learning rate and thus the balance between R&D and demonstration/deployment can be determined. Determining the right pace of deployment is essential, because if the deployment is not sufficient, industry is not able to make the required investments in infrastructure build-up as well as production capacity. If the deployment is too fast, the learning effects are not able to penetrate the production process. As a result additional investments in R&D and deployment have to be made. Since hydrogen and fuel cells are moving more into the deployment phase more research is needed in the two-factor learning curve and this needs to be translated into a solid deployment strategy optimizing R&D and deployment efforts. As also recommended by the HyWays project a corresponding monitoring framework needs to be set up ensuring the right balance between R&D and deployment is maintained (HyWays, 2007b).

3.2 Scenario analysis

Over the years several scenarios have been made in which hydrogen is one of the envisaged future energy vectors. As described by the Roads2HyCom 'Snapshots' report (Ros, 2007) most of the reference cases (base line) of the scenario studies indicate a very small role for hydrogen. In other words, hydrogen is not likely to enter autonomous; specific incentives have to be provided in order to overcome initial barriers. In the hydrogen case of scenario studies where there are substantial policy incentives (e.g. CO_2 price) and/or high oil and gas prices, hydrogen becomes more important especially for the transport sector. Fuel cells on the other hand (using natural gas) keep playing a minor role in the industry and in the household sectors.

What often is missing in these scenario studies is a good description of how hydrogen and fuel cells enter the energy system. Most attention is often paid to the long term forecast. This often has to do with the methodology used by the model. Models used for long term forecasts look at costs of a technology compared to competitive technologies. Models with perfect foresight do take into account the future prospect where traditional simulation models only take into account the conditions over the next (rather than all) simulation periods. The use of perfect foresight is, in general, one of the characteristics of so-called optimisation models. If no further restrictions are set, the cheapest technology (least cost optimisation) obtains the full market share. In a simulation model, usually the market share is divided based on the competitiveness of a technology, implying that also less cost effective technologies obtain a (modest) market share. In practice, the introduction of hydrogen does however not purely depend on the cost/benefit ratio. As indicated before, other socio-economic issues also play a role. Non-economical aspects (barriers as well as opportunities) need to be put into a better description of the introduction strategy for hydrogen and fuel cells.

By looking at early markets a better insight into the role of hydrogen and fuel cells can be gathered. Early markets and niche markets can play an important role in the introduction of hydrogen and fuel cells, although they alone may not be sufficient to bring down costs for mainstream markets through economy of scale (Roads2HyCom document R2H4005PU, "Analysis of Opportunities and Synergies in Fuel Cell and Hydrogen technologies"). However, early markets are parts of the full (commercial) market with (slightly) deviating characteristics. Early markets may exist due to deviating requirements with respect to:

1. Costs: some markets can tolerate higher costs with respect to the provided service. This holds for example for markets with only one provider or markets where costs can be transferred to the end-user

2. Technology: for some markets, the daily driving distance, required maximum speed and refuelling pattern may deviate from the general requirements

3. Other aspects, such as high concentrations of pollutant emissions

As a result, a higher tolerance exists with respect to the additional cost by utilising (some of) the advantages offered by hydrogen and fuel cell technology. This specifically holds for early markets that encompass favourable technological, economic and other conditions (e.g. pollution). Examples of early markets are remote areas (e.g. islands) for stationary hydrogen end-use applications or public buses in city centres for hydrogen in transport applications. Niche markets are specialised markets where applications that share some components with 'regular' hydrogen applications are used. Examples of niche markets are auxiliary power units on boats, aerospace (fuel cell for power production), fork lifts, specialised vehicles to transport disabled people at airports and the use of small fuel cells in portable consumer electronics. Specifically in the U.S., the military has served as early market for high tech innovations.

Niche markets may play a role by, for example, making the general public more familiar with the (positive) contribution of hydrogen technology. Nevertheless, usually either the size of their market compared to main markets (e.g. the market for fork lifts and specialised vehicles at airports is much smaller than the market for passenger cars) deviate significantly in technological properties (e.g. the fuel cell in consumer electronics has to produce Watts rather than kilo Watts). Secondly, the characteristics of the technology applied in the niche market may deviate substantially from the characteristics in the main markets. Therefore niche markets are not expected to pave the way on their own for the introduction of hydrogen in main markets. They are considered to be supportive rather than a main driving force.

However , getting more insight into early and niche markets is needed in order to get a better understanding of the early deployment of hydrogen and fuel cells and the spill over effects between different applications. Up until now, this area has hardly been addressed from a socio-economic perspective. An increase of these activities is required, along with developing a better understanding of how different market introductions with different market entry dates can contribute to the deployment of hydrogen and fuel cells. The HFP DS report, for instance, outline the following entry dates:

- 2006/2008 Small portable sector
- 2010 Early markets domestic heat and power
- 2015 Large Stationary fuel cell CHP
- 2020 Transport

The competitiveness of hydrogen technologies will gradually increase in time as costs go down (and profits up). Introduction of hydrogen fuelled vehicles will occur earlier in different market segments. It may happen that hydrogen fuelled vehicles are introduced earlier in the early markets with large fleets of vehicles (e.g. postal delivery services, government fleets, etc.). Understanding the different needs and possibilities of several early and niche markets and regions is crucial. Clearly, this also addresses the need to look at market entry and deployment in a 5 – 15 years perspective, taking into account various socio-economic aspects. For this purpose a comprehensive scan of different markets and regions has to be made (Bunzeck, 2008).

A wide number of energy chains exist for hydrogen. By means of well-to-wheel analysis, the implications of each of these energy chains can be determined. This type of analyses can play a major role in determining the right strategy for the introduction of specific hydrogen chains. Periodically, the underlying data used in these well-to-wheel studies need to be checked and new insights need to be incorporated. Also, it is important that these well-to-wheel studies encompass the short, medium to long term, even though it is complicated to make a detailed estimate with respect to future performance and costs.

Related to that is also the necessity to take into account the origin of resources when modelling the impact of the introduction of hydrogen into the energy system. Models, which have the technological detail to fully address the consequences of various hydrogen energy chains, have usually a limited geographical scope. On the other hand, models that encompass various regions on a global scale are usually very limited in their technological detail. There are, however, a number of technology rich bottom up models available with a global scale that potentially could model hydrogen in this detail. Learning more about the origin of the resources for hydrogen will tell more about the security of supply (one region is more stable than the other and diversification is preferred) and also global emissions may be affected due to the choice of specific chains that strongly reduce emissions on a European level.

One of the key requirements for hydrogen technologies is to bring down the costs for end-use applications. The potential for this is huge, since mass manufacturing has not started yet. Learning curves are an important tool for estimating the future costs of hydrogen technology and can as such play an important role in various fields, such as design of policy support schemes (required intensity) and evaluating technological progress in relationship to future targets outlined in a roadmap.

For hydrogen, some roadmaps have been produced at different points in time, such as the HyNet roadmap (see www.hyways.de/hynet/) and its follow up the HyWays roadmap (see www.HyWays.de). Even though these roadmaps should to some extent be robust, it is important to have them re-evaluated and updated about every five years, ensuring that future targets are still set in line with recent developments.

Hydrogen technology will go down in cost fast as deployment goes up. However, initially hydrogen specific support schemes are needed rather then general schemes supporting sustainability in order to be able to compete with incremental options. First of all, a timely implementation is required, implying that the support scheme should be in place before barriers do seriously hamper the deployment. Secondly, the support schemes should have the flexibility to adapt to the rapid changing competitiveness of the hydrogen technology. On a policy level, the sense of urgency has to be raised. In addition, a policy framework – in order to harmonise support in Europe – should be developed which can be tailor made then on a member state level. The policy framework should address the needs of industry and end-users as well as take into account the requirements from politics to be set on the characteristics of such a scheme.

Interests of key stakeholders may differ. Alignment of the expectations and interests is of key relevance in order to ensure that support will be lost. From an innovation perspective, in the first phase of introduction of a new technology only a limited number of large-scale demonstration projects might be needed. However, a substantial number of regions (or countries) might be very keen on already participating in this very early innovation stage. Also interests on the member state level may not be in line with the technological requirements. On a member state level, the main priority is to reduce emissions in the short run (i.e. Kyoto time frame or at its best post-Kyoto – 2020) at minimum costs, cost effectiveness being a major criteria. Hydrogen does not fit in the portfolio of measures to achieve these goals. Nevertheless, and perhaps even specifically, the ability to reduce emissions massively on the long run is essential in order to mitigate the consequences of climate change.

Further research is needed on how to obtain and ensure the balance between R&D and deployment. Both aspects will reduce costs, but need to be in balance in order to reach the break even point at minimum costs and as soon as possible.

Further questions that need to be answered are:

- What are the technological performance needs of the end-users in terms of availability of the technology (drive cycle, load factor, durability, etc.)?
- What are the characteristics of the reference technology in order to identify gaps (economic, technical, other)?

- What is the expected development of energy demand and what is the potential role for hydrogen?
- What are the regional conditions that may harness or hinder hydrogen deployment?
- What is the general and local attitude towards hydrogen and fuel cells (public acceptance, 'not in my back yard' syndrome (NIMBY))?
- What are the (potential) policy incentives and governance tools (including permission processes) that may harness or hinder hydrogen deployment?
- What are the Training and Education needs?
- Can hydrogen and fuel cells be an economic viable option?

As a result of this scan further insight into the deployment strategy of hydrogen and fuel cells is gathered. This can provide useful input for a more targeted policy support measures.

3.3 Policy incentives

Hydrogen and fuel cells are considered a radical innovation. This means changes have to be made in various parts of the energy chain before hydrogen can be introduced. In this perspective, hydrogen differs from other renewable energy technologies. For example, wind and solar electricity are other production methods to produce electricity, but require no radical changes in the end-use application (the same electrical appliances can be used as we used now). Biofuels require new production facilities but can be blended with existing fuels and require no (or minor) changes to the vehicle engine. This is not the case for hydrogen and (hydrogen) fuel cells. Changes have to be made for the production, distribution and end-use applications.

Policy support can help tackle specific barriers, which need to be overcome for the introduction of hydrogen and fuel cells (see also Roads2HyCom Deliverable 7.4, (Bader, 2008)). Given the nature of the technology and the fact that the technology is still in the first phase of the innovation trajectory, R&D and demonstration support is needed. As outlined in the Roads2HyCom "Political Will" study (Lako, 2007) the budgets for R&D for hydrogen and fuel cells are increasing worldwide. However, technology development needs to go hand in hand with technology deployment support. The industry involved in the hydrogen and fuel cell technology field need to make considerable investments before they can start mass producing hydrogen technologies. In the EU, over 15 million vehicles a year are being sold. This implies that several thousands of hydrogen vehicles need to be produced first, before one can even start talking about making a comparison between production costs of the reference vehicle and hydrogen vehicles (Bunzeck, 2008).

A report published by the HyWays and HyLights projects (HyWays, 2007 and Bunzeck, 2008) outlines several policy support measures that can be used to help the introduction of hydrogen in the energy system. The situation in Europe is quite diverse. There are 27 Member States, which means there are 27 different taxation and support schemes. In general, taxes on vehicles are high in countries without significant automotive industry. This offers the opportunity for major incentives through tax exemptions. Countries with a strong automotive industry have in general limited taxes (on top of V.A.T.) for vehicles. This implies that the existing framework offers little opportunities for substantial support of hydrogen vehicles. This leads to the controversy that countries with no automotive industry offer the best opportunities for introduction of advanced vehicles, where countries with a strong automotive industry have created a kind of policy lock in for the conventional technology.

Also the level (national, regional or local) at which policy support is regulated differs between the member states. At the moment the EU has the framework programme (FP) by which they support R&D of hydrogen and fuel cells. National governments also provide R&D support, but additionally can exclude hydrogen from excise duty, road tax and other tax measures. The national government can also be an early adopter of the technology by incorporating hydrogen fuelled vehicles in their fleets and use fuel cells for combined heat and power (CHP) for their buildings/offices. This latter function can also be fulfilled by regional/local governments. Additionally they can create an attractive environment for hydrogen by introducing measures like limited city centre access, preferred parking, use of bus lanes, etc.

Up to now however, the work on policy support for hydrogen and fuel cells has been limited to measures that could stimulate the market entry and early deployment of hydrogen. A further analysis on how a coherent policy support framework will impact hydrogen deployment is urgently needed. There needs to be an alignment of the policy support measures at the different levels of the government to improve the efficiency of the support. Otherwise, policies are likely to be inconsistent and can even be counterproductive (e.g. if hydrogen production is taxed as part of energy taxation, see Roads2HyCom Deliverable 7.4 (Bader, 2008)). As deployment strategies need to be prepared now, additional research on the overall regulatory framework is needed. On top of that, further research on how these policy support measures can be introduced as budget neutral options is required.

Within the Roads2HyCom project related work has been done and a report on how to stimulate SMEs in the hydrogen and fuel cell field has been published (Mönter, 2007). In the further research know-how to support hydrogen and fuel cells further insight into the specific needs of SME have to be considered as well.

3.4 Externalities

Externalities or external cost are cost of purchase or use of a technology which are not reflected directly in the price. By means of the external costs approach, an estimate can be made of the current damage costs to society (in a broad sense). The most important categories of external cost are climate change, air pollution, noise and accidents.

The external costs of transport are large (estimated at about 8% of EU GDP (INFRAS, 2000)) but the estimates are uncertain. Values can be obtained from the EXTERNE project, but current technology has improved and has changed the external cost values considerably. The Needs project looks to update the external cost values for transport (Needs, 2008). For various methodological reasons, calculating the external costs of, for example, climate change will remain to be difficult. Since 'no climate change' is not even an option anymore and 'limit the impact of climate change' is the starting point (e.g. by requiring that the average world temperature can't increase more than 2°C), one could argue that the external costs are 'infinite' due to the fact that that irreversible effects do occur.

No studies exist which clearly point out the external costs for stationary applications. Future research should look into this and make a distinction between fuel cells in industry and in households.

For hydrogen and fuel cells externalities can vary substantially, depending on how the hydrogen is produced. In case the hydrogen is produced from renewable sources, external costs are negligible. Therefore by including externalities in the cost of current technologies hydrogen and fuel cell technologies (together with all other sustainable technologies) can gain price advantages. The main challenge for research is to look into how externalities can be internalized in policy and/or in pricing. Nowadays sometimes road pricing or vehicle pricing starts to take into account the CO_2 emissions, but other types of emissions are excluded (e.g. PM, NO_x, etc.).

3.5 Conclusions and recommendations:

The concept of learning curves can provide valuable insight with respect to cost and time needed to reach the break even point. The concept of how to balance learning by doing (deployment) and learning by searching (R&D) is however still poorly understood. The optimal balance between R&D and deployment likely depends on both the technology as well as the innovation phase the technology has reached. Technological learning is also a major factor in scenario analysis. By developing scenarios for the transition toward a hydrogen based energy system, robust pathways and key technologies can be identified as well as the impact to enabling factors such as various policy schemes. The set of energy models to be used to analyse the hydrogen transition should have sufficient technological detail as well as regional coverage. Resources need to be modelled over their full energy chain so that both emissions during production and distribution are included and the contribution to security of supply can be assessed. Security of supply should not solely be seen as resources that need to be imported by Europe, but also take the amount and location of the resources into account.

Several studies have analysed the impact of current and future policy instruments in order to determine to what extent the cost gap between hydrogen and fuel cells and the reverence technology can be closed. Given the fact that series production has yet not started and the reference technology has been mass manufactured for decades, the – yet substantial – cost gap will likely go down rapidly. Early markets will have to play an essential role before hydrogen specific policy incentives are able to bridge the cost gap. A series of early markets is needed imposing increasing demands on the technology. It has turned out that the characterisation of the evolution of early markets is not as straightforward as considered upfront. Stakeholders are yet hardly prepared to deploy hydrogen technologies since they lack information on both the end-use applications as well as hydrogen infrastructure. In this context, it should also be mentioned that these stakeholders in the past only had to deal with the end-use application, but now they may also have to consider how to build up the required hydrogen infrastructure.

4. Public acceptance

Hydrogen and fuel cells are considered to be a radical innovation. It will not only require changes in end-use applications, but also infrastructure and production of hydrogen. Therefore hydrogen and fuel cells will change the way we are used to doing things and the acceptance of the users and the public is crucial for a successful introduction of hydrogen and fuel cells. If the technology is not accepted by the general public, as well as the stakeholders that have to invest in building up production capacity and infrastructure, this will seriously hamper the deployment of the technology, ultimately endangering a successful introduction.

4.1 General public, local actors, consumers and key stakeholders

Public acceptance has various dimensions. A distinction needs to be made between the general attitude (general public), attitude on the local level, people who use the end-use technology (consumers) and stakeholders that have to enable the transition (e.g. building up the energy infrastructure, see (Mourik, 2005)). The general public may have a positive attitude towards a specific technology, but if it is deployed in their back yard, they may seriously oppose it (NIMBY-effect). A second issue is the perceived risk vs. the actual risk. For advanced technologies, the public is not able to make an accurate risk estimation but has to rely on other mechanisms, such as trust on the opinion of actors they respect most within this context. Rare incidents may influence the perception dramatically, even though the actual risk is way different. In the case of hydrogen, there is a complication that the attitude towards some elements may be positive, but if negative feelings towards one of the elements in the energy chain exists, the attitude towards the whole energy chain may change. People may like the fuel cell vehicle, but if they dislike the hydrogen production method, they will not purchase (accept) the fuel cell vehicle.

Acceptance may increase strongly in the case where the new technology offers functionality that could not be provided by the conventional technology. For example, a fuel cell vehicle can be designed in a different way than a conventional vehicle, since the drive train can be built differently. The new vehicle could be designed to maintain reasonable climate conditions when parked (e.g. one could set up a link between the vehicle and a cellular phone, giving the car a signal to turn on the air conditioning. When stepping into the vehicle half an hour later, the temperature is at an acceptable level). Such a system does not have to work at full power, it can take the time to gradually change the climate conditions. Features like this could help to significantly increase the acceptance of the new vehicle.

Industry involved in the hydrogen and fuel cell field are well aware of the importance of public acceptance. That is one of the reasons they conduct public acceptance studies asking the users involved in demonstration projects their opinion about the hydrogen and fuel cell use in transport and stationary use. The AcceptH2 project, for example, aimed to support the future introduction of hydrogen-fuelled buses by conducting a systematic evaluation of public perceptions, values, and intended and actual use of hydrogen-fuelled buses in the CUTE project. Also, the automotive industry (OEMs) mostly conducts surveys with their users. In these surveys they focus on all aspects involved in the handling of the vehicle and the refuelling (Fuhrman, 2007).

Missing so far within the scope of these studies are:

- A broader spectrum of studies and approaches
- A fuller combination of the economic and the social issues as they are bound to technology development
- Analysis of participation of users in designing demonstration projects
- Design of studies involving social scientists
- Critical appraisal of costs (willingness to pay), not only by the general public but also companies
- Willingness of actors to become engaged either as investor or risk-taker as producer or user
- Cost benefit analysis considering social, environmental and economic terms
- Looking at fuel choices within the emission-limits accepted as pan-European policy
- Comparison costs and benefits of available fuel choices for Europe
- New approaches to involve the public such as stakeholders discussions, focus group tests, blog sites, etc.

There should be attempts to address means of cooperation and participation rather than (passive) acceptance. Constructive technology assessment is one of many methods that concentrate on a dialogue between and interaction with (new) actors. It brings together all stakeholders involved (users, producers, government, general public) in the design phase of a project. Herewith, a distinction should be made between involving the end-user in technology development and involving the end-user in technology deployment. Usually, manufacturers do substantial panel research in order to find out whether the design of the product is right or not. This part of end-user involvement is outside the scope of this project. More important is the involvement of various stakeholders in the technology implementation trajectory. It is crucial that key stakeholders get involved in the early stage of project design while changes are still possible. This involves not only consumers, but all relevant stakeholders which can influence the success of the introduction of the technology. A European funded project which works on and with a similar methodology is the Create Acceptance (CA) project (www.CreateAcceptance.net). CA developed and tested a methodology on several new energy technologies (hydrogen, CCS, wind). The methodology brings together all stakeholders involved and sets up a dialog in order to bring forward all concerns and lets the participants come up with solutions. By doing so the project coordinator can change his project proposal so it will satisfy all the stakeholders. This would also be a good approach for hydrogen and fuel cell technologies, especially for the large scale demonstration project and early commercialisation phases.

4.2 Perception of the general public

Measuring the attitude of the general public for new advanced technologies is very complicated. If the deployment is still negligible, the general public has limited sources to base their opinion upon. When asked, several mechanisms are used to form an opinion, such as associative mechanisms or opinions of stakeholders they trust most. However, the "opinion" is only a first rough indication and subject to change when they learn more about what the technology really implies for them (and the groups they want to associate with) in practice.

The participation method as developed within the CreateAcceptance project, see previous paragraph, does not include the general public as a whole, except from the local public where the (demonstration) project takes place. For complex technologies, the public (general, local) is not able to form an opinion themselves, but have to rely on the opinion of other actors they trust most. Trust in actors is probably influenced by cultural differences, but in general NGO's are usually seen as one of the most trustworthy actors where industry is in general trusted least. Raising general public awareness is mostly regarded as a task for the government. They should 'educate' the general public on hydrogen and fuel cells and assist interested people to learn to appreciate the technology and even prepare for a carrier within the field.

In demonstration projects of hydrogen and fuel cells in transport it is regrettably often the case fire departments do not know how to handle the permission request for refuelling stations. The HyApproval project is formulating a draft for a hydrogen station handbook, attempting to outline what needs to be taken into account before and during the request for approval to build a refuelling facility for hydrogen. Nevertheless the unfamiliarity of the relevant authority personnel calls for education and training. Harmonisation of the variety of rules that apply in the member states makes the process complicated and slow. Only in one case, public perception slowed down the installation of a hydrogen depot for months (Hornchurch, CUTE project in London).

The lack of experience with hydrogen and fuel cells also plays a prominent role when looking at the attitude of rescue services such as the fire brigade and first-aid teams. Given the urgency of their activities, any conditions that will slow down their response time will have a negative impact on their operational success and will affect their attitude. Since their knowledge about hydrogen applications is not yet at the same level as for conventional applications, there is – not surprisingly – some reluctance with respect to the deployment of these technologies. Getting familiar with the technology, i.e. by incorporating how to handle specific situations in their professional training, is the most effective way to get around this issue. Potential topics to be addressed are, for example, how to deal with 'high' voltages involved in the electric motor and fuel cells. In other words the government itself and all the public services need education on the safety aspects of hydrogen and fuel cells. A negative attitude of rescue services will severely affect the perception of safety of the general public. As a next step, it is essential to design and show hydrogen stations as part of everyday-life and invite the public to get acquainted to hydrogen technology through simulations or station visits.

Where vehicles are so-called luxury products where design and branding play a major role in purchase decisions, this does not hold for stationary fuel cells for cogeneration purposes. Basically, the end-user is only interested in the service: access to heat and power. How this is provided is of little interest. Reliability and costs are however major issues. Obviously, there are a number of relevant boundary conditions to be met. The size of the equipment should not (or not a lot) exceed the size of the conventional technology. Otherwise it might not fit in the attic or basement. The end-user can hardly make a judgement of the risk involved by himself, so he has to rely on the opinion of experts he trusts as well as personal observations. Obviously, the end-user will not buy the equipment if the fitter advises against this technology. If the fitter does not support the technology, he will not inform his client about the 'opportunities' offered by the new technology. History has shown that the support of fitters is a key factor in the introduction of a new technology. The introduction of the condensing boiler in the residential sector was severely hampered by the fact that fitters were unable to handle, at that time, the complex electronics of the boiler. Only after increasing the knowledge level of the fitters, the fitters started selling and installing the condensing boiler.

On a local level, the attitude of stakeholders directly affected by the technology may differ substantially from the general public perception. "Not In My Back Yard" (NIMBY) or "Not Under My Back Yard" (i.e. in case of CO_2 storage) attitudes, along with "Please In My Back Yard", are important mechanisms to take into account. There is obviously a positive attitude for transport by means of passenger vehicles, but his does not imply that people have a positive attitude towards a conventional fuelling station next to their house (or office / business). On the other hand, the deployment of a specific technology may also bring positive effects to the community in terms of welfare. In some countries, farmers have been very keen on installing windmills on their property due to the substantial profits generated. The technology did fit quite well with their core activities – i.e. the land area necessary for the windmills is negligible and the loss of a couple of square metres (and the investment in the windmill) was definitely compensated by the profits. The same holds for some industrial activities. When conducting interviews with the general public about the odour of a sugar beet factory, people living in a major city about 10 kilometres from the factory heavily complained about the odour. However, in the small village next to the factory, people responded "doesn't it smell great" rather than complain. For them, they associated the odour with having a job and creating local welfare, since a substantial number of people living in the village were employed at this factory.

4.3 Role of the media

Public acceptance will depend on achieving and maintaining trust. Access and flow of information plays a key role in this. The impact of information and trust people have is influenced by media sources and the framing of the messages. People most likely have relatively high confidence in the objectivity of certain types of media, such as news items broadcasted on public TV or articles in specific newspapers. On the other hand, people do expect that other magazines have a slightly biased focus and therefore they will also judge the information in that context. Also the framing of the messages plays a role. If quotes are included of a well respected scientist people will trust this message over the statement of a representative of industry with major interests at stake. Also, information can be provided in a rather selective way, providing only or mainly the arguments supporting a specific opinion.

Attitudes may change in time. Therefore, safe guarding public acceptance, based on sound arguments, requires monitoring and constant effort. Only temporarily, one may be able to create acceptance within a stakeholder group based on biased information. In time, also the other relevant information will be revealed. As soon as the stakeholders find out that they were informed incorrectly (manipulated), all support will be lost (forever). So, creating public acceptance is only possible if there are sound arguments to actually accept the technology.

The media thus is also an important actor when looking at public acceptance. Most companies, for example, have a test day for their new vehicles open to reporters only. This also holds for hydrogen vehicles. However, sometimes unexpected side effects occur. Using a robot for the fuelling of a hydrogen vehicle lead to the response that apparently fuelling of the vehicle would be very dangerous. This was not the issue: the engineers just wanted to combine an advanced way of fuelling with and advanced vehicle.

4.4 Monitoring of public acceptance

Safe guarding public acceptance is one thing, but maintaining and monitoring it is an essential part of this process. In the early stage where the knowledge about this new technology is virtually non-existent, people do have to form an opinion. Even though some valid mechanisms exist for that (see the previous section) the resulting opinion is brittle and subject to change.

Within Europe every year there is a ‘public opinion analysis’ within each European Union Member State. The results are published yearly in the ‘Eurobarometer’ report. Additionally, apart from the yearly reports discussing the EU in general, there are special issues focussing on one specific sector, technology or topic. For example cultural values, the expansion of the EU or e-communication. To monitor the acceptance and familiarity of hydrogen and fuel cells there could be a Eurobarometer special issue report. This should be repeated (yearly) in order to get insight into how the knowledge of the public and perception of the public of hydrogen and fuel cells is progressing. However, on top of that specific monitoring is needed in order to address the local dimensions of technology acceptance.

4.5 Conclusions and recommendations

Up until now, only limited studies have been carried out trying to measure both stakeholders interests as well as public acceptance (Fuhrman, 2007). This is partly due to the fact that attitude and acceptance of the general public, end-users (including consumers) and key stakeholders are difficult to measure, since their opinion is not yet based on their own experiences and therefore just a first indication and subject to change. It is crucial to make a distinction between these stakeholder groups and deal with all these aspects. A specific point of attention here are cultural differences – results may vary substantially between countries and even regions.

Another major factor – and both factors likely amplify each other – is that within research organisations investigating the transition towards a hydrogen based energy system the knowledge to measure acceptance (in a wide sense) is usually limited or even entirely lacking. At the university level, this type of knowledge is in principle available, but the focus of the research groups within is on a more fundamental level trying to understand how the process of technology acceptance works (identify and explain the mechanisms) herewith focusing on the individual level. At this level, the attitude itself (do people accept the technology or not) is of limited relevance, but the process of forming an opinion is the key area of research. Within the area of CCS, for example, first initiatives have been taken to build up the required knowledge infrastructure at research organisations. A number of partnerships have been set up between research organisations and universities (e.g. between ECN and the University of Leiden in the Netherlands) addressing both the fundamental aspects as well as providing concrete answers with respect to attitude towards a specific technology, building up research capacity at energy research centres.

It is recommended to facilitate (invest in) the knowledge transfer between more fundamental oriented university level towards energy research centres. This is not only necessary for the case of hydrogen and fuel cells, but also beneficial (required) for other advanced technologies. Secondly, it is likely that the knowledge on mechanisms on how individual preferences are formed exceeds by far the knowledge on how the opinion / attitude of a large group is formed. It is recommended to make this a specific research topic. Finally, specifically the impact of current and future policy instruments on purchase and user behaviour needs to be investigated, such as for example, energy labels for vehicles.

5. Safety, Standards and Regulations

5.1 Introduction

This chapter deals with regulations, codes and standards (RCS) forming a societal requirement for safe public use of hydrogen, with some emphasis on the use of hydrogen as a fuel for vehicle (refuelling station and interface with vehicle).

5.2 Identified Societal Needs in Relation to Hydrogen safety

The following subjects can be identified when dealing with (hydrogen) safety:

- Regulatory requirements
- Safety hazards abatement
- Risk perception
- Consumer aspects

Below these subjects will be covered in some detail.

5.3 Regulatory requirements

The various aspects of safety assurance are covered by many regulatory requirements, some very detailed, others very general. In Roads2HyCom WT1.5 an overview is given of regulations, codes and standards that are applicable to (although not necessarily confined to) hydrogen installations. These are summarized below. For more details the reader is referred to Roads2HyCom Report R2H1009PU (Reinders, 2008).

European Directives

67/548/EEC
73/23/EEC – Low Voltage Directive, LVD
80/779/EEC
89/336/EEC – Electromagnetic Compatibility Directive, EMC
89/391/EEC
89/654/EEC
89/655/EEC
91/271/EEC
93/68/EEC – CE Marking Directive
94/9/EC – ATEX Product Directive (also known as ATEX 95 and ATEX 100)
94/55/EC – ADR
96/49/EC – RID
97/23/EC – Pressure Equipment Directive, PED
98/24/EC
98/37/EC – Machinery Directive, MD
1999/36/EC – Transportable Pressure Equipment Directive, TPED
1999/92/EC – ATEX User Directive (also known as ATEX 137)

ISO standards, drafts, reports and specifications

ISO 11114-1
ISO 11114-4
ISO 13984:1999
ISO 13985:2006
ISO/DIS 15869
ISO/TR 15916:2004
ISO 16110-1
ISO/CD 16110-2
ISO 17268:2006
ISO/TS 20012
ISO/DIS 22734-1
ISO/CD 22734-2
ISO 26142

CEN standards

EN 1127-1:1997
EN 1252-1:1998
EN 1626:1999
EN 1797
EN 1839:2003
EN 4126-1, 2, 3, 4, 5, 6, 7
EN 13160-1:2003
EN 13237:2003
EN 13463:2001
EN 13648-1, 2, 3
EN 13673-1:2003
EN 13673-2:2005
EN 14522:2005

IEC standards

IEC 60079-0
IEC 60079-10
IEC 60079-14
IEC 60079-17
IEC 60079-19

CENELEC standards

EN 60079 – Part 1, 10, 14, 17, 19

EIGA standards

IGC 06/02
IGC 15/06
IGC 23/00
IGC 75/07
IGC 121/04
IGC 122/00
IGC 134/05
IGC 137/06

NFPA standards

NFPA 50A – Superseded by NFPA 55
NFPA 50B – Superseded by NFPA 55
NFPA 52
NFPA 55
NFPA 221

Other standards and codes

CGA G-5.4
CGA G-5.5
CGA H-3
ASME B31.3
ASME B31.12

For specific applications additional requirements may apply, or need to be developed, or existing requirements should be amended. For example, for the hydrogen onboard storage and supply part of the vehicle neither ECE regulations nor EEC directives did exist until in 1999 EIHP undertook the exercise to draft such regulation documents for submission to UNECE. Other ECE regulations and EEC directives, dealing with other safety relevant parts of the vehicle, had to be adapted to hydrogen technology as well. EIHP undertook the efforts to develop amendments to these regulations. In particular the following ones (Harmony, 2004):

Subject	EEC-Directive/ECE-Regulation
1. Emissions	70/220/EEC incl. latest amendment & ECE R83
2. Fuel tanks/rear protective device	70/221/EEC incl. latest amendment & ECE R34/58
3. Diesel smoke	72/306/EEC incl. latest amendment & ECE R24
4. Identification of controls	78/316/EEC incl. latest amendment
5. Fuel consumption	80/1268/EEC incl. latest amendment & ECE R 101
6. Engine Power	80/1269/EEC incl. latest amendment & ECE R84
7. Diesel emissions	88/77/EEC & ECE R49
8. Side impact	96/27/EC & ECE R95
9. Frontal impact	96/79/EC & ECE R94
10. Roadworthiness tests	96/96/EC & PTI
11. CO2 labeling	99/94/EC
12. Base Directive	70/156/EEC incl. latest amendment
13. Electric Vehicles	NEW EC Directive & ECE R100
14. Defrost/Demist	78/317/EWG (already under progress)

This multitude of regulations, codes and standards (RCS) may easily lead to a slow, bureaucratic approval process. Hence RCS efforts should also take note of these dangers and allow for a non-bureaucratic introduction of new technological / scientific findings into regulatory and standardisation processes. This shall ensure that no undue hurdles are being established by early RCS activities. For example, do valves of pressure vessels have to be approved on single tanks prior to the composition / assembly of tank storage systems when these assembled systems have to be approved for safe operation anyhow? Other items can be the frequency and type of recurring inspection of components. For instance do hydrogen storage containers or other components have to be removed from a vehicle or not for recurring testing?

5.4 Safety hazards abatement

In addition to providing the intended services any citizen expects that technical systems used in every day life, can be used safely, or the risks imposed should be comparable to systems he already appreciates and is familiar with.

Safety assurance is generally dealt with through the following hierarchy (preferred order) of measures:

1. **Prevention** of accidents by application of state of the art technology and use of technical (engineering) standards (Best Available Technology - BAT).

2. **Mitigation** of consequences by creation of a safety zone or a safety distance between a hazard source and a (vulnerable) target that may be affected. Targets can be people that can be wounded or even killed, but also buildings that may catch fire or collapse, or the environment that may be polluted (although the latter will not be further discussed here). Certain protective measures (e.g. fire walls) may reduce required safety zones.

3. **Repression** by optimal preparation of emergency services (contingency planning).

The regulations, codes and standards of the previous paragraph cover (parts) of the items above, with the vast majority focused on prevention, as this is by far the most desirable way to assure safety.

When dealing with safety one should make a distinction between professional use and home use (consumers). Professional workforces dealing with hydrogen are specially trained in industrial complexes or captive fleet operations. Also personnel operating, supervising, inspecting or maintaining refuelling stations with hydrogen dispensing facilities will be specially trained. These specially trained people can operate hydrogen equipment safely.

Any hydrogen-specific regulation and standardisation effort has to take into account the transfer of hydrogen use from the professional sector to every day applications in private homes, private cars or in publicly accessible refuelling stations.

It has to be ensured that normal, untrained people can use hydrogen applications at least as safely as conventional applications (i.e. hydrogen cars as compared to gasoline cars, or hydrogen fuel cell CHP as compared to natural gas CHP, etc.). This is an area where regulations and standards can ensure proper handling and management of hydrogen.

In addition to protecting the user/consumer of hydrogen, the general public also has to be protected from any hazards possibly involved in the wider use of hydrogen. This means that the vicinity of hydrogen installations has to be taken into consideration when such an installation is being planned, approved, erected and operated, as is done today for each installation containing dangerous substances, such as refuelling stations and fuel storage.

To decide which safety distance to apply, which safety measures are appropriate, or what a contingency plan should look like, a safety assessment of an installation (in its environment) should be carried out. The risk imposed by an installation will depend on the amount of dangerous substance present, the characteristics (e.g. flammability) of the substance, quality and reliability of the installation (frequency of failure of components), as well as the way in which an installation is operated (competence of personnel).

In Roads2HyCom WT1.5 (Reinders, 2008) an overview is given of methods to assess the safety of an installation (Dow Fire and explosion index, FMEA, HAZOP, What-if, etc.).

An overview of safety distances that may be applied is given in HySafe document D26 as well as the more recent IGC Doc O6/02/E and IGC Doc 15/06/E. In EIGA document IGC 75/07 a method is shown to calculate safety distances, taking all relevant variables into account. This method is especially suitable for new applications (see HyApproval Handbook for approval of Hydrogen Refuelling Stations chapter 8.2 for an example).

As safety hardly ever can be 100% guaranteed, it is necessary to agree on a (minimum) level of protection that should be reached. This can be a difficult issue, especially when third parties (i.e. the general public, outside the premises of an installation) are involved. Currently there is no EU wide “accepted protection level”, nor is there an EU wide agreed method to define the “level of danger” to the public imposed by installations containing dangerous substances. As the safety to the general public is of particular importance for authorities this may hamper the process of issuing permits for installations.

Below a method is shown that is often used for safety assessments of installations and to determine if (and which) safety measures are required or to determine (by authorities) if a permit for construction / operation of such an installation can be issued. It is based on the concept of risk. As said, such an analysis is not always required. Sometimes only part of such an analysis is necessary (e.g. calculations of consequences or effect distances).

5.5 Risk assessment method

This section aims to explain a risk assessment process as a key part of a safety assessment. This process could be followed when seeking to obtain a building or operational permit for an installation containing hydrogen. The process covers the different methodologies and the main hazards to be assessed. The method can also be used as part of a safety management procedure.

The following **concepts** are involved in risk assessment:

- **Acceptable risk:** Every risk below a minimum level of risk society is willing to face.
- **Consequence:** Severity of harm caused to people, or damage done to equipment or effects in the common operation of the process due to an accident.
- **Harm:** Physical injury or damage to the health of people, or damage to property or the environment.
- **Hazard:** Potential source of harm
- **Probability:** Likelihood of occurrence of a determined event, or fraction of time of occurrence of a certain event in an operation. Expressed as a number between 0 and 1, where 1 is certainty of the event to occur and 0 the certainty of the event not to occur.
- **Risk:** Combination of the probability of occurrence of harm and the severity of that harm.
- **Risk assessment:** A risk analysis followed by a risk evaluation.

During a **risk analysis** all realistically thinkable hazards are identified and consequences are estimated. Such a combination of a hazard and a consequence that may result if a hazard is released is an accident scenario. There could be hazards that are very remote but with severe effects (like an explosion of a hydrogen storage vessel causing many casualties) and other hazards, with less severe consequences but more frequent (like ignition of a small release of hydrogen from a tube damaging a dispenser). Usually a limited number of consequence types are used in a risk analysis and the frequencies (occurrences/yr) of all hazards resulting in a particular consequence type are added together. If the number of occurrences per year exceeds the acceptance frequency of this consequence the risk is not acceptable and measures need to be taken. In Roads2HyCom WT1.5 techniques are indicated that can be used for identification of accident scenarios.

If there is no code or standard prescribing or advising **risk acceptance criteria**, several alternative strategies can be carried out. The three strategies discussed by the European Integrated Hydrogen Project phase 2 (EIHP 2) are:

1. Comparing with statistics (e.g. from existing petrol stations in case of HRS), giving an historic average risk level.

2. Comparing with estimated risk levels from risk analyses.

3. Comparing with general risk in society.

Also, a distinction can be made between various target groups:

- **General public (Third party or external risk)**

  Third party risk considers how events on the refuelling station can affect areas outside the refuelling station boundaries and includes people living and working in the vicinity of the refuelling station or travelling through the neighbourhood. Usually the most stringent criteria are used for third party risk.

- **Customers (second party)**

  This will assess people visiting the site (e.g. refuelling station area) to use the facilities. These people will be exposed to the risks at the site for a limited period of time, while visiting the facilities. Therefore, the risk contribution to each individual will be very low. However, it would be unreasonable to use this as an argument for not considering this risk.

- **Personnel working on site (first party)**

  This includes personnel involved in operation, inspection and maintenance of the installation. Generally, a higher risk level will be considered acceptable for this group than for Third party. An individual risk criterion, setting limits to the risk of each individual working at the station, is the most relevant.

The most widely used criteria for third party risks originate from The Netherlands. Two criteria are used:

- **Individual (or geographical) risk**

  The term geographical risk (abbreviated as GR) indicates the probability per year that a person residing on a certain location may fatally be injured by an accident occurring at the nearby plant. It assumes that it is an average person that resides at that location during 24 hours a day and is unprotected. GR decreases with increasing distance from the hazardous source. The distance between the source and vulnerable targets (like houses, schools, etc) should exceed the value where GR = 10-6/yr.

- **Societal Risk (SR)**

The societal risk (abbreviated as SR) is the probability that a number of persons (N) simultaneously will be fatally injured given possible accidents at the plant. The people involved are assumed to have some means of protection (e.g. by staying indoors) and to be exposed only for some time depending on the particular case. In the Netherlands the following advisory value applies for SR:

$$SR < 10\text{-}3/N^2$$

The square in the denominator indicates a progressive aversion of larger accidents

Examples of acceptance criteria for worker on site are the following:

- Dutch authorities suggest a death rate (i.e. probability for a death to occur) of 1 10-4 per year (base death rate for the age group 10 to 14 years) in any process should not be exceeded for personnel working on site.

- UK authorities use a death rate of 2.8·10-4 per year (base death rate for the age group 5 to 14 years in the UK) that should not be exceeded in any process.

In the EIHP2 project it was decided to compare with general risks in the society, mainly because of a lack of relevant statistics and risk analyses of existing petrol stations. This choice also satisfies the general criteria of assuring that the risk level associated with hydrogen applications should be similar to or smaller than the risks associated with comparable non-hydrogen systems. For further details of the risk acceptance criteria developed the EIHP2 project can be consulted.

Often a risk matrix is used to evaluate the risk as assessed above. For each of the consequence categories an acceptance frequency is set. The risk acceptance criteria established by the European Integrated Hydrogen Project (EIHP) is shown in risk matrix of Table 5.1. The meaning of each colour is shown in Table 5.2. In Table 5.3 and Table 5.4 interpretations of severity and probability categories are shown as proposed in the EIHP project. An alternative for the consequence categories is shown in Table 5.5.

These risk acceptance criteria are given as a guide by the EIHP. The aim is to have no hazard categorized as H (red), and to minimise the number of hazards categorized as M (yellow).

For external risk the number of casualties is generally used as the only relevant consequence.

Table 5.1: Risk matrix developed in the EIHP2 project

		PROBABILITY (per year)				
		A (<0.001)	B (0.01-0.001)	C (0.1-0.01)	D (1-0.1)	E (10-1)
SEVERITY	1 (Catastrophic)	H	H	H	H	H
	2(Severe loss)	M	H	H	H	H
	3 (Major damage)	M	M	H	H	H
	4 (Damage)	L	L	M	M	H
	5 (Minor damage)	L	L	L	L	M

Table 5.2: Risk levels in the risk matrix for acceptance criteria proposed by EIHP

Level name	Description
High (H)	High risk, not acceptable. Further analysis should be performed to give a better estimate of the risk. If this analysis still shows unacceptable or medium risk redesign or other changes should be introduced to reduce the criticality.
Medium (M)	The risk may be acceptable but redesign or other changes should be considered if reasonably practical. Further analysis should be performed to give a better estimate of the risk. When assessing the need of remedial actions, the number of events of this risk level should be taken into consideration.
Low (L)	The risk is low and further risk reducing measures are not necessary

Table 5.3: The probability levels in the risk matrix for acceptance criteria proposed by EIHP

Level	Description	Definition	Frequency
A	IMPROBABLE	Possible, but may not be heard of, or maybe experienced world wide.	About 1 per 1000 years or less
B	REMOTE	Unlikely to occur during lifetime/operation of one filling station	About 1 per 100 years
C	OCCASIONAL	Likely to occur during lifetime/operation of one filling station	About 1 per 10 years
D	PROBABLY	May occur several times at the filling station	About 1 per year
E	FREQUENT	Will occur frequently at the filling station	About 10 per year or more.

Table 5.4: Description of consequence severity levels as proposed in the EIHP2

Level	Description	Definition		
		People	Environment	Material
1	CATASTROPHIC	Several fatalities	Time for restitution of ecological resource such as recreation areas, ground water >5 years	Total loss of station and major structural damages outside station area
2	SEVERE LOSS	One fatality	Time for restitution of ecological resource 2 - 5 years	Loss of main part of station. Production interrupted for months.
3	MAJOR DAMAGE	Permanent disability Prolonged hospital treatment	Time for restitution of ecological resource < 2 years	Considerable structural damage Production interrupted for weeks
4	DAMAGE	Medical treatment Lost time injury	Local environmental damage of short duration (< 1 month)	Minor structural damage Minor production influence
5	MINOR DAMAGE	Minor injury Annoyance Disturbance	Minor environmental damage	Minor

Table 5.5: Types of consequence levels in the risk matrix for acceptance criteria developed based on the EIHP2

CONSEQUENCE LEVEL	ASSET DAMAGE	HUMAN DAMAGE
Extremely severe damage	Collapse of nearby dwelling houses	One or more fatalities of pedestrians or dwellers
Severe damage	Major damage of nearby dwelling houses	One or more fatalities of customers or station workers
Damage	Minor damage of nearby dwelling houses	Injury and hospitalization
Small damage	Windows broken	Injury and medical treatment
Minor damage	No damage to nearby dwelling houses	Minor injury

5.6 Risk perception

Safety records from sectors where professionally trained people use hydrogen (such as in refineries or chemical complexes) show an excellent level of safety and demonstrate that hydrogen does not pose particularly higher risks than other combustible and explosive gases or substances (such as natural gas, LPG, acetylene, DME). This is also demonstrated by many hydrogen fuelling demonstration projects performed during the last 20 years all over the world.

Work forces dealing with hydrogen are specially trained in today's industrial complexes or captive fleet operations. Also personnel operating, supervising, inspecting or maintaining refuelling stations with hydrogen dispensing facilities will be specially trained as it is for today's fuels. As the experience from industry shows, these specially trained people can operate hydrogen equipment safely.

Also, "objective" assessments of hydrogen safety using generally accepted methods have so far not shown that the use of hydrogen would be more dangerous than the use of comparable, well accepted substances like LPG and natural gas.

However, rather that objective data it is public's perception of safety that will determine the pace with which hydrogen applications will become part of everyday life, and a small number of very few prominent accidents (most notably the Hindenburg fire in 1937) over the last 70 years and negative press coverage, appear to have given hydrogen an image of being particularly dangerous.

As public exposure to the use of hydrogen has been extremely limited, so has been the number of 'occasions' to demonstrate its safe use to counteract the popular belief that it is not safe. It is only by ongoing demonstrations of the safe use of hydrogen, and by seriously addressing all preconceived ideas, no matter how irrational or 'wrong' that public acceptance can be gained. Hence appropriate education and training initiatives will have to accompany the widespread introduction of hydrogen use in every day life. Government, NGOs, research organisations and major industrial stakeholders will have to share this obligation.

It is of equal importance to emphasise the *benefits* to be had from hydrogen applications for the public or consumer. Hence, demonstration projects should be selected in which advantages of hydrogen applications above alternatives can be made clear.

After all, no matter how remote a risk may be, no one will be willing to take such a risk if there is no benefit to be gained.

5.7 Consumer aspects

Several real or perceived obstacles of different quality may impede the access of citizens to a technology or a service.

In order to facilitate the easy and safe use of any technology in everyday life, essential prerequisites have to be fulfilled.

There has to be a sufficient level of information on the technology or service provided.

The language in which it is communicated has to be understandable in order to be received by the user.

The components / service should be easy to use / access by a diversity of people, in terms of physical and intellectual capacities as well as practical skills.

An appropriate user guide can be very supportive, provided the variation in the level of knowledge and skills of different users is taken into account. In general, the confidence of the user in the product or service he/she wants has to be sufficiently developed to motivate the consumer to buy and use the product without any preoccupation.

A better-informed consumer is required in energy issues in general and about hydrogen in particular (Altmann, 2004). Very often decisions are based on false, incomplete, or biased information. This is also valid for hydrogen, e.g. with regard to its product and safety characteristics. Here, simple to digest but still thoroughly correct information will have to be provided. To what degree such information can be provided in standardised formats or be required by regulatory instruments is still open for debate. Maybe energy or CO_2 labelling ‘standards’ adopted in the EU or the USA could serve as a first indication which way to go.

6. Education and training

The ability to make full use of innovation, such as fuel cells and hydrogen technologies, for economic growth and prosperity depends on its ability to mobilize the human capital of its citizens. Human capital can be defined as the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of economic, social and personal wellbeing. In the case of fuel cell and hydrogen, which is a new socio-technical system, the scarcity of human capital could be a bottleneck for the development of the manufacturing and use of the technology.

Human capital is increased by knowledge creation, diffusion and absorption. In this chapter knowledge creation can be defined as basic and applied research, but also about education of new students. Knowledge diffusion capacity is about developing skills to increase the process of transferring research to products. Knowledge absorption is about the re-educating of the existing work force, but also the education of customers. This chapter will discuss different issues of the present situation and of the human capital in the fuel cell and technology innovation system.

6.1 Employment in the fuel cell and hydrogen sector

How many people are working in the sector now? And how many will be working in the sector if the goal of the hydrogen and technology platform will happen? A more relevant question is their background and education level. However, no such data is available therefore the number of people is used as a proxy. PricewaterCoopers annually assess the present situation of the global public fuel cell companies. In their assessment 2007 they have assessed 26 major public fuel cell companies (PWC, 2007). The total global employment in these 26 companies is 3434. The fuel staff employment of European companies is 212. These numbers are not the total number of all people working in the sector, because the PWC study did not consider the number of fuel cell staff in the major automotive companies, nor did it include staff working in private fuel cell companies. Another sector not included is the hydrogen infrastructure.

Another study estimated that the direct employment if the US fuel cell industry in 2002 was 4500-5500 (Breakthrough Institute, 2002). These numbers indicate that the number of the people working in the sector is rather small.

The crucial issue could be whether as a result of the introduction of hydrogen and fuel cells the import/export shares will change. One could argue that it may be easier to safeguard employment in Europe by switching to FC production, since it is expected that higher educations level (and more complex production) is needed.

By how much will the number of working staff need to increase and what does it mean for their education level? Breakthrough Institute assessed the future direct employment potential of the fuel cell industry in US until 2021. In Table 6.1 the results are summarized. The following are the resulting job creation outcomes for the base, high capitalization and low capitalization cases:

Table 6.1: Job creation summary 2021 US fuel cell industry

SECTOR	High	Base	Low
Automotive	16 981	15472	10 468
Stationary	47 095	41 333	29 269
Portable	3 063	3 033	2 973
Major components	8 321	7 438	5 235
Total	**75 460**	**67 276**	**47 945**

These projections only reflect job creation directly associated with the manufacturing of fuel cells for transportation, stationary and portable applications. Indirect jobs are not included. Although the study is carried out in a US context the numbers show the potential of jobs in Europe. It is a significant increase of jobs from the present situation. There will be an education need to increase the human capital in the fuel cell and hydrogen sectors.

The European project HyWays carried out a study with the two objectives to identify possible sector shifts and employment effects due to the application of hydrogen in the energy system till 2030 (Wietschel & Seydel, 2007). The focus of the study was the introduction of hydrogen in the transport sector. The study considered the effects in selected countries in Europe. In total the selected countries consist of 71% of the population. The study concluded that the major effect of the introduction of hydrogen "is a shift between economic sectors". Some employment gains are possible for some EU Member States assessed if there is no significant change in import/export flows. The major shift is from the historical automotive sector to the new hydrogen vehicle technology sectors. The new hydrogen conglomerate consists mainly of fabricated metals, the electrical and the machinery plastic sector and the chemical sector. This will lead to job increases and need of research in these sectors instead of the classical automotive sector. The HyWays study is only focusing on the transports sector. The consequences in other sectors is not assessed. However, the HyWays study showed that maybe there will not be a massive increase of labour, but instead a shift between sectors is the dominant consequence. HyWays recommends, as a policy recommendation workforce skills in hydrogen technologies should be available in time in order to be properly prepared for this. Several groups will be need education.

6.2 Knowledge creation capacity

To increase the human capital a core group to support is researchers. They can be defined to be the professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems, and in the management of the projects concerned. They are an important part of the knowledge creation capacity in a region or nation.

Basic research is needed for the knowledge creation capacity. In a literature review by SPRU (Martin et al, 1994) about economic performance and publicly funded basic research different types of benefits from publicly funded basic research were identified. There are several forms of benefits and they are interconnected.

- Increasing the stock of useful information;
- New instrumentation and methodologies;
- Skills, especially skilled graduates;
- Access to networks of experts and information;
- Complex technological problems solving;
- Creation of firms, 'spin-off' companies.

Increasing the stock of useful information is perhaps the most well known output of basic research. T he overall useful output of basic research is codified information, which any organisation and person can use in their present work without any economical compensation.

New instrumentation and methodologies is the 'capital goods' of the scientific research industry. Their use to the commercial sector can create the basis for production as well as for industrial research activity.

Skills, especially skilled graduates, may well form the key short-term link between basic science and industry. Many firms need graduates for R&D or in some other technical functions, actively seek research-trained people. The graduates have high tacit ability to acquire and use knowledge Senker (1995). The graduates do not only transfer their acquired knowledge to their companies, because studies of basic-research roots of knowledge used in innovations showed that industrial R&D workers use their education to acquire new knowledge also (Gibbons and Johnston, 1974).

Access to networks of experts and information is important for company R&D departments. These companies cannot afford to generate most of the knowledge they need, so therefore their is a need for a "search" function to identify and absorb external knowledge. Formal and informal participation in scientific networks is therefore important. Scientists tend to organise in invisible colleges, made up of people who are the front runners (de Solla Price, 1963).

Complex technological problems solving is another method in which basic science contributes to the economy, which means supporting the use the stock of (basic) knowledge to industrial needs. Companies often use basic researchers as a source of **new knowledge in specialist fields of science and engineering**. he companies involved in innovative branches could need help to keep with developments at the leading edge of research.

- Practical help and assistance, such as interpreting results from test equipment.

- Creation of 'spin-off' companies is often thought to be a major benefit of research in academia and research institutes, yet the empirical evidence for this is at best mixed (Arnold and Balázs, 1998).

These benefits have been empirically verified by Arnold and Thuriaux (1998). They also identified a seventh category: Access to facilities, such as instrumentation. This often plays a role in the barter of ideas and resources which typifies scientific networks.

All these benefits can be used as argument why support in basic research in the area of fuel cell and hydrogen could increase the knowledge creation capacity of Europe. A major learning is that codified information or products are the only benefits of basic research. The SPRU literature review was focusing on basic research, but several of the benefits could be to some extent transferred to publicly financed applied research.

Another arguments could be the close connection between research and the education of students. If the researchers have the knowledge of new research they can transfer this to new students.

6.3 Knowledge absorption capacity

Knowledge absorption is about the re-educating of the existing work force, but also the education of customers and key groups.

An important education group is early adopters. They will be the first customers. Early adopters need to understand near-term opportunities and prepare using these technologies in the future. Publicly available and credible information about early markets for fuel cell could increase the diffusion of the technology.

Fleet owners and operators are an important early adopter. They could need education packages about hydrogen basics; hydrogen production, distribution, and delivery; vehicle operations and maintenance facilities; hydrogen powertrains and vehicles; prototype light-duty hydrogen vehicles; prototype hydrogen transit vehicles; specialty hydrogen vehicles; and hydrogen life-cycle costs and training.

Educational packages to support regions and cities will also be important. The Roads2HyCom Handbook for Communities can be used to increase the knowledge absorption capacity of civil servants and other stakeholders (Roads2HyCom, 2007).

The existing workforce could also need educational packages in hydrogen technologies. Since there will be a job shift between sectors.

Several real or perceived obstacles of different quality may impede the access of citizens to a technology or a service. In order to facilitate the easy and safe use of any technology in everyday life, essential prerequisites have to be fulfilled:

- There has to be a sufficient level of information on the technology or service provided.

- The language in which it is communicated has to be understandable in order to be received by the user.

- The components / service should be easy to use / access by a diversity of people, in terms of physical and intellectual capacities as well as practical skills.

- An appropriate user guide can be very supportive, provided the variation in the level of knowledge and skills of different users is taken into account. In general, the confidence of the user in the product or service he/she wants has to be sufficiently developed to motivate the consumer to buy and use the product without any preoccupation.

- A better-informed consumer is required in energy issues in general and about hydrogen in particular (Altmann, 2004). Very often decisions are based on false, incomplete, or biased information. This is also valid for hydrogen, e.g. with regard to its product and safety characteristics. Here, simple to digest but still thoroughly correct information will have to be provided. To what degree such information can be provided in standardised formats or be required by regulatory instruments is still open for debate. Maybe energy or CO_2 labelling ‘standards’ adopted in the EU or the USA could serve as a first indication which way to go.

The success of the implementation of hydrogen also depends on the success of a number of other technologies, specifically in the production sector. Failure of CCS implies that different production chains have to be chosen. If wind energy does not go down in costs as fast as projected (or CSP), clean fossils may become more dominant. Also the sustainability and availability (price) of biomass is a major issue. These sectors also need educated staff so they will be successful. Therefore too narrow a focus upon supporting the hydrogen sector could be counter productive.

6.4 Conclusions

The education chapter main problems and knowledge gaps are:

1. **The required number of people with workforce skills in hydrogen technologies** should be available in time in order to be properly prepared for the development of hydrogen technologies. To support this development some education policy suggestions are:

   – Continue to support basic and applied research,

   – Support post-graduate professional development training;

   – Develop of an EU network of graduate courses;

   – Develop a EU wide national curriculum integration programme for H2 & FC;

   – Encourage human capital investment in adults by the private sector;

- Develop educational package to increase the connection between university and the private sector.

2. **Several real or perceived obstacles of different quality may impede the access of citizens to a technology or a service.** To support the removal of some of the obstacles some policy recommendations are:

   - Develop information packages about hydrogen technologies for citizens.
   - Support early adopters.

3. **Since the development of hydrogen technologies will depend of the development of other technologies, support multi-technology projects** where hydrogen, CSS, battery, wind energy technology projects are demonstrated together. The multi-technology skills of the projects member could be useful in the future.

7. Conclusions and recommendations

Socio-economic research covers a wide range of topics varying from techno-economic research on cost reduction (e.g. learning curves) and scenario analysis, regulation codes and standards, education and training and acceptance (general public, end-users and key stakeholders). This report aims to provide a brief overview of the state of the art of these areas, identifying the major research priorities. Based on the analysis, the following conclusions and recommendations were drawn.

- In an effort to address the critical shortage of equity finance the Commission should investigate the feasibility **of establishing a European Trust Fund**, along the lines of the Carbon Trust[10] established by the UK government, thereby leveraging investment in emerging companies whilst at the same time leaving the lead investment and technology decisions to the market.

- Favourable **tax legislation to enhance investment in high-risk enterprises** needs to be implemented. Although it is recognised that the EU cannot legislate for Member State tax arrangements, the EU should proactively support the deployment of such schemes in all member countries.

- It is recommended that both member states and regions investigate methods of **extending financial support schemes to small bilateral R&DD partnerships**. At the same time, effort should be dedicated to **lowering the administrative burden** faced by particularly smaller, micro companies when applying for government / EU support programmes.

- The Commission should seek to **improve communications between directorates** with the aim of ensuring, for example, financial issues and opportunities, above and beyond framework grants are given more prominence in R&DD events and its literature. The JTI for its part should also consider this recommendation, not least in order to avoid similar criticisms in the future.

- The lack of awareness European H2&FC developers exhibit in the area of finance needs to be addressed. Potential options are to **promote practical financial courses** with credits specifically for scientists from undergraduate level through to PhD as well as similar (free or at least low-cost) courses for independent H2&FC developers.

- The EU should investigate the feasibility of establishing a **European Public Procurement Agency** for promising near-commercial technologies.

- **Balancing R&D and deployment support** is a key prerequisite for reaching the break-even point as fast as possible at minimum cost. This balance is

[10] The Carbon Trust was set up, and is financed by Government in 2001 as an independent company with the aim of accelerating "the move to a low carbon economy by working with organisations to reduce carbon emissions and develop commercial low carbon technologies." To this end the Carbon Trust also act as a co-investor in early stage companies including independent H2&FC developers, managing both venture capital and seed funds. See http://www.carbontrust.co.uk/investments.

likely to be technology dependent and also may change while the technology further matures. The driving factors are however still poorly understood. Further research is needed in order to enhance innovation policies. Furthermore, the concept of technological learning plays a crucial role in energy models used to study the transition towards a hydrogen-based energy system.

- The set of models used to study the transition towards a hydrogen energy system need to have sufficient technological detail in order to **fully assess impacts from well to wheel**. This also implies a thorough regional coverage. The impact on security of supply should not be evaluated solely on changes of the import dependency of Europe, but need to include the **amount and origin of the resources**.

- There is yet limiting expertise at energy research centres in order to deal with the various aspect of technology acceptance. It is recommended **to facilitate (invest in) the knowledge transfer between more fundamental oriented university level towards energy research centres**. This is not only necessary for the case of hydrogen and fuel cells, but also beneficial (required) for other advanced technologies. Secondly, it is likely that the knowledge on mechanisms on how individual preferences are formed exceeds by far the knowledge on how the **opinion / attitude of a large group is formed**. This aspect is still underexposed. It is recommended to make this a specific research topic. Finally, specifically the **impact of current and future policy instruments on purchase and user behaviour** needs to be investigated, such as for example energy labels for vehicles.

- The required number of people with **workforce skills in hydrogen technologies** should be available in time in order to be properly prepared for the development of hydrogen technologies. Therefore, support for basic and applied research needs to be continued, e.g. by supporting post-graduate professional development training, development of an EU network of graduate courses, development a EU wide national curriculum integration programme for H_2 & FC, encouraging human capital investment in adults by the private sector and development of an educational package to increase the connection between university and the private sector.

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