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TECHNICAL ASSISTANCE AND ECONOMIC ANALYSIS IN THE FIELD OF LEGISLATION PERTINENT TO THE ISSUE OF AUTOMOTIVE SAFETY:

EVALUATION OF THE IMPACT (EXTENDED IMPACT ASSESSMENT) OF THE INTRODUCTION OF HYDROGEN AS FUEL TO POWER MOTOR-VEHICLES CONSIDERING THE SAFETY AND ENVIRONMENTAL ASPECTS

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SUBMITTED BY TRL LIMITED

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Executive Summary

This study has examined the effects of different policy options concerning the introduction of hydrogen powered vehicles into the type-approval framework, in the EU27 Member States. The regulatory options considered to accommodate the introduction of hydrogen vehicles were:

Option 1: '*No policy change'*. There would be no further changes to the present situation. Currently, there is neither European type-approval legislation nor comprehensive Member State level legislation in place for hydrogen powered vehicles.

Option 2: '*Legislation at EU level'*. This option would involve the adoption of new type approval legislation at EU level, which would set out harmonised provisions to ensure the safety of hydrogen vehicles. The European Commission would first pass framework legislation, and then specify detailed technical requirements in a second step, which would involve a comitology Regulation. The provisions would then be in line with those set out in the draft proposals for UNECE Regulations (UNECE, 2003a, UNECE, 2003b).

Option 3: '*Legislation at Member State level'*. This option would involve adoption of legislation at Member State level to accommodate the introduction of hydrogen vehicles.

This study looked at the impacts of each option on safety, economic matters and the environment. A group of stakeholders was consulted, and a questionnaire was circulated to interested parties.

Key findings of the study are that:

1. The options have impacts on all EU citizens and businesses, on citizens of non-EU countries and on the EU27 Member State governments. The main impacts concern safety, the economy, air quality and noise impacts on people, and costs for businesses.

2. Option 1 is not feasible. To date, research into Hydrogen vehicles has assumed a minimum standard of safety. If this minimum standard were not met in production hydrogen vehicles, it would allow the introduction of new and unknown safety risks. Option 1 would form a barrier for the development of hydrogen technology in the EU, and could entail increased public safety risks. For example, Option 1 would leave open the possibility of substandard vehicles being sold in the EU, perhaps by new entrants to the market. Option 1 would also result in unduly high costs of the approval of hydrogen vehicles.

3. Option 2 is the most advantageous approach. It involves lower costs to industry than would be the case with option 3, and brings environmental benefits sooner than with option 3. Safety standards would be uniform across the EU27 Member States, and should be higher than with either of options 1 or 3.

4. The UNECE proposals for safety regulation (UNECE, 2003a, UNECE, 2003b) and the European Commission's draft proposal for a Regulation (European Commission 2006i) are broadly similar, but contain some differences that are potentially significant. The UNECE proposals require some additional tests that could be significant for vehicles which are not subject to regulatory impact tests.

5. The safety data in the public domain for hydrogen vehicles shows that current prototypes appear to be at least as safe as non-hydrogen production vehicles, when tested. There is a lack of data in the public domain on hydrogen vehicles that either exceed current 'typical' safety levels significantly, or that have not met those levels.

6. The environmental impacts of hydrogen vehicles will be greatest when they are introduced for passenger cars, which are 'M1' category vehicles. Positive impacts should arise in the areas of noise, and exhaust emissions that are harmful to air quality. However, the best available forecasts indicate that it will be 2020 before hydrogen vehicles will constitute even 1% of total annual passenger vehicle kilometres driven in the EU27 states.

7. The cost of the type approval process for the manufacturers was also assessed. Conclusions were made on the basis of Motor Vehicles Regulations 2006 (SI 1638). This memorandum has been prepared by the Vehicle Certification Agency, an Executive Agency of the UK's Department for

Transport. The document cites approximate costs to manufacturers per type approval of €160,000. A manufacturer would therefore face a cost of around €160,000 for a centralised, single EU type approval. In a worst case, the manufacturer might instead face costs of €4.3million, if each vehicle had to undergo type approval in 27 different member states. However, neither of these figures is significant in comparison to either:

(i) The extra costs that would be incurred if manufacturers had to develop different designs of each vehicle for different Member States;

(ii) The environmental benefits provided by the earlier introduction of hydrogen vehicles, which would occur with Option 2.

Glossary

CNG- compressed natural gas

Diffusion coefficient- describes the rate of diffusion of molecules or particles, depending on size, viscosity and temperature.

Euro 4, 5, 6- Emissions standards for light duty vehicles

Euro IV, V, VI- Emissions standards for heavy duty engines

Fuel cell- An electrochemical energy conversion device, which is designed for continuous replenishment of the reactants

Hybrid vehicle- Vehicle that uses a combination of petrol and electricity for motive power, so as to increase efficiency and thereby reduce emissions

Hydrogen embrittlement- the process by which various metals, most importantly high-strength steel, become brittle and may crack, following exposure to hydrogen

Hydrogen vehicle- A vehicle that uses hydrogen as its primary source of power for motion

IC- Internal Combustion – an engine that burns fuel by combustion at high temperature

LPG- Liquid petroleum gas

NOx- Nitrogen dioxide and Nitric Oxide

Asphyxiation- is a loss of consciousness due to the presence of too little oxygen or too much carbon dioxide in the blood.

1 Project process

1.1 Project background and tasks

The European Commission is carrying out an Impact Assessment (IA) of the various policy options in relation to the possible introduction of hydrogen powered road vehicles on a commercial basis. The options particularly concern common safety requirements for hydrogen storage systems in hydrogen vehicles in the EU27 states.

In June of 2006, TRL was commissioned by the European Commission (EC) to help with the Impact Assessment work. TRL is providing input for the Commission's assessment of the impacts of the policy options, and advice on technical aspects of the safety requirements. This report is TRL's final project report.

TRL's work has followed the requirements of the Impact Assessment Guidelines provided by the European Commission; see the reference Impact Assessment Guidelines (2005). The report was developed and structured according to these guidelines.

TRL has gathered and evaluated information about the impacts of the various policy options on safety, the economy and the environment. The work included an analysis of the costs and benefits. It is expected that this final project report will form the basis for the European Commission's Impact Assessment.

The project commenced with a literature review and a review of existing and proposed legislation.

In particular, the following documents were examined:

- Preliminary proposal for a Regulation of the European Parliament and of the Council relating to the type-approval of hydrogen powered motor vehicles (European Commission 2006i).
- UNECE Proposal for a new draft regulation: Uniform provisions concerning the approval of: specific components of motor vehicles using compressed gaseous hydrogen; vehicles with regard to the installation of specific components for the use of compressed gaseous hydrogen (TRANS/WP.29/GRPE/2003/3) (UNECE 2003a).
- UNECE Proposal for a new draft regulation: Uniform provisions concerning the approval of: specific components of motor vehicles using liquid hydrogen; vehicles with regard to the installation of specific components for the use of liquid hydrogen (TRANS/WP.29/GRPE/2003/14) (UNECE 2003b).

The proposed UNECE legislation was developed within the EIHP project, however, they have not been adopted. The draft EC proposal is based on the technical requirements of the proposed UNECE regulations.

The review included a search of the International Transport Research Documentation database (ITRD), which covers a full range of transport related topics. A consultation was organised through a questionnaire. This was followed by an analysis of safety and environmental issues by TRL.

1.2 Literature and legislation reviews

The results of the literature review are presented in Annex A. The full list of documents and internet sources that were consulted are presented in Annex B. The literature review identified the current understanding of the safety and environmental issues surrounding the introduction of hydrogen vehicles. This information was used to determine the implications of the introduction of hydrogen vehicles, legislative requirements, and to help quantify the costs and benefits.

The legislation review is presented in Annex C. One issue for the TRL study is the compatibility of various EU policy options with legislation in other world regions. This is included within the Regulation review.

1.3 Consultation and expertise

TRL and the European Commission developed and circulated a questionnaire, which has gathered information in a structured way. The final version of the questionnaire was distributed to the members of the Hydrogen Working Group and other interested parties on Tuesday 25th July 2006. The deadline for replies was 15th September 2006. Five replies were received. TRL was able to use two of the responses during the analysis for this report. Annex D is a copy of the questionnaire. Annex E summarises the responses to the questionnaire.

TRL and the European Commission held a meeting to start the project on 19th July 2006. Members of the 'Working Group on Hydrogen' attended the meeting and were invited to express their views on that occasion. The Working Group on Hydrogen comprises of representatives of:

(i) Different services of the European Commission;

(ii) The vehicle and component manufacturing industry;

(iii) Member State governments;

(iv) Other stakeholders.

A further meeting with the Working Group was held at TRL on 14 November 2006. Eighteen representatives attended, together with five TRL staff. TRL also attended the Working Group meeting held on 12 February 2007.

In addition to circulating the questionnaire, TRL has:

(i) Made contact directly with groups that are involved in the 'Clean Urban Transport for Europe' (CUTE) project. These groups have recent 'hands on' experience of operating vehicles that are powered by hydrogen fuel cells. They have also published evaluation reports for the CUTE project.

(ii) Visited Mercedes-Benz's bus division, who build the 'Citaro' buses for the CUTE project. The Citaro buses run on compressed hydrogen. Mercedes Benz has provided TRL with the safety and environmental analyses for these buses.

(iii) Visited Mercedes-Benz's hydrogen car development division.

(iv) Obtained information from the manager for CUTE activities in Reykjavik, Iceland.

A clear message from stakeholders is that hydrogen power has reached very different stages of development in different classes of vehicle. Box 1 below lists the essential lessons.

Box 1: Key information from the consultation

1. Hydrogen fuel cell buses are in use today in small numbers. A second generation of bus will be in service from 2008. On 5th October 2006, the European Commission announced a new order for zero emission buses from an international alliance of five European cities and one region of Canada (EC 2006).

2. Hydrogen power is in use in prototype passenger cars. However, some aspects of these vehicles are further from mass production than buses.

3. The study was unable to find evidence that hydrogen power will be used in heavy goods vehicles, above 12.5 tonnes, in the foreseeable future.

2 Discussion of policy options

2.1 Introduction

A full life cycle assessment of the use of hydrogen in vehicles would comprise the three stages shown in Figure 2.1 below. This impact assessment only covers the third stage, ‘use in vehicles’ in line with the European Commission's preliminary draft proposal on the type-approval of hydrogen vehicles (European Commission 2006i).

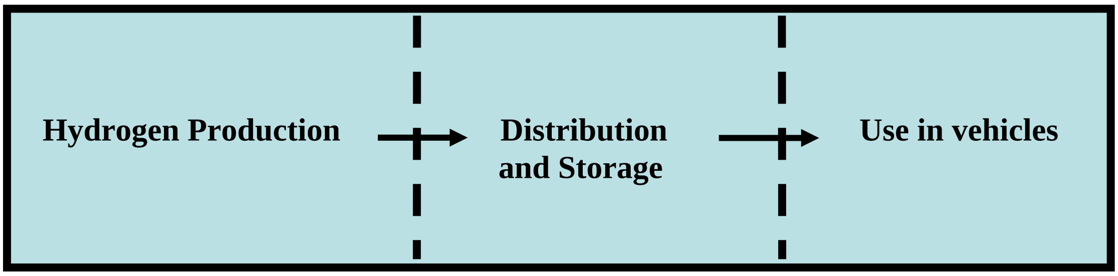


Figure 2.1. Life cycle assessment of hydrogen for road vehicles.

2.2 Options for evaluation

At the beginning of the study, the European Commission set out the three options for evaluation in the Impact Assessment, Table 1.

Table 1: Options for Evaluation in Impact Assessment

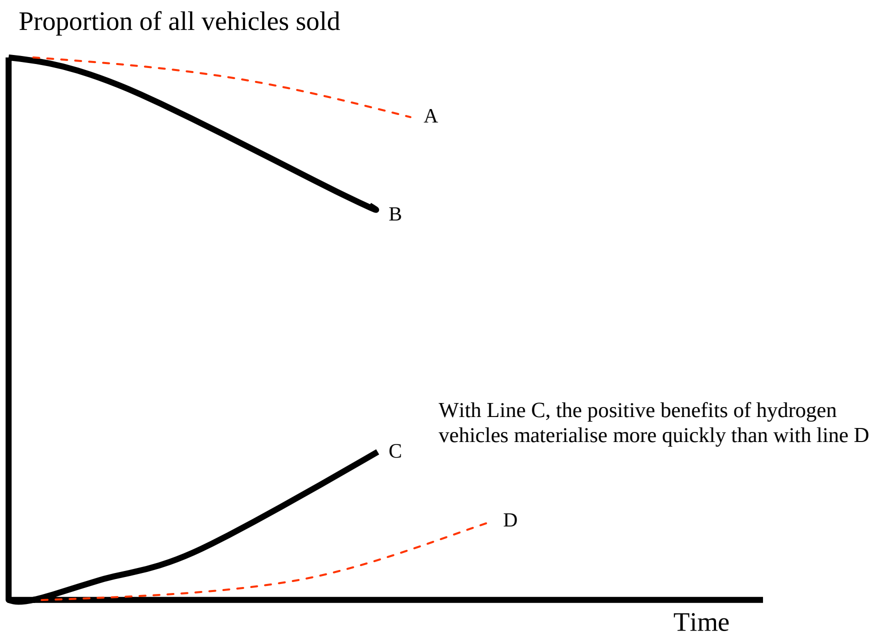
Option Number	Description of Option
Option 1	‘No Policy Change’ This would involve no further changes to current vehicle legislation to accommodate the introduction of hydrogen vehicles.
Option 2	‘Legislation at EU level’ This would involve new type approval legislation at EU level, covering the safety of hydrogen vehicles. An EU Regulation would be adopted. Changes would also be made to existing type-approval Directives and Regulations that govern the construction of vehicles.
Option 3	‘Legislation at Member State level’ This would involve leaving individual Member States to pass legislation to accommodate the introduction of hydrogen vehicles.

The Impact Assessment relates to each of the passenger vehicle categories M1-M3 and goods vehicle categories N1-N3. These vehicle categories are defined in Annex G.

2.3 The introduction and effects of hydrogen road vehicles

Since the outset of the project, two broad issues concerning the introduction of hydrogen road vehicles have been apparent.

The first issue concerns the rate at which any benefits of hydrogen vehicles become evident. Figure 2.2 below represents graphically the effects of different rates of introduction of hydrogen vehicles in the EU27. Clearly, any positive safety and environmental benefits from these vehicles accrue at a rate that depends how rapidly petrol and diesel vehicles are replaced. ‘Alternatively fuelled’ vehicles, such as those running on CNG or LPG, are too small a proportion of all vehicles to be represented in Figure 2.2.



Key to figure:
A: Proportion of vehicles powered by petrol and diesel, with only slow introduction of hydrogen
B: Proportion of vehicles powered by petrol and diesel, with rapid introduction of hydrogen
C: Proportion of vehicles powered by hydrogen, with rapid introduction of hydrogen
D: Proportion of vehicles powered by hydrogen, with slow introduction of hydrogen

Figure 2.2. Different rates of introduction of hydrogen vehicles

The second issue concerns the difference between the impacts of a hydrogen vehicle and the impacts of conventional petrol, diesel and hybrid vehicles. Figure 2.3 shows the likely differences in environmental impact over time, in future years. Clearly, the absolute advantage that hydrogen vehicles offer over conventional vehicles is likely to narrow, as conventional vehicles improve.

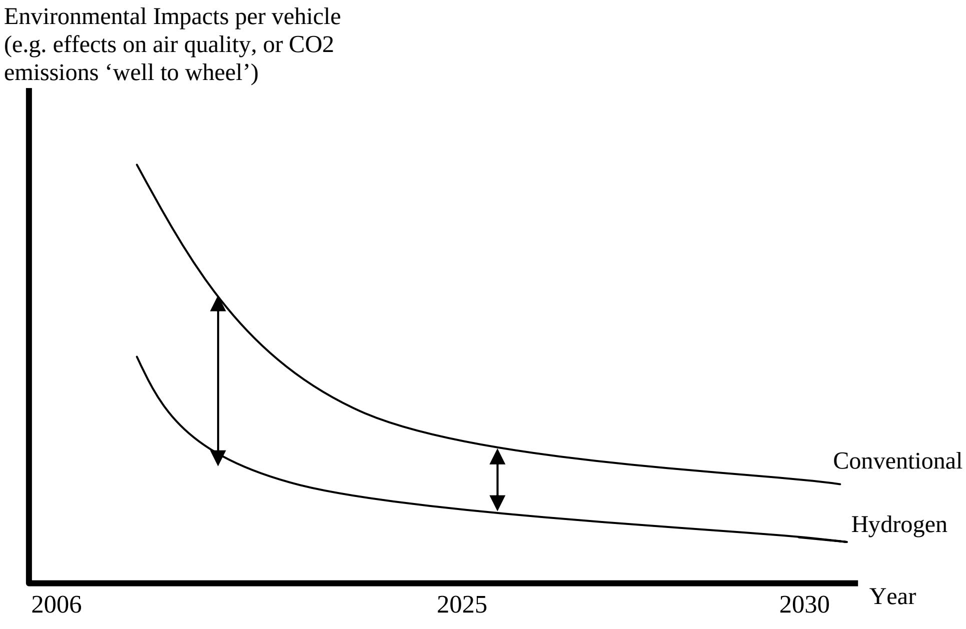


Figure 2.3. The impacts of hydrogen and conventional vehicles

2.4 Results of the evaluation of Options 1-3

An early result of the study was the realisation that Option 1 was not feasible. There are several reasons for this finding:

(i) Some existing EU or national legislation does not contain any provisions that address the safety of hydrogen vehicles. This would leave the market for these vehicles unregulated. Existing vehicle manufacturers do have a brand image to protect, and extensive experience of vehicle safety. There would clearly therefore be a strong commercial incentive for existing manufacturers to produce safe hydrogen vehicles, even in an unregulated market. However, such safeguards would not apply to new companies who had the opportunity to start hydrogen vehicle production in an unregulated market, and they would represent a higher risk. All research into hydrogen vehicles to date has assumed a minimum standard equivalent to that of existing or proposed legislation. All of the current understanding on the safety of hydrogen vehicles is based on this minimum standard of system. If this minimum standard were not met in production hydrogen vehicles, it would allow the introduction of new and unknown safety risks.

(ii) Some provisions of existing EU or national legislation are not compatible with hydrogen vehicles. Any manufacturer who commercialised hydrogen vehicles would therefore find themselves in breach of EU legislation governing the type-approval of vehicles.

Annex F provides a list of EU Directives that would require at least some amendment.

(iii) Option 1 would form a barrier for the development of hydrogen technology in the EU, and could entail increased public safety risks. Manufacturers would be more reluctant to invest, if offered only a fragmented market. Industry aims to introduce hydrogen vehicles commercially at the earliest opportunity, and Option 1 is not compatible with that aim.

(iv) Option 1 would result in unduly high costs of the approval of hydrogen vehicles, which clearly would not be in the interests of the industry. In response to the questionnaire, the majority of comments that were received were in support of legislation. In fact, none of the consultees supported Option 1 in their questionnaire responses.

For the above reasons, this report has discarded Option 1.

The remainder of this report only assesses the economic, safety and environmental impacts of Options 2 and 3.

Option 2, EU wide legislation, is the preferred option. The reasons for this are given in Chapters 10 and 11. Importantly, Option 2 would open up markets in some Member States where hydrogen vehicles could not currently be sold.

Option 3 remains a viable option, in the technical sense that it would allow the introduction of hydrogen vehicles. However, option 3 involves disadvantages for both the automotive industry and the public. See also chapters 10 and 11.

Table 2 below shows a summary comparison of the policy options. It clearly shows that Option 2 would be the most effective.

Table 2: Summary comparison of policy options

Policy option	Effectiveness	Efficiency	Consistency
Option 1: No policy change	Option deemed not feasible		
Option 2: Regulatory approach at EU level	High	High	High
Option 3: Legislation at Member State Level	Medium	Low	Low

3 Affected parties

3.1 Who will be affected by the benefits or negative impacts?

There are three key groups who will be affected by the environmental and safety impacts:

- The EU27 governments
- EU citizens and businesses
- Non-EU citizens

3.2 The EU27 governments

The EU27 governments incur very large expenditure as a consequence of vehicle exhaust emissions and noise. This expenditure covers direct health costs, and social support for citizens who are unfit to work. The main impact pathways are:

(i) Poor air quality, which leads to respiratory illness and premature death; and

(ii) Noise, particularly during sleep periods, which exacerbates ischemic heart disease and mental illnesses. See for example page 8 of Health Commission (2003).

The other major source of government expenditure is on physical measures to reduce transport noise. This includes low noise road surfaces, which tend to cost approximately twice as much as equivalent coarser surfaces, and are not as durable. Noise barriers and sound insulation for buildings also incur costs, particularly for local authorities in urban areas.

Hydrogen fuel cell vehicles reduce noise, emissions of particulates and emissions of oxides of nitrogen. To the extent to which hydrogen fuel cell vehicles come into use, they will lead to corresponding reductions in expenditure by both central and local governments. However, internal combustion (IC) engine hydrogen vehicles do not show all the advantages of fuel cell hydrogen vehicles. Current designs of IC hydrogen engines appear to have similar noise and NOx performance to the latest designs of conventional vehicles.

Hydrogen vehicles also reduce emissions of carbon monoxide and unburnt hydrocarbons. However, new conventional petrol, diesel and hybrid vehicles in 2020 are likely to emit only negligible quantities of these pollutants, so the relative benefit of hydrogen vehicles will be correspondingly small.

The remaining important issue is the impact on levels of public safety. The Commission’s proposal seeks to ensure at least equal safety levels between hydrogen and conventional vehicles. With improved or equivalent safety levels, there is the potential for less public spending on health.

Governments are currently endeavouring to reduce the number of deaths and injuries on the roads through advancement of vehicle and road safety. There is no reason to believe that this need be changed by the introduction of hydrogen vehicles.

3.3 EU citizens and businesses

Every citizen of the EU27 Member States is affected by the environmental impact of vehicles. Particular issues are vehicle noise, air quality and climate change.

When evaluating the effects on citizens and businesses, care needs to be taken to avoid ‘double counting’. Benefits to citizens in terms of improved health should not be counted in addition to the reduced hospitalisation and social costs for governments resulting from the same improvements. Businesses will benefit because of reduction in hospitalisation, employee illness and premature death due to the impacts of road transport. The effects on business will become more important, as the proportion of all workers in older age groups increases.

A further impact is the cost of CO_2 permits in the EU 'Emissions Trading System' (ETS). Some stakeholders consider that the CO_2 emissions from surface transport should be included in the ETS. To the extent that hydrogen vehicles reduce CO_2 emissions from the road transport sector, there will be reductions in the cost to businesses of permits, and the marginal cost of achieving reductions in other sectors.

The safety implications for citizens are potentially even greater than those faced by governments. Any reduction in safety that occurred due to the introduction of hydrogen vehicles would directly impinge on the lives of individuals at a personal level. Whilst governments place a financial value on the life of each of their citizens, this can not account for the full impact on individuals for the loss of another. If there was any significant safety deterioration due to the introduction of hydrogen systems there would be an erosion of public confidence. This could have the potential to undermine the future of hydrogen technologies. Therefore, it is essential that hydrogen systems which are introduced are of a sufficient safety standard.

3.4 Non-EU citizens

Non-EU citizens will be affected in similar ways to EU27 citizens. This will happen:

(i) Directly, when non-EU citizens work in the EU, or visit;
(ii) When vehicles registered in the EU are sold outside the EU as 'used' vehicles, or are driven to those countries for business or leisure;
(iii) Safety and environmental standards devised in the EU may be adopted as legislation by countries outside the EU. These standards also influence the designs used by vehicle manufacturers, who may sell vehicle designs that were developed for the EU in other markets.

4 Safety

4.1 Overview

This chapter identifies safety issues associated with hydrogen powered vehicles. The implications for legislation and the risks to the population of introducing hydrogen vehicles to the road network are assessed.

4.2 Safety issues

By reviewing existing literature research on hydrogen safety, this report has identified several safety issues for hydrogen vehicles. The full literature review is presented in Annex A. A number of key safety issues which must be addressed before hydrogen vehicles can be introduced are included in Table 3. The Table also considers mitigation factors and a comment on how the draft Commission proposal has considered the safety issues.

The safety of hydrogen systems has been investigated by many bodies using a combination of testing and numerical simulation methods. However, a lot of the research that has been conducted is not available in the public domain. In all of the available research identified, only systems which are compliant with, or exceeding the requirements of the proposed legislation or current standards (such as ISO requirements for pressure vessels) were investigated. The consequence of this is that the safety assessments do not identify the implications of a hydrogen system which is of a lower or higher standard than the current baseline. It is not reported whether the tested systems have been designed to be minimally compliant with the legislation, so their performance may exceed that of the legislation. Further research, or release of data not currently available to the public, would be necessary to assess the safety impacts of introducing such systems.

The available research indicates that a hydrogen system can be designed to reduce the inherent risks of the fuel, as described in Table 3. The published research generally concludes that the systems are at least as safe as gasoline vehicles. This viewpoint was also stated by stakeholders in the Hydrogen Working Group meeting on 14th November 2006. However, the details required to definitively verify this assertion are not available. For instance the integrity of hydrogen systems in high severity impacts has not been quantified by public domain research. There is no requirement for conventional fuel systems to be designed to survive higher severity impacts, but the consequences of such impacts is well known from accident data, which shows that fire and explosion remains very rare. While hydrogen systems have been evaluated in standard crash test configurations, the effect of placing hydrogen systems in such high severity impacts is not known. It can been assumed that hydrogen systems follow the same relationship as conventional systems with regards to risk in higher severity impacts, however, further research would be required to determine the accuracy of this assumption.

Research indicates that hydrogen fuel systems designed and constructed to standards equivalent to the proposed legislation (European Commission 2006i; UNECE, 2003a, 2003b) would have no significant safety disbenefits when compared with conventional vehicles. This was explained to us during the visit to vehicle manufacturers. It was confirmed that every vehicle coming from the manufacturing line meets all the required safety standards. Limitations are:

- The publicly available information is limited.
- The risks from systems of a higher or lower standard than that presented in the available research are unknown.
- The behaviour of hydrogen systems in untested scenarios is assumed to follow the same relationship as conventional vehicles.

Table 3: Safety issues with hydrogen vehicles

Impact area:	
Fire / Explosion	**Issue** As hydrogen ignites and explodes over a greater concentration range the fire and explosion risk may be greater if a release is uncontrolled. A hydrogen flame is invisible and radiates little heat to the surrounding area, which could present an increased risk to those providing assistance. Hydrogen can be stored under high pressure in compressed gaseous form, increasing the risk of explosion. **Mitigation / Regulation** Research has indicated that an automobile fire with a controlled release of hydrogen may be no more dangerous than with a gasoline fuelled vehicle. The high diffusion coefficient means that a hydrogen leakage will very quickly dissipate in free air. The regulation aims to minimise the risk of hydrogen release by requiring impact, penetration, bonfire, etc, tests.
	Issue The electrical discharge energy to ignite hydrogen is much lower. **Mitigation / Regulation** A typical electrical discharge contains enough energy to ignite gasoline. Regulation aims to minimise the risk of hydrogen release. Regulation requires that no electrical current passes through hydrogen containing parts.
Impact Protection	**Issue** Insufficient impact protection of a hydrogen storage system would result in a much greater risk of uncontrolled hydrogen release. The hydrogen storage container(s) must have sufficient integrity to withstand an impact. The rate of leakage from the container(s) after an impact must be limited. The structure used to mount the container(s) to the vehicle must have sufficient integrity.

	Mitigation / Regulation The tank cannot be mounted in a location where it is exposed to a high risk of impact damage without an additional protective structure. Regulation requires an acceleration test including the mountings.
Release in enclosed area	**Issue** In an enclosed space there is a risk of the concentration of hydrogen exceeding the lower flammable limit. **Mitigation / Regulation** Hydrogen has a high diffusion coefficient in free air. Published research indicates that there are circumstances under which the hydrogen leaked from an enclosed vehicle will cause critical flammability levels to be reached. However, the high diffusion coefficient of hydrogen means that these situations should only occur infrequently provided vehicles have in-built monitoring. Regulation requires that systems which detect and then stop leaks are fitted.
	Issue Release of hydrogen into the passenger compartment could present a risk of fire or asphyxiation to occupants. This can cause passengers to lose consciousness due to the presence of too little oxygen or too much carbon dioxide in the blood. **Mitigation / Regulation** Regulation does not allow release into the passenger compartment
General safety issues	**Issue** If appropriate materials are not selected hydrogen can cause significant deterioration in fuel system components by diffusing into steel and other metals, causing embrittlement. As a result, the metal will break or fracture at a much lower load or stress. **Mitigation / Regulation** Regulation requires a hydrogen embrittlement test.
	Issues Fuel cell vehicles operate at high voltages so there are issues of electrical shock, isolation and ignition. **Mitigation / Regulation** Vehicles are subject to existing legislation which should prevent this risk. Every vehicle arriving from the manufacturing line meets all

	the required safety standards. Fuel cell vehicles would be subjected to existing legislation that provides protection against these risks.
	Issues Electric (e.g. hydrogen fuel cell) vehicles may be quieter than current vehicles, so would give little or no warning of their approach to other road users. This could potentially increase the risk on an injury accident, particularly to vulnerable road users. **Mitigation / Regulation** This issue is not addressed, currently the risk it presents is unknown. The level of noise reduction is dependent on the technology employed and may not be as great as some sources have reported due to additional noise provided by auxiliary components
	Issues Different procedures for dealing with fires may be required, e.g. do not extinguish a hydrogen flame unless necessary as it could spontaneously/ explosively reignite. Currently, M1 vehicles are not required to carry external identification that they are carrying hydrogen. **Mitigation / Regulation** This issue is not considered in the examined version of the draft EC proposal for Regulation (European Commission 2006i). Anecdotal evidence from fire fighters suggests that incidents involving LPG fuelled vehicles are made more difficult and dangerous because they do not have any clear and consistent markings. Therefore, it can be interpreted that the same issues could exists with hydrogen vehicles, however, further research would be required to substantiate this opinion.
	Issues It has been hypothesised that the mass distribution and stiffness of vehicles may change from that of current vehicles to incorporate the new technologies. This may have an effect on the protection to occupants and other road users. **Mitigation / Regulation** Hydrogen vehicles will be subject to the same type-approval procedures as current vehicles so will be required to meet the same standards. In the long-term hydrogen vehicles may also be included in consumer test programmes which will encourage manufacturers to maximise protection.

	Issues The quantity of water emitted from fuel cell hydrogen vehicles has been demonstrated to potentially be no greater than from conventionally fuelled vehicles. However, water vapour emissions from the hydrogen internal combustion (IC) engine may be twice as high. The water vapour emissions from fuel cell vehicles are at lower temperature. An increase in quantity or decrease in temperature could increase the risk of poor visibility or road conditions, although the extent would be highly dependent on the amount of change to the number of hydrogen vehicles. **Mitigation / Regulation** The extent of this issue is unknown at present and will be highly dependent on the hydrogen system. This issue is not addressed by legislation.
Bus specific issues (M3)	**Issues** Current hydrogen bus designs have the hydrogen system mounted on the roof of the vehicle, which could have implications for the vehicle stability and rollover protection. Roof mounted hydrogen systems may be subjected to significant loading in the event of bus rollover. **Mitigation / Regulation** Vehicles will be subject to stability and rollover protection tests under existing legislation. Rollover protection is only to ensure protection of occupants. Systems such as ESP could be utilised to increase bus safety by reducing the risk of rollover and damage to a roof mounted hydrogen system. Encouragement of these systems would have an additional safety benefit for non-hydrogen fuelled buses. Further research would be required to determine whether the requirements of the proposed legislation are sufficient to ensure the safety of the hydrogen system in bus rollover.
	Issues Passengers must be protected from hydrogen leakage and high voltages. **Mitigation / Regulation** Regulation does not allow leakage or venting into passenger compartment. Existing legislation should provide protection from high voltages.
	Issues Storage of multiple vehicles in one facility must not result in critical flammability levels being reached.

	Mitigation / Regulation High dissipation rate of hydrogen reduces likelihood of build up. Regulation requires vehicles to monitor the hydrogen concentration being emitted to ensure that it remains below critical levels. However, this can only be monitored in the immediate vicinity of the vehicle, so there is a risk of hydrogen reaching critical levels if the emissions from several vehicles gather in one area. The high dissipation rate of hydrogen reduces the likelihood, but this remains a risk.
	Issues Procedures and training for vehicles maintenance must reflect the different risks that are present in hydrogen vehicles. **Mitigation / Regulation** Operational issues, out of scope of the legislation relating to the type-approval of vehicles.

4.3 Safety legislation

To ensure that hydrogen systems with unknown safety disbenefits are not introduced, it is necessary to implement legislation.

Existing and proposed regulations and standards from around the world have been reviewed to determine the most important features for hydrogen safety and how they attempt to control the issues identified in Table 3. The draft proposed EC legislation (European Commission 2006i) and the proposed UNECE legislation (UNECE 2003a, 2003b) are reviewed in Section 4.4.

In addition to the introduction of new legislation, a number of existing EC Directives and UNECE Regulations would need to be amended to allow the introduction of hydrogen vehicles. These are identified in Annex C.

Standards and regulations can be implemented using three possible approaches; design-based, performance-based, or a combination. Design based standards specify exactly how the regulation must be met. Performance based regulation specifies only the required outcome, which provides freedom to design different ways to achieve that outcome. In general, the majority of UNECE and EC regulations tend to be performance based, to permit innovation where possible. Standards such as ISO tend to be highly design prescriptive.

Design based regulation can be limiting, preventing an alternative design or specification that could give better performance. New technology, which was not suitable when the regulation was introduced, may offer benefits beyond the minimum requirements. It is expected that design based regulations can be implemented more quickly because it may take more time to set out the requirements in a performance based regulation. Performance based regulations may require that new test methods be developed.

It was reported by the European Integrated Hydrogen Project (EIHP) that there is general agreement world-wide that the proposed UNECE regulations contain the necessary technical content. The proposed UNECE regulations have also been harmonised with ISO and SAE documents, while retaining the UNECE's performance-based requirements philosophy.

Within the EU, policy can be introduced at either at EU level or by individual Member States. This corresponds to Options 2 and 3, respectively, within the Impact Assessment. If implemented at EU level, a new EU Regulation would be adopted and existing Directives and Regulations which are affected would be amended. It is assumed in this assessment that all Member States which allowed hydrogen vehicles, would only allow systems of an equivalent safety level as those in the legislation outlined above. It is not anticipated that any Member State would choose to allow the introduction of lower standard systems as there is no research currently available to justify this action.

Review of requirements of proposed UNECE Regulations and EC Directive

The following documents were reviewed to determine whether the identified safety issues have been adequately addressed:

- Preliminary proposal for a Regulation of the European Parliament and of the Council relating to the type-approval of hydrogen powered motor vehicles (European Commission 2006i).
- UNECE Proposal for a new draft regulation: uniform provisions concerning the approval of: specific components of motor vehicles using compressed gaseous hydrogen; vehicles with regard to the installation of specific components for the use of compressed gaseous hydrogen (TRANS/WP.29/GRPE/2003/3) (UNECE 2003a)
- UNECE Proposal for a new draft regulation: uniform provisions concerning the approval of: specific components of motor vehicles using liquid hydrogen; vehicles with regard to the installation of specific components for the use of liquid hydrogen (TRANS/WP.29/GRPE/2003/14) (UNECE 2003b).

The proposed UNECE legislation was developed within the EIHP project, however they have not been adopted. The draft EC proposal is based on the technical requirements of the proposed UNECE regulations.

Table 4 lists the tests which the hydrogen storage container and system components are required to be subjected to within the proposed legislation. As detailed in Section 4.3 the proposed EC legislation is being prepared in two stages, firstly a general framework legislation, and secondly a comitology proposal detailing technical requirements. The framework legislation document was reviewed, which details the tests that shall be performed, but does not detail the performance requirements which have to be met in these tests. The proposed UNECE Regulations set out performance requirements for each of the tests in Table 4.

The EC and UNECE documents require the same series of tests to be performed, except for additional tests to the container in the UNECE regulations. For example, additional pressure and leak tests are required. The inner tank burst pressure test should assess the same criteria as these tests so they may be unnecessary.

This study aimed to identify the research on which the tests and assessment criteria were based, and also to identify any research which commented on the suitability of the test and criteria. As is shown in Table 4 the publicly available information is very limited. ISO and CEN Standards, and the derivation of their tests and values, which provide the basis of some of the tests, were not considered within this study. A separate study would be necessary to perform this evaluation.

In addition to testing on component parts, the proposed legislation details design requirements, which include:

- The hydrogen system shall be installed such that it is protected against damage as far as is reasonably practical.
- No hydrogen components shall be located near the exhaust of an ICE or other heat source, unless shielded.
- In the event of hydrogen leakage or venting, hydrogen shall not be allowed to accumulate in enclosed or semi-enclosed spaces.

These design requirements are necessary to ensure the safety of the system.

It is considered that the requirements within the proposed UNECE and EC legislation consider the principal aspects of safety which have been identified in Table 3. Further research may be required to provide supporting evidence to performance requirements.

Research, such as that reported by Fürst *et al* (2005), has been conducted on systems which are designed to be compliant with the proposed UNECE regulations. The systems have been demonstrated to be safe in a range of impact conditions.

The development of the proposed UNECE Regulations was carried out in conjunction with ISO and SAE to maximise the harmonisation of the legislation. This ensures that an equivalent safety standard is attained across the legislation. Safety research has been conducted with systems of this standard, and in all presented cases the system was able to address the main safety issues.

Table 4: Testing requirements of proposed UNECE and EC legislation

LIQUID HYDROGEN CONTAINER
Pressure test
• Pressurise to 1.3(MAWP + 0.1MPa) for 10mins No equivalent test is listed in the proposed EC legislation. ISO/DIS 13985-1 specifies qualification test including pressure cycling tests and burst tests. The test requirements in the ISO document are much more involved and would tend to lead to a more conservative design. In particular the ISO document addresses impact damage to the vessel which is not addressed in the EIHP document (Woods *et al,*, 2002).
Leak test
• Leak test with gas containing 10% helium No equivalent test is listed in the proposed EC legislation
Inner tank burst test
• Pressurise to 3.25(MAWP + 0.1MPa) or 1.5(R_m/R_p)(MAWP + 0.1MPa) No information on the appropriateness of the selected test pressure was identified in the literature, however ISO/DIS 13985-1 specifies different liner types (Woods *et al,*, 2002): • Welded metallic inner vessels: 3 x max possible permissible operating pressure • Seamless steel inner vessels: 2.25 x max possible permissible operating pressure • Glass: 3.65 x max possible permissible operating pressure • Aramid: 3.1 x max possible permissible operating pressure • Carbon: 2.35 x max possible permissible operating pressure
Thermal autonomy test under fire
• Place above 590^{o}C fire for 10mins – at least 5mins before PRD opens and tank pressure must not exceed 1.36MAWP No information on the appropriateness of the selected temperature or duration was identified in the literature. The ISO/DIS 13985-1 standard is more stringent with a requirement of 30 minutes under fire at least 900 C with the pressure not to exceed 1.2MAWP (Woods *et al,*, 2002).
Maximum filling level test
• Maximum filling level should be 95% of the tank volume No information on the appropriateness of the selected criteria was identified in the literature.
Acceleration test
• A container shall be mounted so that no damage occurs and there is no uncontrolled release of hydrogen when subjected to : M1 & N1 class vehicles: +/- 20g in direction of travel, +/- 8g perpendicularly M2 & N2 class vehicles: +/- 10g in direction of travel, +/- 5g perpendicularly M3 & N3 class vehicles: +/- 6.6g in direction of travel, +/- 5g perpendicularly No test procedure is given in the UNECE Regulations for this test. There is no requirement on the duration which the acceleration must be applied for. The acceleration levels are consistent with those applied in the LPG and CNG regulations. No evidence supporting the selected acceleration levels was identified. The acceleration levels applied are lower than can be experienced within many crash situations, e.g. peak B-pillar acceleration in EuroNCAP frontal impacts are often greater than 30g. The EuroNCAP test set-up was selected as being representative of a 'typical' accident, therefore it can be concluded that in a significant proportion of impacts the system will be subjected to a higher deceleration. Vehicles which are subject to the frontal or side impact Directives will be exempt from the acceleration test. Initially hydrogen vehicles may be in low production volumes which are exempt from the impact tests.
Hydrogen compatibility test
• Conducted in accordance with ISO/DIS 11114-4

LIQUID HYDROGEN COMPONENTS
Pressure test
No information on the appropriateness of the selected criteria was identified in the literature.
External leakage test
No information on the appropriateness of the selected criteria was identified in the literature.
Seat leakage test
No information on the appropriateness of the selected criteria was identified in the literature.
Endurance test
No information on the appropriateness of the selected criteria was identified in the literature.
Operational tests
No information on the appropriateness of the selected criteria was identified in the literature.
Corrosion resistance
No information on the appropriateness of the selected criteria was identified in the literature.
Resistance to dry-heat
No information on the appropriateness of the selected criteria was identified in the literature.
Ozone aging
No information on the appropriateness of the selected criteria was identified in the literature.
Temperature cycle test
No information on the appropriateness of the selected criteria was identified in the literature.
Pressure cycle test
No information on the appropriateness of the selected criteria was identified in the literature.
Hydrogen compatibility test
As per container

COMPRESSED GASEOUS HYDROGEN CONTAINER
Acceleration test
As for liquid hydrogen containers
Burst test
No information on the appropriateness of the selected criteria was identified in the literature.
Ambient temperature pressure cycling test
No information on the appropriateness of the selected criteria was identified in the literature. The StorHy (www.storhy.net) project recommended this be replaced with only an extreme temperature/ pressure cycling test (below)
LBB performance test
No information on the appropriateness of the selected criteria was identified in the literature.
Bonfire test
No information on the appropriateness of the selected criteria was identified in the literature. The StorHy project recommended a fire engulfment test (separate tests on pressure relief devices and cylinders, measurement of explosive pressure surge) (no details available).
Penetration test
No information on the appropriateness of the selected criteria was identified in the literature.
Chemical exposure test
No information on the appropriateness of the selected criteria was identified in the literature.
Composite flaw tolerance test
No information on the appropriateness of the selected criteria was identified in the literature.
Accelerated stress rupture test
No information on the appropriateness of the selected criteria was identified in the literature.
Extreme temperature pressure cycling test
No information on the appropriateness of the selected criteria was identified in the literature. See ambient temperature pressure cycling test above
Impact damage test
No information on the appropriateness of the selected criteria was identified in the literature. The StorHy project considered that this test (drop from 1.8m) was not onerous enough and recommended that it be replaced with a more rigorous impact test (no details available).
Leak test
No information on the appropriateness of the selected criteria was identified in the literature.
Permeation test
No information on the appropriateness of the selected criteria was identified in the literature. StorHy recommended alternative methods be used for the permeation test (no details available).
Boss torque test
No information on the appropriateness of the selected criteria was identified in the literature.
Hydrogen gas cycling test
No information on the appropriateness of the selected criteria was identified in the literature.

COMPRESSED GASEOUS HYDROGEN COMPONENTS
Material tests
No information on the appropriateness of the selected criteria was identified in the literature.
Corrosion resistance test
No information on the appropriateness of the selected criteria was identified in the literature.
Endurance test
No information on the appropriateness of the selected criteria was identified in the literature.
Hydraulic pressure cycle test
No information on the appropriateness of the selected criteria was identified in the literature.
Internal leakage test
No information on the appropriateness of the selected criteria was identified in the literature.
External leakage test
No information on the appropriateness of the selected criteria was identified in the literature.

4.4 Safety conclusions

The presented research has demonstrated that a high standard hydrogen fuel system has a safety level comparable to conventionally fuelled vehicles within the scenarios considered. Implementation of the proposed draft legislation for hydrogen vehicles (UNECE 2003a) will ensure a high standard of system. The exact standard of systems that have been investigated is not available in the public domain. If these systems were not designed to be minimally compliant with the proposed legislation, but rather were designed to a higher standard, then the understanding of systems which minimally comply with the legislation is limited. Further research with systems which are designed to be minimally compliant with the legislation is necessary to quantify the behaviour of such systems. The availability of data on the performance in legislation tests of systems which have been demonstrated to perform adequately in vehicle tests may provide an alternative to further testing.

Based on the available data there is no reason to believe that the introduction of systems to the standard of the proposed legislation will have any negative impact on accident frequency or severity.

The understanding of sub-standard hydrogen systems is very limited; therefore, it is recommended that such systems should not be allowed. This assessment assumes that only hydrogen vehicles which meet these safety standards are introduced.

Although the hydrogen systems which have previously been investigated have been shown to be safe the following potential risks have been identified:

- Differences in the testing requirements of proposed UNECE and preliminary draft EC legislation have been identified, with UNECE requiring additional tests. It is intended that the requirements shall be aligned in the final version, however if this does not occur the reason for these differences, and any supporting research, should be investigated.
- The behaviour of hydrogen fuel systems in non-standard test conditions has not been fully investigated. The consequences of other impacts need to be quantified to ensure safety in all 'real-world' scenarios.
- Systems which have been tested were designed to meet existing or proposed hydrogen legislation. However, it is unknown whether such systems exceeded the minimum requirements of the legislation. Further research with minimally compliant systems would provide greater confidence in the levels set.

4.5 Scenarios of safety measures

One aim of this project was to identify and compare selected safety scenarios:

“*Within the most beneficial policy option, different scenarios of safety measures will be established, that will result in different levels of technical measures in the proposed legislation to ensure the safe operation of hydrogen powered vehicles on European roads. The safety scenarios will also be evaluated on the basis of their cost-benefit ratio. The scenario with the best cost-benefit figure will be identified and on this basis, TRL will make recommendations on the technical elements of the proposed legislation*.”

Given the current levels of research and understanding of hydrogen fuel systems this task is not possible. Research has only identified the consequences of introducing hydrogen systems which are of a standard equivalent to that in the proposed UNECE and preliminary EC legislation. These systems have been shown to have no significant safety disbenefits. Further research would be necessary to identify the safety impact of allowing the introduction of hydrogen systems of a lower standard.

The characteristics of hydrogen are such that it is hypothesised that it would be unsafe to allow introduction of unregulated hydrogen systems. Research into unregulated hydrogen systems would be required to quantify the magnitude of risks from such systems. TRL recommends that unregulated production hydrogen systems should not be allowed within any EU member state. Systems of any standard lower than that of the proposed legislation also present an unquantified level risk so should not be allowed without further research to quantify the risk.

Determining monetised costs of implementing hydrogen systems of varying safety standards, with any degree of accuracy, is not possible for the following reasons:

- Hydrogen systems are still in the very early stages of development, therefore the technology which will be implemented is unclear. The particular safety implications of any one of these systems would be different.
- Research does not exist which quantifies the implications of systems of differing standards. That is, no systems of either a lower or significantly higher known standard than that proposed in legislation have been investigated. It is therefore not possible to determine the benefits or disbenefits that such systems would confer on society.

5 Environment

5.1 Introduction

This chapter considers the impacts on the environment of the use of hydrogen as a road fuel. The first step is to divide the impacts into those that are significant, and those that are insignificant, for the purposes of the Impact Assessment. The remainder of the chapter then discusses the significant impacts.

The Impact Assessment Guidelines require an assessment of the absolute impacts of each of Options 2 and 3. However, the main issue of interest for this section of report is the difference between the impacts of the policy options on the environment.

5.2 Which impacts of hydrogen are significant?

The project has clarified the areas in which hydrogen vehicles will have significant impacts, see Table 5. Here ‘impacts’ may be positive or negative effects, or both.

The choice of the term ‘significant’ is important. The impact areas in the left column below are those in which the impacts are large enough to warrant more detailed assessment in the view of the authors. The impact areas in the right column are those which are considered to be second order or very small impacts.

Table 5: Significant and insignificant impacts

Hydrogen as a vehicle fuel has significant impacts on:	**Hydrogen as a vehicle fuel does not have significant impacts on:**
Air Quality/Human health	Soil quality
Greenhouse gas emissions and the use of energy	Waste generation
Noise	Biodiversity, fauna and flora; animal and plant health, food and feed safety
Mobility	Landscape
Material assets; Renewable and non-renewable resources	Population
Water quality	Cultural heritage including archaeological and architectural heritage
Likelihood of environmental risk	
The environmental consequences of firms’ activities	

The topics listed in the two columns of Table 5 are based on two sources. One is the list provided in Table 2, on page 30 of the Impact Assessment Guidelines (2005). The second is the list of environmental topics in the Strategic Environmental Assessment Directive, Directive 2001/42/EC.

In addition to the topics in Table 5, two further issues specified in the SEA Directive have also been considered:

(i) The interrelationships between the various impacts; and

(ii) The *‘secondary, cumulative, synergistic, short, medium and long-term, permanent and temporary, positive and negative effects of the……topics……, where appropriate.’*

Figure 2.1 makes clear that this report deals with the use phase of hydrogen in vehicles. However, the production, distribution and storage of hydrogen entail further substantial impacts in some of the environmental areas identified in Table 5. However, these stages are out of scope of the present study. Details of ‘well-to-wheel’ impacts of hydrogen production and use in vehicles are given in the reference Joint Research Centre (2006).

5.3 Description of the impacts of options 2 and 3

Table 6 summarises the impacts of options 2 and 3 under each impact area listed in Table 5. All statements about hydrogen vehicles’ impacts are relative to those of petrol and diesel vehicles.

Monetary estimates are available for most of the impact areas identified in Table 6.

Table 6: Impacts of Options 2 and 3

Impact area:	Main issues identified
Air Quality/Human health	Hydrogen powered vehicles in all of classes M1-M3 and N1-N3, on all roads, will lead to reductions in background levels of particulates and Nitrogen Dioxide. Hydrogen buses and N1 commercial vehicles will lead particularly to reductions in levels of particulates and nitrogen dioxide in urban areas. As considered in Chapter 4, hydrogen systems of a high standard are not expected to have any negative impacts on accident frequency or severity.
Greenhouse gases	The production and use of mass produced hydrogen vehicles will cause emissions of carbon dioxide. The amount of the emissions will depend mainly on how hydrogen is produced, distributed and stored. These issues lie outside the scope of this report.
Mobility	In the light of current EU approaches to fuel taxation, we assume that a large proportion of the cost to consumers of any fuel in 2020 will depend on the carbon emissions from the production and use of that fuel. However, taxation policies cannot be predicted more than a decade in advance. It is also not clear what the ‘well to wheel’ emissions from hydrogen as a road fuel will be, when hydrogen is mass produced. We cannot therefore yet conclude that hydrogen fuel would cost consumers less than petrol and diesel. As a consequence, we cannot predict whether hydrogen would lead to increased mobility, at any given level of disposable income.
Noise	Fuel cell powered vehicles will have low levels of engine and transmission noise. Their tyres will however still generate noise. If hydrogen powered vehicles are heavier than current vehicles, of equivalent load capacity, then tyre noise may even increase slightly, for example due to the use of wider tyres. In this report, we assume that noise levels from internal combustion engined hydrogen vehicles will be similar to those of new conventional vehicles.
Material assets; Renewable and non-renewable resources	Fuel cells and hydrogen storage tanks require different materials to internal combustion engines and petrol or diesel fuel tanks. The impacts on material use may be positive or negative. As an example, fuel storage tanks in hydrogen vehicles are likely to require more steel or alloys than modern plastic petrol or diesel tanks. The only hydrogen powered internal combustion engined passenger vehicle that is available in 2007 is reported to be 220 kgs heavier than the conventional model on which it is based.

	If mass-produced hydrogen powered vehicles were heavier, then they would need stronger brakes, and would wear tyres more rapidly. The net effect on material assets depends greatly on whether mass produced hydrogen vehicles are more or less durable than petrol and diesel vehicles, which is currently not known.
Water quality	The quality of water in rivers and in standing bodies of water is affected by vehicles through: (i) Particulates from brakes and tyres, particularly through run off from roads; (ii) Particulates and NOx emissions from vehicle exhausts, particularly when rain removes these from the atmosphere; (iii) Spills of petrol and diesel, from crashed or damaged vehicles, and from leaks in supply tanks and pipelines. Fuel cell hydrogen vehicles will not produce effects (ii) and (iii). Internal combustion engined hydrogen vehicles will not produce particulates from exhaust gases, and will not show effect (iii).
Likelihood of environmental risk	Hydrogen vehicles bring some risk of leaks of hydrogen and fire. However, these risks are likely to reduce over time, as technology matures. Most technologies become less risky to the environment as society gains experience with them. Importantly, fire and leakage of hydrogen are not major environmental risks, since their consequences are more in the area of safety. Safety risks are dealt with in Chapter 4 of this report.
The environmental consequences of firms' activities	Levels of solid waste production from vehicle manufacture, such as the mass of residue sent to landfill, are already very low. The production of hydrogen vehicles is unlikely to change this. However, conventional vehicle production requires large quantities of water, and this may be affected by the production processes used for hydrogen vehicles. Businesses cause impacts through the use of cars for business, through commuting, and from the movement of freight by road. This is of course also true for employees of governments and local authorities. The overall environmental benefits of hydrogen vehicles should lead to reductions in the environmental consequences of these operations.

6 Quantification of benefits I: Impact of vehicles

6.1 Introduction

The Impact Assessment Guidelines (2005) require an assessment of the impacts '*in qualitative, quantitative and monetary terms where possible and appropriate*', see page 26 of the Guidelines.

There is sufficient information available to make quantified estimates of the benefits of hydrogen vehicles in terms of air quality, noise and CO_2 emissions. It is only possible to make qualitative comments on the impacts in the remaining areas in the left column of Table 5.

The approach taken in this report has been to assume that:

(i) Hydrogen vehicles will be sold as substitutes for conventionally powered petrol, diesel and hybrid vehicles, which would otherwise have been sold. So this report has assumed that the advent of hydrogen powered vehicles will neither cause an expansion of the total number of vehicles on the roads, nor reduce the number.

(ii) Hydrogen vehicles will enter the fleet in the EU27 Member States at the rates predicted by the 'Hyways' project. Data from this project has been supplied by the co-ordinator of the Hyways project. See the comments in Chapter 7, and the data in Table 12.

(iii) That the impact of a hydrogen powered vehicle on any environmental variable should be measured in comparison to the impact of a new petrol or diesel vehicle, which would otherwise have been sold. For this comparison, we have used information on the environmental impacts of the petrol or diesel vehicles that will be available in the years when hydrogen vehicles will be sold. So this report has had to consider how much the environmental impacts of conventional vehicles will improve by the period 2017-2025.

In order to quantify the impacts, it is necessary to know:

(i) What proportion of the current environmental impacts from road transport is due to each category of vehicle M1-M3 and N1-N3. Given the timescale for the introduction of hydrogen vehicles, we need a projection of future impacts.

(ii) The rate at which hydrogen vehicles will be introduced into the EU27 countries under options 2 and 3, in each category.

However, there is large uncertainty in three key issues, which are discussed in Table 7.

Table 7: Discussion of uncertain issues for Options 2 and 3

Issue	Description and approach taken
1. The rate of introduction of hydrogen vehicles in categories M1-M3 and N1-N3 into the vehicle fleet.	It is necessary to know what percentage of road miles will be driven by hydrogen vehicles, in each future year, in each of categories M1-M3 and N1-N3. This can be estimated, based on the Hyways project's data on the share in the total vehicle fleet for hydrogen vehicles in future years. Uncertainty arises, and therefore caution is necessary, because of experience with earlier automotive technologies. The rate at which previous new technologies have actually entered the vehicle fleet has differed greatly from the predictions. For example, sales of petrol electric hybrid vehicles have been far below the predicted levels.
2. The difference in environmental impacts between hydrogen vehicles and future petrol and diesel vehicles.	It is not clear how much the environmental impacts of new petrol and diesel vehicles will have decreased by the time that hydrogen vehicles become widespread. This depends both on the year of introduction of hydrogen vehicles, and the pace of European Union emissions standards legislation. Projections of the environmental impacts of non-hydrogen conventional vehicles can be made, based on: (i) The latest information about future exhaust emissions standards. Euro 6 emission limit values relating to light-duty vehicles will enter into force in 2014, see reference European Parliament 2006 and European Commission 2006f. Euro VI standards relating to heavy-duty engines are very likely to be in force by 2015 at the latest. (ii) In January 2007, the EU Commission presented proposals for reducing CO_2 emissions per kilometre for passenger cars and light duty vehicles, i.e. classes M1 and N1. See reference EC(2007). The proposed measures will enforce mean emissions for new passenger cars of 130g CO_2/km by the year 2012. Combined with other measures, for example on fuel and tyres, these should bring emissions down to 120 g CO_2/km. The objective for light commercial vehicles is 160 g CO_2/km by the year 2015. It is likely that both of these limits will have been reached by the period of interest in this report, 2017-2025.
3. The incentive effects of government taxation policies.	Government policies on fuel taxation, together with 'registration' and 'circulation' taxes, will potentially determine the rate at which hydrogen vehicles are introduced. Policies in these areas are currently leading to reductions in CO_2 emissions from conventional vehicles. See pages 21-22 of reference EC(2002), and EC(2005). Financial incentives have already been used in some EU27 member states to encourage purchase of vehicles fulfilling more stringent emissions standard before the date on which legislation made these mandatory. Taxation policies are likely to be a deciding factor in both the rate of environmental improvement of conventional vehicles, and the rate at which hydrogen vehicles become widespread. Taxation policies remain largely in the hands of the Member States, and subject to relatively frequent change.

6.2 Distance driven annually by M1, N1, M2 and M3 vehicles in the EU25

This section compares the environmental impacts of M1, N1, M2 and M3 vehicles, based on recent statistics and predictions for the EU27 in 2010 and 2020.

Many vehicles in category N1 are derived from vehicles in category M1 that are from the same manufacturer. These are often referred to as 'car derived vans'. They tend to have engines, transmissions and control systems that are almost identical to those in the cars on which they are based. This trend is growing. For this reason, the environmental impacts per kilometre of M1 and N1 vehicles will be considered together.

The statistics held by Eurostat and other databases for buses and coaches do not differentiate between vehicles in categories M2 and M3. In order to use Eurostat's statistics on passenger kilometres in the EU27, we treat travel by category M2 and M3 vehicles together.

Vehicle manufacturers informed us that there is no development of hydrogen technology in category N2 and N3 vehicles. The reason is that bigger vehicles would require a lot of their cargo space to be transformed into the fuel tank. The current consensus view is that hydrogen will only be used in N2 and N3 vehicles as a secondary power source.

Passenger Transport Statistics for the EU in 2003

Table 8 below is based on Eurostat statistics for 2003.

Table 8: Passenger transport distances in the EU27 States in 2003

Mode	Passenger kilometres travelled in EU27 (thousand million)	Estimated vehicle kilometres in EU27 (thousand million)	Percentage of total vehicle kilometres for all M1+M2+M3 traffic
Passenger car (M1)	4444	2813	98%
Bus and coach (M2 and M3)	483	54	2%

Source of passenger kilometres data: Eurostat

The 'vehicle kilometres' column in Table 8 consists of estimates, because this data is not published by Eurostat. However, we can check these figures against exact figures for one large member state. This allows us to check whether the percentage figures in the final column of Table 8 are accurate. The UK Department for Transport (2006) quotes total car and taxi traffic for Great Britain in 2005 as 397.2 thousand million kilometres. Total bus and coach traffic was 5.2 thousand million kilometres. So car and taxi traffic is 98.7% of the 402.4 thousand million total, with bus and coach traffic being the other 1.3%. These percentages give confidence in the 2% figure in the final column of Table 8, and suggest that it may be an upper estimate.

DfT(2006) quotes total traffic for class N1 vehicles as 62.6 thousand million kilometres. So total car, taxi, van, bus and coach traffic for Great Britain in 2005 was 465 thousand million kilometres. Bus and coach traffic was only 1.1% of this total.

The figures in Table 8 are important for calculating the total environmental impact of all vehicle traffic in the EU27, and hence the improvement that hydrogen vehicles could bring.

Passenger Transport Statistics for the EU in 2020

The final report from the EU 'ASSESS' project looked at four policy scenarios for the development of transport (EC2005a). The report gave predictions for both the years 2010 and 2020. Table 9 below shows mean values for those four scenarios, and compares them with the passenger transport statistics for the year 2000 that are given in the same report.

Table 9: Passenger transport in 2010 and 2020

Year	Passenger kilometres travelled by car (M1) in EU27 (thousand million)	Passenger kilometres travelled by bus and coach (M2 and M3) in EU27 (thousand million)	Ratio of passenger km travelled by car to passenger km travelled by bus and coach
2000	4419	480	9.2
2010	5258	499	10.5
2020	5910	494	12.0

Source: Tables 14, 16, 18 and 20 of EC2005a

The data in Table 9 shows that bus and coach travel, as a proportion of all passenger kilometres travelled, will continue to decrease in the EU27 states. This prediction accords with the historical pattern observed over the last 20 years in the EU15 member states.

6.3 Impacts per vehicle: Euro 5 and Euro V

The data on vehicle kilometres driven needs to be augmented by information on the impacts per kilometre driven.

Table 10 compares the environmental impacts per kilometre of vehicles in categories M1, N1, M2 and M3. Euro 5 emissions standards for light duty vehicles will come into force in 2009 for new car models and 2011 for all new vehicles of an existing model, see European Parliament 2006. The Euro V standards apply to heavy duty engines. Some light and heavy duty vehicles on sale in 2006 already meet these standards for some pollutants.

Note that exact comparisons are not possible, due to the variety of test methods applied to light and heavy duty vehicles. Heavy duty vehicles must meet an emission limit per kWh of power generation. In Table 10, we have listed the approximate ‘per kilometre’ emissions to which the ‘per kWh’ value equates.

Table 10: Environmental Impacts per vehicle kilometre with Euro 5 and V

Vehicle Category	Permitted noise emissions (dB)	Euro 5 and V permitted particulate emissions (g/km)	Euro 5 and V permitted NOx emissions (g/km)	Typical CO_2 emissions (g/km)
M1 petrol	74dB(A)	0.005	0.06	165
M1 diesel	75dB(A)	0.005	0.18	150
N1 diesel	75dB(A)	0.005	0.18-0.28	200
M2 and M3 diesel	80dB(A)	Typically 0.05g/km; 0.02g/kWh permitted	Typically 4g/km; 2g/kWh permitted	750
Approximate ratio of emissions M3:M1	4:1 Assumes traffic is a line source of noise	10:1	30:1	5:1

Sources: Table 1 of Annex 1 of European Parliament 2006; EU legislation; mean vehicle performance statistics

Conventionally powered passenger vehicles on sale in 2006 need only meet Euro 4 emissions standards. However, many petrol engined 'spark ignition' vehicles already emit only a fraction of the future Euro 5 emission limits. Type approval test measurements are given below for four current models, with the figures in brackets being the percentage of the future Euro 5 NOx limits:

(i) The Honda Civic hybrid emits 0.012 gNOx/km (20%).
The Toyota Prius emits 0.010 gNOx/km (17%).

(ii) A 1.4 FSI Volkswagen Golf emits 0.019 gNOx/km (32%).
A 1.6 Vauxhall/Opel Zafira MPV emits 0.037 gNOx/km (62%).

Real-world usage of vehicles on the roads currently increases actual emissions above the type approval values. This relates to several different effects. One key issue is the difference between the test cycle and the speeds and accelerations actually encountered in real world driving. For NOx emissions, a key issue is the proportion of time spent driving in real world conditions at speeds that are significantly higher than the maximum speed reached in the test cycle.

It is also important to note that many diesel 'compression ignition' vehicles have emissions in the type approval test that are close to the permitted maxima. The European Commission's Euro 5 Impact Assessment expands on these issues. See pages 18 and 20 of reference European Commission 2006h.

6.4 Impacts per vehicle in 2020

Chapter 7 below demonstrates that hydrogen vehicles are first likely to be used for significant road mileages from around 2017-2020 onwards, depending on the vehicle category. Some guidance to the maximum emissions of conventional vehicles beyond 2017 is provided by the Euro 6 limit values, see Table 2 of Annex 1 of European Parliament 2006, and the Euro VI emissions proposals. However, the Euro 6 and Euro VI standards will be several years old by the period of interest.

The Euro 6 standard for light duty vehicles will enter into force in 2014. The Euro 6 standard will reflect the widespread availability of NOx reduction exhaust 'after treatment' systems for diesel vehicles. The percentage reductions in NOx emissions with Euro 6 will in fact be similar to the step change in g/km particulates emissions that is now being achieved in production vehicles with diesel particulate filters.

With Euro 6, the mass of particulates in g/km will not be lowered from the Euro 5 standard. However, the current system of mass limits on particulates will be augmented by an entirely new standard, with a limit on the number of particles emitted by diesel engines (EP2006). This limit might be introduced even earlier than the date for Euro 6 standard. Such a standard will help to limit the number of 'ultra-fine' particles, which penetrate deepest into lungs.

The references European Commission (2006e) present the latest thinking on the Euro VI standard for heavy duty vehicles. See particularly Appendix B and Table A on page 4 of European Commission 2006e. We assume that the strictest emissions scenarios considered in EC(2006e) for Euro VI will have become the norm by 2017-2025, the period of interest to this report. These are PM10 emissions of 0.01 g/kWh, and NOx emissions of 0.2 g/kWh. These figures are however only an estimate, since no EC proposal has been adopted yet, and the limit values are subject to political decision for the Euro VI stage and beyond.

Table 11 below summarises this knowledge of future emissions standards, and predicts environmental impacts per vehicle kilometre for conventional vehicles in 2020. These figures will be used later in this report to quantify the impacts of introducing hydrogen vehicles as substitutes for the conventional vehicles available in 2017-2020.

For all diesel vehicles, the NOx and particulates levels in Table 11 correspond to the Euro 6 limits, and the estimate of possible emission limits for heavy-duty vehicles in the given timeframe. The NOx emissions limits in Table 11 for petrol M1 vehicles correspond to the levels from the best vehicles available in 2006, which we assume will become the norm at some time during 2017-2025. See the text that follows Table 10 for examples of such vehicles. However, emissions from petrol engines may be of lower relevance by 2017-2025. In early 2006, diesel vehicles took a larger proportion of new M1 sales in the EU27 than petrol vehicles, and the proportion of all sales going to diesels is still rising. Diesels already constitute almost all N1 sales. The inherent efficiency advantages of diesels will ensure their popularity, due to the continuing need to reduce CO_2 emissions from road transport.

Table 11: Environmental impacts per vehicle kilometre for conventional vehicles in 2020

Vehicle Category	Particulate emissions (g/km)	NOx emissions (g/km)
M1 petrol	0.005	0.01
M1 diesel	0.005	0.08
N1 diesel	0.005	0.08 – 0.125
M2 and M3 diesel	Typically 0.025g/km; 0.01g/kWh permitted	Typically 0.4g/km; 0.2g/kWh permitted
Approximate ratio of emissions M3:M1	5:1	5:1

Further changes to type approval legislation will make the ‘real world’ emissions of production vehicles closer to these test limits than is the case with current vehicles and legislation. For example, vehicles will need to meet these test limits for 160,000 km of use from new. In addition, technology to identify individual ‘high polluting vehicles’ in traffic is being deployed on the road network.

The European Commission has a target of 120 gCO_2/km from M1 vehicles by 2012, see also Table 7. We assume that this target will have been reached for all new M1 and N1 vehicles by the period 2017-2020. In 2006, a demonstrator diesel-electric N1 vehicle from Peugeot has achieved 99 gCO_2/km (Ricardo, 2006). A demonstrator M1 diesel electric vehicle from DaimlerChrysler achieved 85 gCO_2/km. Both were based on production vehicles. So, with diesel electric hybrid technology, the goal of 120 gCO_2/km is clearly achievable. The Mark II Smart car with a diesel engine, which is on sale in 2007, is reported to have CO_2 emissions of 90 gCO_2/km.

Table 11 does not include an assumption that legislation will reduce noise impacts significantly, given the very long time scale of the current work to bring in a new noise type approval test. Noise limits are assumed to remain those in Table 10 above.

6.5 The relative impact of M1, N1, M2 and M3 vehicles

With the Euro 5 and V emissions standards, it is clear that M2 and M3 vehicles have around 6-8 times the environmental impact of M1 and N1 vehicles, per vehicle kilometre driven. With Euro 6 and VI, Table 11 shows that M2 and M3 vehicles have around 5 times the impact on air quality of M1 and N1 vehicles, per kilometre driven.

Section 6.2 demonstrates that bus and coach traffic is a small proportion of all traffic. For every vehicle kilometre driven by a bus or coach, around 75 kilometres are driven by vehicles in categories M1 and N1. Table 9 shows that, by 2020, this will rise to around 100 kilometres.

If 100 kilometres are driven by category M1 and class N1 vehicles for each kilometre driven by class M2 and M3 vehicles, then the total distance driven in the EU27 by M1 and N1 vehicles will have around 20 times the impact on air quality of the distance driven by M2 and M3 vehicles, in 2020.

This analysis shows that the rate of adoption of category M1 and N1 hydrogen powered vehicles is the key to understanding the environmental impacts that hydrogen vehicles will bring. Even if 50% of new M2 and M3 vehicles were powered by hydrogen in 2020, for example, the effect on air quality would be equal to the effect that would result from only 2.5% of the M1 and N1 vehicles running on hydrogen.

7 Quantification of benefits II: Rate of introduction of hydrogen vehicles

7.1 Introduction

There is no reliable prediction of the number of hydrogen vehicles that will be sold in the EU27 in future years, in each of categories M1-M3 and N1-N3. In fact, it appears that such a prediction is not possible in 2007, because volume sales lie at least a decade away. This is a major hurdle to an accurate quantification of the benefits of hydrogen vehicles.

We do however have the results of the 'Hyways' project, which provides 'scenarios' for the rate of introduction of passenger cars into the 'EU15' states. The 'EU15' are the fifteen states that were Member States of the EU prior to 2004. In this report, we have extrapolated the Hyways data to cover the EU27 states.

In Annex H of this report, we discuss several predictions of the rate of introduction of hydrogen vehicles. This annex makes clear the uncertainty in any such forecasts.

7.2 The Hyways scenarios for the rate of adoption of hydrogen passenger cars

The European Commission has requested that this project use scenarios for the rate of introduction of hydrogen vehicles from the 'Hyways' research programme. The Hyways project is described in reference Hyways, (2006a). In December of 2006, the co-ordinator of the Hyways project provided their latest set of 'scenarios'. This is unpublished information (Hyways 2006).

The Hyways data provides scenarios for the proportion of vehicles in the EU15 Member States that will be powered by hydrogen in future years. The rates given for the years 2017-2025 are reproduced in Table 12 below.

Table 12: Introduction rates for hydrogen vehicles

Year	Scenario a: Extreme high policy support, fast learning	Scenario b: High policy support, fast learning	Scenario c: Modest policy support, modest learning
2017	1.0%	0.2%	0.006%
2018	1.5%	0.4%	0.02%
2019	2.3%	0.7%	0.04%
2020	3.2%	1.2%	0.1%
2021	4.4%	1.7%	0.1%
2022	5.7%	2.4%	0.2%
2023	7.3%	3.2%	0.4%
2024	9.1%	4.1%	0.6%
2025	11.2%	5.1%	0.8%

Source: Hyways 2006

The Hyways scenarios did offer data for years prior to 2017. However, we consider that 1% of all passenger cars in use would need to be hydrogen powered, before the effects are significant enough for consideration in this cost benefit analysis.

The Hyways scenarios also offer data for the years after 2025. There are two problems with this data. Firstly, the accuracy of forecasts generally falls the further into the future those forecasts are made. Secondly, we do not have accurate predictions of the NOx, particulates, and noise of new conventional vehicles that will be on sale after 2025. We are therefore unable to estimate the environmental benefit that hydrogen vehicles might potentially offer in comparison to those conventional vehicles.

7.3 How do the Hyways scenarios correspond to the options?

Scenario b in Table 12 specifies both 'High policy support', and 'fast learning'. This level of encouragement for the introduction of hydrogen vehicles exceeds the benefits that would be gained only by passing EU legislation. Scenario b implies more than just the presence of a regulation relating to European type-approval requirements for hydrogen powered vehicles. For example, key components of a package of 'high policy support' might include taxation incentives for the early introduction of hydrogen vehicles, policies to scrap older vehicles and encourage fleet renewal, and a public information campaign.

However, including hydrogen vehicles in the type approval process would contribute to the introduction of the vehicles. This report uses the introduction figures from the Hyways scenario b as a proxy prediction for the rate of introduction of the hydrogen vehicles under Option 2. This will clearly lead to an estimation of the maximum environmental benefits that would arise from Option 2.

The option of legislation at EU level would have several key effects:

(i) With option 2, the single market across the EU27 would be less fragmented than with option 3.

(ii) With option 2, Member States are likely to introduce converging rules for approval of vehicles.

With option 2, there would be less delay than is likely with option 3. With option 3, experience shows that some Member States may take longer to introduce national legislation than would be achieved under option 2. The result is that option 2 would lead to an earlier introduction of hydrogen vehicles than option 3. A more rapid rate of adoption with option 2 would clearly bring environmental benefits sooner.

7.4 Population predictions for EU15 and EU27

The Hyways (2006) scenarios include estimates of population in only the 'EU15 states', in each year up to 2030.

The Hyways (2006) data show the population in the EU15 states rising from 389.9 million to a peak figure of 390.4 in 2020-2022, then falling to 390.3 in 2025. This is a variation of 0.1% over the period 2017-2025, which is a far lower percentage than the error ranges of several of the estimates in this report. For this reason, we will assume a population of 390 million in the EU15 in each of the years 2017-2025.

After discussions with the European Commission, the authors of this report have decided that the Impact Assessment should cover the EU27 states. These are the EU25 states that were Member States of the European Union in December 2006, plus Romania and Bulgaria that joined on 1 January 2007. In 2005, the ten accession states that had joined the EU in 2004 had a population of 74 million. Bulgaria and Romania have a combined population of 29 million. These twelve states therefore add 103 million to the 385 million inhabitants of the EU15 in 2005, which is 27%. We will therefore add 27% to the EU15 population figure of 390 million in the years 2017-2025, bringing the total to 495 million for each of the years 2017-2025.

7.5 'Motorisation' rate and total number of M1 and N1 vehicles

The Hyways data includes estimates of the 'motorisation rate' of the EU15 states. This is conventionally defined as the number of passenger cars per 1000 inhabitants. Clearly, we need an estimate for the EU27. The authors of this report consider that the two following considerations are most important in settling this:

(i) The 10 accession states that joined the EU in 2004 have shown economic growth rates of up to 11% per annum, which is more than four times that of the EU15 states in the same period. In the period from 2006 until 2017-2025, the best performing accession states will reach standards of disposable income that comfortably exceed those of some of the EU15. Estonia and Latvia appear on course to do this first. Motorisation rates correspond closely with disposable income. We will therefore consider the motorisation rate figures from the Hyways scenarios to be applicable to all EU27 states in the period 2017-2025.

(ii) The motorisation rates in the Hyways data for the period 2017-2025 rise from 536 cars per 1000 inhabitants to 540. This variation of less than 1% is far less than the range of error in several other predictions that are needed in this report, so we will assume a motorisation rate of 540 for each of the years 2017-2025 for the EU27 states.

Taking the motorisation rate of 540 passenger cars per 1000 inhabitants and the population figure of 495 million, provides us with an estimate of the number of passenger cars. In each of the years 2017-2025, we assume that there will be 267 million passenger cars.

The Tremove database figures discussed in Annex H predicted 9.5 % as many N1 vehicles as M1 vehicles in 2020. We will therefore add 9.5% to the total of 267 million passenger cars. We therefore assume a total stock of 292 million N1 and M1 vehicles in each of the years 2017-2025.

Concerning the assumptions made in the above figures:

(i) Variations in individual Member States taxation policies, and in the fuel price, lead to uncertainties of several percent in each of the predictions. In the light of this, the assumptions of a variation of less than 1% in the population and motorisation rate in the EU27 in 2017-2025 do not add appreciable errors.

(ii) The cost figures and the estimates of the values of environmental damage used later in this report have error ranges of between 10% and 100%. These are therefore the error ranges that determine the precision of the estimates in this report.

7.6 Predictions for the rate of adoption of M1 and N1 hydrogen vehicles

Using the data in Table 12 and the total of 292 million M1 and N1 vehicles in the EU27 states, we can now predict the total number of hydrogen vehicles in each of the years 2017-2025.

We are treating the ‘Scenarios’ from the Hyways2006 data as predictions under each of options 2 and 3. As discussed in section 7.3, Scenario b corresponds most closely to Option 2. Scenario c corresponds most closely to option 3. However, we need to exercise considerable caution, since it is clear that:

(i) The percentage figures in Table 13 below for Option 2 are likely to be an overestimate of the effects of an EU Regulation, alone.

(ii) Scenario c ‘*Modest policy support, modest learning’* can be considered to correspond to leaving individual Member States to pass their own legislation, i.e. Option 3. However, the options for evaluation in this report do not involve different rates of ‘learning’, so scenario c can only be taken as an approximation of Option 3.

During February 2007, the Hyways team provided further information about the Hyways scenarios. In essence, these scenarios are postulations of introduction rates for vehicles that might occur. The scenarios help to focus thinking, but they are not formal predictions.

Table 13 below shows the percentage figures from Table 12 for introduction rates. For both options 2 and 3, columns have been added to show the numbers of actual M1 and N1 vehicles that would be in use.

For option 2, a column has been provided that converts the number of vehicles into billions of vehicle kilometres driven on the EUs roads. We need a mean annual mileage figure for all the hydrogen vehicles, across all Member States and for both N1 and M1 vehicles. We have taken this to be

20,000km. This is higher than the mean mileage for all vehicles, because the hydrogen vehicles in the Table will all be relatively new in the years 2017-2025, and vehicles have significantly higher mean mileages in the first years for which they are on the road. Figure 5.1 of Joint Research Centre (2003) shows how strong this effect is for six Member States plus the EU mean figure, with substantially higher annual mileages of newer vehicles. A figure as high as 20,000km is justified, given both the presence of N1 vehicles in the figures in Table 13, and the fact that the cost of driving each kilometre has fallen since the relatively old data in Figure 5.1 of Joint Research Centre (2003).

We stated earlier that a minimum of 1% of all passenger cars in use would need to be hydrogen powered, before the effects are significant enough for consideration in this cost benefit analysis. A major factor in selecting this 1% threshold is that the first examples of vehicles that use new technology tend not to be representative of final mass production configurations. This was the case for the first modern diesel powered passenger cars. It has also been the case with the first modern hybrid vehicles on public sale. The Honda Insight in the 1990s incorporated construction materials that are generally not used in the hybrid vehicles that are on sale in 2007. In the main part of this report, we therefore, will not analyse further the impact of the hydrogen vehicles under scenario 3 from 2017-2025, because the percentage of hydrogen vehicles does not reach 1% during that entire period. However, Annex J reproduces Tables 16-18 for the numbers of hydrogen vehicles that are listed in Table 13 for Option 3, in order to allow a comparison of the overall benefits.

Table 13: Predicted rate of adoption and use of M1 and N1 hydrogen vehicles

	Option 2			Option 3	
Year	**Hydrogen vehicles as a % of all vehicle stock**	**Number of hydrogen powered M1 and N1 vehicles (million)**	**Annual vehicle kilometres driven (billion)**	**Hydrogen vehicles as a % of all vehicle stock**	**Number of hydrogen powered M1 and N1 vehicles (million)**
2017	0.2%	0.6	12	0.006%	0.0
2018	0.4%	1.2	24	0.02%	0.1
2019	0.7%	2.0	40	0.04%	0.1
2020	1.2%	3.5	70	0.1%	0.3
2021	1.7%	5.0	100	0.1%	0.3
2022	2.4%	7.0	140	0.2%	0.6
2023	3.2%	9.3	186	0.4%	1.2
2024	4.1%	12.0	240	0.6%	1.8
2025	5.1%	14.9	298	0.8%	2.4

The total of all vehicle kilometres driven by hydrogen vehicles under Option 2 is 1110 billion. We assume in this report that this distance is a direct substitute for kilometres that would otherwise be driven by new conventional petrol and diesel vehicles in the same years, including some hybrid conventional vehicles.

7.7 The rate of adoption of hydrogen vehicles in categories M2, M3, N2 and N3

Given the relatively small number of M2 and M3 vehicles in the EU, we consider that their adoption will have relatively low impacts in comparison to M1 and N1 vehicles. See the discussion in section

6.5 of this report. For this cost benefit, the impacts of M2 and M3 hydrogen vehicles are only likely to be relevant to urban air quality. We deal further with this issue in chapter 8.

The power demands on smaller N2 vehicles are comparable to those of M3 vehicles. At first sight therefore, it might be assumed that hydrogen power would be introduced at a similar rate in category N2 vehicles to the rate for category M3 vehicles. However, there are two main differences:

(i) N2 vehicles are operated almost exclusively by the private sector. Without specific incentive schemes, private sector operators have less incentive to introduce technologies that improve urban air quality than the local authorities who operate many bus services.

(ii) Bus services are often local in nature. The vehicles can therefore be re-fuelled at one or two dedicated hydrogen re-fuelling stations, as has been the case with the 'CUTE' buses. On the contrary, category N2 vehicles often operate over a much larger area and distance. Operators may typically wish to redeploy such vehicles to different regions, during their working life. The lack of a comprehensive hydrogen re-fuelling infrastructure across the EU27 therefore represents a much larger constraint for purchasers of category N2 vehicles than for operators of M3 vehicles. It is also likely to affect the resale value of these vehicles, which will cause operators to be reluctant to buy them.

There is little current interest in using hydrogen in category N3, large goods vehicles. Some industry commentators have stated that hydrogen cannot be used for class N3 vehicles in the foreseeable future. This was confirmed during the consultation phase of this report. As a comparison, we know that in 2007 the N3 vehicle sector is around ten years behind the M1 sector in adopting petrol or diesel hybrid power technology. Taking such a long time delay into account, we might expect the first N3 hydrogen fuel cell vehicles in class N3 to be available from 2016-2020 at the earliest. These vehicles might then make up 1% of all new sales sometime around 2025-2030 under option 2.

For the reasons given in the previous paragraphs, we have not sought to quantify the rate of introduction of hydrogen as a power source in N2 and N3 vehicles.

One note of caution is necessary here. The total vehicle kilometres of N2 and N3 vehicles are much larger than those in category M2 and M3 vehicles. If hydrogen were to be used in N3 vehicles, contrary to the opinions given to us by industry, this would have a much greater effect than converting a similar proportion of the M2 and M3 vehicles.

Eurostat reports the new registration figures shown in Table 14 below for the EU27 states in 2004.

Table 14: Annual new goods vehicle and bus/coach registrations

Vehicle Category	Number of new vehicles registered in 2004
Buses and coaches 3.5-16 tonnes	9876
Buses and coaches > 16 tonnes	22873
Goods vehicles 3.5-16 tonnes	110270
Goods vehicles > 16 tonnes	246509

The much larger impact of N2 and N3 vehicles is clear, particularly given that some N3 vehicles may drive 250,000km/annum.

8 Quantification of benefits III: Monetisation of benefits

We can make valuations of each of the environmental benefits that hydrogen vehicles will bring in the areas of noise, air quality and emissions of CO_2. This chapter therefore considers the value of benefits that would arise as a consequence of option 2, using the data on % of the vehicle stock and percentage of all vehicle kilometres shown for option 2 in Table 13.

8.1 Discounting

It is possible to discount future benefits and costs into prices in a single year, in order to make them comparable. The rate of discounting and the percentage reduction for each future year are laid out on pages 39-41 of the 'Annexes to the Impact Assessment Guidelines'. Table 15 below reproduces these values for the years 2017- 2025, using the 4% discount rate. These values allow us to discount back to 2007 as the base year.

Table 15: Discount factors used for benefits

Year	Discount rate of 4%
2017	0.676
2018	0.650
2019	0.625
2020	0.601
2021	0.577
2022	0.555
2023	0.534
2024	0.513
2025	0.494

8.2 Benefits for noise

For the calculation of benefits, we need to derive a figure for the noise of hydrogen vehicles. We are assuming here that there will be no further improvement in legislation on noise levels from conventional vehicles between now and 2020. This is because the latest proposals for tightening of EU legislation on vehicle type approvals do not foresee any reductions before 2014. Even then the reductions will be gradual, and will be implemented using a different test procedure than is currently used. Only tyre noise legislation appears to offer benefits in noise from road transport, although the lower noise levels will not change greatly the value per decibel from further improvements beyond that point.

Hydrogen fuel cell vehicles produce noise from their tyres. However, we assume that there is negligible propulsion system noise, i.e. no 'engine', 'transmission' or 'exhaust' noise.

As the speed of a vehicle rises, tyre noise represents an increasing proportion of noise from the vehicle. Considering a typical range of vehicle types and speeds, tyre noise can be estimated to be 50% of noise generated by a vehicle. A hydrogen fuel cell vehicle would therefore produce 50% less noise than a comparable vehicle with a conventional internal combustion engine. For a 'line source' of noise, such as a stream of traffic, a reduction in noise of 50% from each vehicle equates to a reduction of 3 dB(A) in the noise level at any given observation point.

Hydrogen internal combustion engine (IC) vehicles can be assumed to emit more noise than hydrogen fuel cell vehicles. In February 2007, the hydrogen powered BMW 7 series vehicle was the only hydrogen internal combustion engined vehicle that we believe was close to commercial sale in the EU27. A figure for the performance of this vehicle in the noise type approval test was not available. We assume for the purposes of this report that hydrogen IC vehicles offer no noise advantages over the conventional vehicles that will be available in future.

As part of a previous report for the European Commission, TRL calculated a value of 5.5 billion Euros per decibel per annum for road traffic noise reduction across the EU 25 member states (FEHRL 2006, page 91). We need to add the effects on the 29 million residents of Bulgaria and Romania, to expand this figure from EU25 to EU27. This brings the total to 5.8 billion Euros per decibel per annum.

This figure can then be combined with the estimates of the proportion of all M1 and N1 vehicles that will be powered by hydrogen fuel cells, in order to estimate the noise saving.

Table 16 below takes the information on hydrogen vehicle stock under Option 2 in each future year from Table 13. Based on the discussion above, we assume that:

(i) For every 1% of the category M1 and N1 vehicle stock that is made up by hydrogen fuel cell vehicles, the noise emissions from category M1 and N1 traffic will fall by 0.03dB(A). This is based on the 3dB(A) figure quoted above.

(ii) Category M1 and N1 vehicles will make up 70% of all traffic noise in 2015-2020, a figure close to that for 2006. The remainder of the noise is from M2, M3, N2 and N3 vehicles.

(iii) 90% of category M1 and N1 hydrogen vehicles in the fleet will be fuel cells, with the other 10% being internal combustion engines. Once again, no accurate predictions for these proportions are available.

So for each 1% of the vehicle stock that is made up of hydrogen vehicles, the reduction in traffic noise perceived by the public will be:

0.03dB(A) x 0.9 x 0.7 = 0.02dB(A)

Table 16: Value of noise reductions due to hydrogen fuel cell vehicles in categories M1 and N1

Year:	Proportion of stock that is hydrogen powered	Resulting noise reduction from all traffic @ 0.02dB(A) per percentage (db(A) per annum)	Value of reductions in noise @ 5.8 billion€ per dB(A) (million € per annum)	Value of noise reductions after discounting (million € per annum)
2017	0.2%	0.004	23	16
2018	0.4%	0.008	46	30
2019	0.7%	0.014	81	51
2020	1.2%	0.024	139	84
2021	1.7%	0.034	197	114
2022	2.4%	0.048	278	154
2023	3.2%	0.064	371	198
2024	4.1%	0.082	476	244
2025	5.1%	0.102	592	292
Total				**1182**

8.3 Benefits for air quality

We consider here the benefits for particulate emissions and NOx. Emissions of carbon monoxide and unburnt hydrocarbons from Euro 4 standard vehicles are already very low, so they are not examined here.

Before calculating benefit figures for reductions in NOx and particulates, one major issue requires consideration. This is the fact that environmental economics leads to non-linear relations between the damage due to each pollutant and the level of that pollutant, rather than linear relationships.

The overall emissions of both particulates and NOx from road transport will have fallen by 2017-2025 to much lower levels than is currently the case. By 2017, Euro 4 standard vehicles will be the oldest vehicles in routine use on the roads, and by 2025 most of the Euro 4 vehicles will have been scrapped. The valuations for each unit of these emissions will be much lower than is the case today, because the total levels will be so much lower.

NOx is a 'threshold' pollutant, and the marginal cost per kilogramme of emissions may fall close to zero when the level of NO_2 in ambient air falls below the value that has significant effects on biological systems. Even today, there are very wide ranging costs estimates for the damage done by NO_2. The cost figure is variously estimated as €10,000/tonne or higher, see also page vi of Volume 9 of Externe, 2003b. Note that the marginal value of each pollutant will fall because the emissions of particulates and NOx will have fallen so far by 2020. This is a different situation to the emissions of CO_2, the value of which will rise in future years.

<u>NOx emissions</u>

Page 12 of European Commission (2006c) quotes an abatement cost figure of €4400/tonne for NOx emissions from light duty vehicles. Using this as a surrogate damage cost figure, we can calculate the damage saving due to hydrogen vehicles in categories N1 and M1. Note however that the constituents of NOx vary, and may be very different by 2020.

We assume that a typical new conventional vehicle in the total fleet of category M1 and N1 vehicles will emit 0.05 gNOx/km. This is a mean figure, based on the figures for petrol and diesel M1 and N1 vehicles in Table 11 We assume also that hydrogen internal combustion vehicles will not show any savings in NOx emissions, relative to conventional vehicles.

So for each kilometre driven by a hydrogen vehicle in 2017-2025, there is a saving of 0.045 g NOx. This is based on the 0.05 gNOx/km figure and 90% of the hydrogen vehicles being fuel cell powered. These figures lead to the valuations in **Error! Reference source not found.** below.

Table 17: Value of NOx reductions due to hydrogen vehicles in categories M1 and N1

Year:	Distance driven by hydrogen vehicles in each year (billion vehicle kilometres)	NOx reductions @ 0.045g saving per km (tonnes NOx)	Value of NOx reductions (million €)	Value of NOx reductions after discounting (million €)
2017	12	540	2.4	1.6
2018	24	1080	4.8	3.1
2019	40	1800	7.9	5.0
2020	70	3150	13.9	8.3
2021	100	4500	19.8	11
2022	140	6300	27.7	15
2023	186	8370	36.8	20
2024	240	10800	47.5	24
2025	298	13410	59.0	29
Total				**118**

We can conclude that the value of the reductions in NOx emissions due to the introduction of hydrogen vehicles in categories M1 and N1 in 2017-2025 is very small, in comparison to the value of the noise savings. In the light of the even smaller effects of M2 and M3 vehicles, their NOx emissions can be neglected in this cost benefit analysis. See also section 6.5.

Particulate emissions

Valuations of PM10 particulate emissions are wide generalisations, since they include PM10, PM2.5 and 'sub-micron' particulates. Each of these produces very different levels of damage in humans, per unit weight.

Table B-10 of European Commission's 'UNITE' study on Finland, (UNITE 2002), cites a cost of €9540/tonne of PM2.5 particulates in Helsinki, in 1998 Euro values. We do not have data telling us the proportion of particulates that will be PM2.5 in the total PM10 count allowed by the Euro 6 and VI standards. However, we can obtain an upper boundary for the costs by the crude assumptions that:

(i) All the PM10 emissions are PM2.5 particulates;

(ii) The UNITE 2002 values are appropriate for all particulates emissions, although we know that the damage caused by these emissions outside urban areas is less than in urban areas.

We assume therefore that PM10 emissions in urban areas impose a cost of 11,000 €/tonne in 2006 prices. We assume that neither hydrogen fuel cell or internal combustion engine vehicles emit particulates. So each kilometre driven by a hydrogen M1 or N1 vehicle results in a saving of 0.005g particulates., see Table 11.

Table 18: Value of particulates reductions due to hydrogen vehicles in categories M1 and N1

Year:	Distance driven by hydrogen vehicles in each year (billion vehicle kilometres)	Particulates reductions @ 0.005g saving per km (tonnes particulates)	Value of particulates reductions (million €)	Value of particulates reductions after discounting (million €)
2017	12	60	0.66	0.4
2018	24	120	1.3	0.8
2019	40	200	2.2	1.4
2020	70	350	3.8	2.3
2021	100	500	5.5	3.2
2022	140	700	7.7	4.3
2023	186	930	10.2	5.4
2024	240	1200	13.2	6.8
2025	298	1490	16.3	8.1
Total				**32.7**

The total saving is less than that for NOx. Clearly, it is also not worth calculating the value of emissions from M2 and M3 vehicles, for the same reasons as given above concerning NOx.

8.4 Effects on CO_2 emissions

A wide range of monetary values are used for CO_2 emissions across the EU27. One clear trend is that the most recent valuations tend to be far higher than earlier valuations. For this reason, this report has selected a very recent monetary valuation. However, it appears clear that the trend will be for these valuations to rise in future. If this report were to be written in one or two years from now, the values for CO_2 emissions would be very likely to be higher still. For examples of CO_2 monetary values, see Table 5.8 of EXTERNE, (1997), a European study, and Table 16 of INFRAS,(2004).

This report has chosen a monetary valuation based on the assessment criteria for road transport emissions, which was adopted in September 2006 in the UK. See Table 2 on page 8 of Department for Transport (2006). The value of emissions is assessed as €117/tonne CO_2 in 2006. The value rises by €1.54/annum in 2006 prices, to reflect increasing social damage. The rates for the years 2017-2025 would be those shown in Table 19 below.

Table 19: Cost of CO_2/tonne

Year	**Cost of CO_2 (€/tonne)**
2017	135
2018	136
2019	138
2020	139
2021	141
2022	142
2023	144
2024	145
2025	147

However, it is not clear that hydrogen vehicles will offer any CO_2 advantages over conventionally powered vehicles, by 2017-2025.

The Hydrogen Fuel Cell and Technology Platform (HFP2005) predicts relative efficiencies of hydrogen IC, hydrogen fuel cell and conventional diesel vehicles, for the year 2010 on page 58. This prediction is itself taken from a CONCAWE well-to-wheel study (JRC,2003). HFP (2005) predicts hydrogen fuel cell vehicles as using 47% less fuel than conventional diesel vehicles by 2010. Hydrogen IC engine vehicles would only be 7% more efficient than conventional diesel vehicles by 2010.

However, we know that the currently available hydrogen powered internal combustion engine vehicles require very significant amounts of energy for the production, distribution and storage of the fuel. These vehicles appear, in fact, to be less energy efficient than equivalent conventional vehicles. The extra weight penalty for the on-vehicle hydrogen fuel system is a major cause of this. Given the improvement in energy efficiency of conventional vehicles by 2020, it appears that hydrogen internal combustion engine vehicles are likely to offer no certain CO_2 reductions over conventional vehicles.

Hydrogen fuel cells are efficient at converting hydrogen to motive power. However, the energy required to produce, distribute and store hydrogen fuel puts the net advantage of fuel cells in great doubt.

For the purposes of this report, we consider that there is too little evidence to demonstrate that hydrogen passenger vehicles will offer any certain CO_2 emissions reductions over the conventional petrol, diesel and hybrid vehicles that will be available in 2017-2025. If hydrogen vehicles do offer advantages, it is likely to be due to improvements in hydrogen production, storage and distribution, which lie outside the scope of this report.

8.5 Benefits for safety

To quantify the benefits or disbenefits of safety of hydrogen systems, it is necessary to have detailed information on the systems which have been developed so far. However such information is very limited in the public domain.

One method used for determining the impact of new technologies on the probability and consequences of accidents is to utilise existing accident data to perform predictive studies.

Predictive studies can be conducted by examining accidents where vehicles were not equipped with the specific feature under consideration and making calculations and/or judgements to assess the affect the technology would have on the likelihood and consequences of the accident. Typically, predictive studies have the advantage that they can be used to calculate benefits before the measure has been introduced into the vehicle fleet and can be relatively straightforward to carry out. However, in order to be accurate, there must be a detailed knowledge of how each system will perform in every accident within the dataset. This detailed knowledge of hydrogen systems in all accident configurations is not available.

Research presented in the available literature related to hydrogen systems that were of a standard designed to meet existing or proposed legislation. Systems of this standard were demonstrated to be as safe as conventionally fuelled vehicles in a range of tests evaluating the system in crashes and fires. It is not documented whether these systems were designed to be minimally compliant with the legislation, or by what level they exceeded it.

During the stakeholder meeting on 14th November 2006, it was identified that some vehicle manufacturers have conducted substantial research on the safety of hydrogen systems in passenger vehicles. This research has been performed on systems which are designed to meet the technical requirements of the proposed UNECE Regulations. Representatives reported the systems to be as safe as gasoline fuelled vehicles in all circumstances. However, this research is not in the public domain, therefore it is not possible to assess the safety benefits, or factors which influence them.

As all research has assumed a minimum safety standard there is no information available on the effect on safety of unregulated hydrogen vehicles, therefore the disbenefits of unregulated systems are unknown at present. These disbenefits could be significant so it is advised that such systems should not be allowed without substantial research into their implications on vehicle safety. This research would also be necessary before it would be possible to monetise the disbenefit of unregulated systems.

From the research in the public domain, it is not possible to determine what effect systems of a higher or lower standard would have on safety. Without this information the benefits or disbenefits of these systems cannot be quantified or monetised.

It is concluded that, based on the information available in the public domain, hydrogen systems designed to the specifications of the proposed UNECE legislation appear to confer no significant safety benefit or disbenefit compared with current vehicles. For an accurate assessment considerably more publicly available research would be necessary. Unregulated systems and systems of higher or lower standard present benefits or disbenefits that cannot be quantified without further information.

9 Costs of hydrogen vehicles

9.1 Introduction

The costs of introducing any future technology are difficult to estimate. Fortunately however, some cost figures for hydrogen vehicles are already in the public domain.

Costs for technology fall over time, for a number of reasons. Two critical factors for hydrogen vehicles will be changes to the technology used in vehicles, and cost reductions due to economies of scale when mass production occurs.

9.2 The costs of hydrogen fuel cell passenger vehicles in Category M1 after 2010

The Institute for Environment and Sustainability, of the European Commission's Joint Research Centre, has published several cost estimates for vehicle technology in Europe in 2010 and beyond (Joint Research Centre, 2006).

Appendix 1 of the 'Well-To-Wheels' section of JRC (2006) assumes a cost of 19,560 Euros for a conventionally fuelled class M1 passenger vehicle in 2010. Such a vehicle is used as the 2010 'reference'. Table 20 shows the prices of various different vehicles, compared to this reference. It is assumed that such a vehicle contains a hydrogen system of sufficient standard to confer the environment and safety benefits detailed in the previous section.

Table 20: Costs of different M1 passenger vehicles in 2010, compared to 2010 'reference'

Type of propulsion	Cost (Euros)	Extra cost compared to 2010 'reference' (Euros)	Extra cost compared to 2010 'reference' (%)
Hydrogen internal combustion engine	24,310	4,750	24.3%
Hydrogen fuel cell	31,193	11,633	59.5%
Hybrid internal combustion engine	25,780	6,220	31.8%

Source: Appendix 1 of 'TANK-TO-WHEELS' section of JRC2006

The figures in Table 20 need to be viewed with great caution. In 2007 it is already clear that at least two hybrid internal combustion vehicles are on sale at prices that make them profitable for their manufacturers. The additional costs for these two types of vehicle, compared to other passenger vehicles of similar performance, are already below the 6,220 Euros forecast in the Table for 2010.

The figures in Table 20 were derived for annual production volumes of '50,000+' vehicles per annum. Based on this information, it is possible to predict the rate at which the production costs of hydrogen vehicles will fall.

The cumulative effect of all cost reductions for a new technology will result in an 'experience curve'. The European Commission's 'EXTOOL' project looked in detail at such curves. See pages 2-3 of Neij, L. et al. (2003) for an explanation.

For hydrogen vehicles, the effect can be represented as a graphical plot, showing the cost per vehicle produced, plotted against the cumulative number of vehicles produced.

This report uses a value of 80% for the progress ratio for hydrogen vehicle production. This means that the unit cost of production falls by 20% each time that the cumulative production volume doubles. This is a typical estimate for new technologies. However, there are also arguments for adopting a lower figure than 80%. One key factor is that the development of fuel cell components for vehicles may well be accelerated by knowledge gained in other applications of fuel cells, such as stationary and temporary power generation. Table 21 shows the rate of fall in the cost difference between the hydrogen fuel cell vehicle in Table 20 and the 2010 reference vehicle, using the 80% progress ratio.

Table 21: Reductions in cost of hydrogen fuel cell vehicles after 2010

Cumulative vehicle production	Extra cost over 2010 reference vehicle (Euros)
50,000	11633
100,000	9306
200,000	7445
400,000	5956
800,000	4765

We are not interested in the costs of producing vehicles beyond those costing 5,000 Euros above the reference vehicle. This is because 5,000 Euros is less than the extra cost at which today's hybrid vehicles are profitable for manufacturers. Because vehicles can be sold profitably from this point onwards, there is no further 'cost' to manufacturers in cost-benefit terms of producing hydrogen fuel cell vehicles.

In micro-economic terms, there are two effects. Firstly, some consumers are content to pay 5,000 Euros in order to benefit from the improved environmental performance, or other perceived advantages, of advanced vehicles. The second effect is due to government taxation policies, such as financial incentives for company cars and vans with low emissions. Over the lifetime of the vehicle, these government tax incentives offer a greater saving than the extra cost of purchase of the vehicle. For many consumers and businesses, a combination of both of these effects will lead to purchase of the vehicle, despite its greater cost.

The total estimate for the cost of introduction of hydrogen fuel cell vehicles comprises two components, as follows:

(i) The first 50,000 vehicles will each be assumed to cost 11633 Euros more than the reference vehicle, giving a cost of Euro 582million.

(ii) For the data in Table 21, the best fit curve is

$$Y = 378755\ X^{-0.3219}$$

This best fit curve shows that the 5,000 Euro extra cost is attained with the 689,323rd hydrogen fuel cell vehicle. The cost of production from the 50,000th until the 689,323rd vehicle is the integral of the best fit curve between these two limit values. This is 4,225 million Euros.

The total of the cost figures in (i) and (ii) above is:

582 million Euro + 4,225 million Euro = 4.8 Billion Euros

9.3 Different costs with option 2 or option 3

The costs of hydrogen vehicles will be affected by the form of legislation that is introduced. The time and cost effects of implementing EU level (Option 2) legislation, rather than national level (Option 3), can be assessed.

Table 22 estimates the number of hydrogen fuel cell powered M1 and N1 class vehicles which will be in the vehicle stock across the EU27 countries up to 2025, based on the introduction rate presented in Table 13. With EU wide legislation the development cost of the vehicles will be spread over all the EU markets.

Table 22: Hydrogen vehicle sales with Option 2

Year:	% of all vehicle stock that is hydrogen vehicles	Number of hydrogen M1 and N1 vehicles added to the vehicle stock in each year (million)
2017	0.2%	0.6
2018	0.4%	0.6
2019	0.7%	0.8
2020	1.2%	1.5
2021	1.7%	1.5
2022	2.4%	2.0
2023	3.2%	2.3
2024	4.1%	2.7
2025	5.1%	2.9
Total		**14.9**

In an extreme case, national level legislation would allow each country to develop entirely different regulations. This would then necessitate the development of different hydrogen systems for each country. In reality it is likely that only small variations would exist between countries requirements and completely different systems would not be required. However, by assuming that each country necessitates the development of a specific system produces the ‘worst-case’ scenario. In this situation, the development costs would be incurred for products suited to each member state.

Table 23 presents the number of hydrogen vehicles that would be added to the vehicle stock in a selection of EU countries, based on the introduction rate in Table 13 modified to each country using the Joint Research Centre 2003 estimates.

Table 23: Hydrogen vehicle sales with Option 3

Year:	Introduction rate of hydrogen vehicles (% of all stock)	Number of additional hydrogen M1 and N1 vehicles in stock per country				
		France	Germany	Italy	Spain	UK
2017	0.006%	2,075	2,721	328	1,342	1,923
2018	0.02%	4,846	6,343	776	3,156	4,505
2019	0.04%	6,926	9,046	1,123	4,546	6,461
2020	0.1%	20,778	27,113	3,385	13,680	19,408
2021	0.1%	27	35	4	18	25
2022	0.2%	34,699	45,317	5,624	22,771	32,365
2023	0.4%	69,429	90,676	11,253	45,563	64,760
2024	0.6%	69,489	90,754	11,263	45,602	64,816
2025	0.8%	69,534	90,814	11,270	45,632	64,859
Total		**277,803**	**362,818**	**45,027**	**182,308**	**259,123**

Based on the above assumptions, the time taken for the additional cost per vehicle to reduce to the 5,000 Euro level identified in Section 9.2 would be much greater with Option 3. The number of vehicles sold would reach the required level in 2018 across the whole of the EU with option 2, but the required level would not be reached in any single member state before 2025 with option 3.

The average additional cost per vehicle over the 2017-2025 period is also much higher if national legislation is applied. For instance, in the largest car sales market, Germany, the average additional cost per vehicle over the period is 6,700 Euro, while in a smaller market, such as Italy, the cost per vehicle remains in excess of 11,600 Euro. By contrast, when sales are spread over the whole of the EU, the additional cost per vehicle is 2,684 Euro.

It would be more difficult for manufacturers to make hydrogen vehicles financially viable in smaller member states if legislation was introduced at a national level. Overall, the cost and time for introduction of hydrogen vehicles would be much greater without legislation at EU level.

Although the analysis above is a 'worst-case' scenario of differing national legislation requirements, it illustrates the extra costs for industry of option 3.

9.4 The costs of hydrogen fuel cell vehicles in Categories M2, M3 and N1-N3

The cost estimates derived in section 9.2 also cover class N1 vehicles. Clearly, car-derived vans can use hydrogen fuel cell propulsion systems developed for the cars on which they are based. Any attempt to estimate separately the costs of hydrogen power in class N1 vehicles would therefore represent 'double counting'.

Detailed estimates of the costs of producing hydrogen fuel cell vehicles in categories M2, M3, N2 and N3 are not yet publicly available. The cost of developing hydrogen fuel cells for vehicles in classes M2, M3, N2 and N3 depends on how easy it is to scale up fuel cells and hydrogen storage tanks to the increased power demands of these larger vehicles.

Hydrogen fuel cells are used as a source of electricity for electric motors, which drive the vehicles. Many elements of hydrogen fuel cells and electric motors that are developed for class M1 vehicles should in fact be suitable for use in larger vehicles. For example, electric motors can be deployed around each axle or in each wheel of a multi-axle vehicle. It is however necessary to produce components of sufficient durability for the high demands placed on M2, M3, N2 and N3 vehicles.

This report assumes that the total additional development cost of hydrogen fuel cells for these vehicles is equal to half the cost figure for class M1 vehicles. This is likely to be an over-estimate, which therefore results in a maximum value for the cost figure.

Caution is required with this estimate for one further reason. Hydrogen vehicles in classes M2 and M3 may be sold commercially, but there is much less evidence that vehicles in classes N2 and N3 will be developed. If vehicles in classes N2 and N3 are not commercialised, then a cost figure should not be included in this study for their development.

The total cost figure for developing hydrogen fuel cell vehicles in all categories M1-M3 and N1-N3 would therefore be 4.8 billion Euro x 1.5 = **7.2 billion Euro**

There is great uncertainty in this figure. Given the commercially sensitive nature of development costs, it appears likely that a true figure for the costs will only be known in the years after this development work has actually taken place.

We know that these costs would be higher, if individual Member States set out differing requirements for hydrogen vehicles, in their national legislation. It is however not possible to know how different the requirements might be. In order to know this, we would need to be able to estimate the costs of differing national type approval requirements that clearly have not yet been passed by Member States' legislatures. We also do not know how many differing legislative regimes might arise under Option 3. For example, the EU27 Member States might for example divide into two or three blocks, with each block requiring a relatively minor difference in vehicle configuration.

In order to overcome this uncertainty, we assume that each differing set of national requirements would add 1% to the cost of hydrogen vehicle development. This includes research, engineering, and supporting different vehicle requirements in the different Member States. 1% of the 7.2 billion Euros figure equate to 72 million Euros.

9.5 The costs of hydrogen internal combustion engine vehicles from 2010

Table 20 shows a cost figure of 4,750 Euros per vehicle as the excess cost of a hydrogen internal combustion engine vehicle over the cost of a reference conventional vehicle in 2010.

The figure of 4,750 Euros is below the 5,000 Euro threshold explained in Section 9.2. This report therefore assumes that the sale of hydrogen internal combustion vehicles will be profitable around 2010, so no cost estimate need be made for them.

9.6 The costs of type approval

The cost of the type approval process for the manufacturers was also assessed. Conclusions were made on basis of Motor Vehicles Regulations 2006 (SI 1638:2006). This memorandum has been prepared by the Vehicle Certification Agency, an Executive Agency of the UK's Department for Transport. The document cites approximate costs to manufacturers per type approval of €160,000. A manufacturer would therefore face a cost of around €160,000 for a centralised, single EU type approval. In a worst case, the manufacturer might instead face costs of €4.3million, if each vehicle had to undergo type approval in 27 different member states. However, neither of these figures is significant in comparison to either:

(i) The extra costs that would be incurred if manufacturers had to develop different designs of each vehicle for different Member States;

(ii) The environmental benefits provided by the earlier introduction of hydrogen vehicles, which would occur with Option 2.

10 Summary of costs and benefits of impacts

Table 24 below summarises the monetary impacts identified in all of chapters 4-9

Table 24: Overall monetised impacts of policy options (values in Euro)

Policy option	Economic impacts		Social impacts	Environmental impacts	
	Internal market	**European Automotive Industry**	**European citizens**	**Impacts on climate change**	**Impacts on local air quality**
Option 2: Regulatory approach at EU level	None	None- This option simply facilitates the introduction of hydrogen vehicles by manufacturers	1.2 billion benefit	None	0.15 billion benefit
Option 3: Legislation at Member State Level	0.16 million Euro cost per Member State requiring separate type approval	0.07 billion extra costs per Member State that sets out differing national legislative requirements	0.1 billion benefit	None	0.02 billion benefit

Table 25: Summary of Qualitative Impacts of policy options 2 and 3

Impacts	Qualitative description	
	Option 2	**Option 3**
Internal market	Option 2 would be in accord with the internal market, since it would lead to more uniform safety and environmental standards than option 3. Option 2 would be likely to open up the markets of some Member States, which do not currently allow the use of hydrogen vehicles	Option 3 would lead to a more fragmented internal market for hydrogen vehicles.
European Automotive Industry	Option 2 would be more likely to lead to investment in hydrogen vehicles, since it reduces uncertainty about the market for hydrogen vehicles.	
European citizens	We cannot predict whether hydrogen would lead to increased mobility, at any given level of disposable income, because the costs of hydrogen vehicles and fuel in the period 2017-2025 remain uncertain.	
Impacts on climate change	There is no clear evidence that hydrogen vehicles will have lower impacts on climate change than petrol and diesel conventional, or hybrid, vehicles. The impact on climate change depend mainly on how hydrogen is generated, stored and distributed, which lie outside the scope of this report.	
Impacts on local air quality	Option 2 would improve local air quality, by encouraging the more rapid introduction of hydrogen powered vehicles. Improvements in NOx levels will be greater if hydrogen fuel cell vehicles are introduced, rather than hydrogen IC engined vehicles.	Option 3 would lead to a slower introduction of hydrogen powered vehicles, so improvements to local air quality would be delayed correspondingly.

11 Comparing the options

11.1 Relative effects of the options and recommendations

Table 26 below compares the policy options.

Table 26: Comparison of policy options

Policy option	Advantages	Disadvantages
Option 1: No policy change	Option deemed not feasible	
Option 2: Regulatory approach at EU level	1. Provides lower costs of implementation than option 3. 2. Provides environmental benefits sooner than option 3. 3. Would open up markets in some Member States where hydrogen vehicles cannot currently be sold. 4. Would be likely to lead to higher, more uniform safety standards for citizens than with option 3.	
Option 3: Legislation at Member State Level		1. Leads to higher costs than option 2. 2. Provides environmental benefits later than option 3.

This report recommends Policy Option 2, the passing of an EU regulation.

11.2 Caveats to this report

Although the outcome of the policy option comparison is clear, three notes of caution need to be considered:

<u>(i) The rate of introduction of hydrogen vehicles</u>

Accurate predictions of the rate of introduction of hydrogen vehicles into the road fleet cannot currently be made. Table H3 of this report demonstrates that previous attempts to predict the rate of introduction of new technologies have not been successful, even 2-4 years after those predictions were made. The Hyways team has in fact stated that the ‘scenarios’ that they developed are not predictions. So uncertainty is introduced into this report by the step of using the scenarios as predictions.

Looked at in a broader sense, it is always unrealistic to have confidence in studies that seek to project the sales of competing types of industrial goods, i.e. new types of vehicles, more than a decade in advance. It is also important to note that this report has had to consider the potential impacts of national measures, for option 3, that do not even exist in draft form. The report has therefore had to make broad assumptions, based on expert judgement, about the likely effects of such hypothetical measures.

These issues lead to uncertainty in the lower curve in Figure 2.3 of this report. The effects of Options 2 and 3 will be to change the height and steepness of the lower curve on Figure 2.3 for hydrogen vehicles, but there is clearly uncertainty about the baseline situation against which the effects of these policy options need to be judged.

(ii) The environmental impacts of future conventional vehicles

The absolute values of data used for conventional vehicles in this report are highly uncertain. The level of environmental impacts of conventional vehicles that will compete with hydrogen vehicles, in the timeframe 2020-2025, depends on several developments. New vehicles that meet the Euro VI and Euro 6 standards will have very low emissions of currently regulated pollutants. By 2020-2025, policy attention may in fact have shifted to removing older vehicles from the fleet and usage patterns, rather than requiring further tightening of the standards for new vehicles. It is unclear to what extent carbon dioxide emissions may have reduced, in the light of forthcoming EU legislation, and subsequent tightening of policy. Government financial policies to bring in cleaner vehicles play a large part in introducing these vehicles, and such policies are unknowable now. In addition, type approval tests may well need to be updated, to make them representative of real-world usage of vehicles. There is an opportunity to do this when introducing a new standard for the number of particulates emitted by vehicles, for example. Improvements to the type approval test cycle would further reduce the impacts from conventional vehicles before 2020-2025.

These issues lead to uncertainty in the upper curve in Figure 2.3 of this report. Clearly, the net benefit of hydrogen vehicles depends on the difference between the upper and lower curves.

(iii) The overall benefit:cost ratio

This report provides evidence that the costs of an EU regulation would be lower than member state legislation, and that the environmental benefits would arise sooner. Safety benefits are also likely to be greater. However, this is a conclusion about the impacts of options 2 and 3 relative to 'no policy change'. However, in terms of conventional costs and benefits, it is not clear that the benefits of hydrogen vehicles will outweigh the costs of developing the vehicles. This report does not provide compelling evidence that the benefit: cost ratio of hydrogen vehicles will be greater than, or even equal to, one.

11.3 Vehicles in classes M2, M3, N2, and N3

With the state of our knowledge in 2007, it appears likely that:

(i) Hydrogen power will have the greatest impacts through use in passenger cars and light duty goods vehicles. However, hydrogen power is likely to be used sooner in buses and coaches than in passenger cars and light duty vehicles. More precisely, a greater proportion of vehicles in categories M2 and M3 are likely to be powered by hydrogen in any given future year, than the proportion of vehicles in categories N2 and N3. For this reason, industry is likely to benefit most from the early adoption of an EU regulation for hydrogen power in vehicle categories M2 and M3.

(ii) Hydrogen power is unlikely to be used in significant numbers of heavy duty commercial vehicles, in classes N2 and N3, in the period 2017-2025. However, these vehicles are driven for much greater mean distances per annum than other vehicles. So, if hydrogen power were to be introduced into category N2 and N3 vehicles earlier than currently foreseen by the vehicle industry, this would change the impacts of Options 2 and 3 significantly.

12 References

Department for Transport (2006) *'Transport analysis guidance'*, DfT, October 2006. http://www.webtag.org.uk/webdocuments/3_Expert/3_Environment_Objective/pdf/3.3.5.pdf

European Commission (2002) *'Taxation of passenger cars in the European Union - options for action at national and community levels'* Communication from the Commission to the Council and the European Parliament, September 2002.http://eur-lex.europa.eu/LexUriServ/site/en/com/2002/com2002_0431en01.pdf

European Commission (2005) *'Proposal for a Council Directive on passenger car related taxes'* proposal by European Commission, July 2005. http://eur-lex.europa.eu/LexUriServ/site/en/com/2005/com2005_0261en01.pdf

European Commission (2005a) '*ASSESS Final Report: Annex XVII Indicators'*, Transport and Mobility Leuven, for the European Commission DG TREN. http://ec.europa.eu/transport/white_paper/mid_term_revision/doc/annexes/annex_17.pdf

European Commission (2006) '*Purchasing zero emissions hydrogen powered buses'*, press release reference IP/06/1315, 5 October 2006. http://europa.eu.int/rapid/pressReleasesAction.do?reference=IP/06/1315&format=HTML&aged=0&language=EN&guiLanguage=en

European Commission (2006b) '*TREMOVE description of model and baseline version 2.4.1'*, Draft report, 3 March 2006. *http://www.tremove.org/download/TREMOVE%202.41%20draft%20v03mrt2006.pdf*

European Commission (2006c) '*Impacts assessment for Euro 6 emission limits for light duty vehicles'*, Commission Staff working document, European Commission, 20 September 2006. http://ec.europa.eu/enterprise/automotive/pagesbackground/pollutant_emission/impact_assessment_euro6.pdf

European Commission (2006d) '*Hyways: a European roadmap'*, L-B Sytemtechnik, Ottobrun, Germany, February 2006. http://www.hyways.de/docs/Brochures_and_Flyers/HyWays_External_Document_02FEB2006.pdf

European Commission (2006e) '*Euro VI technologies and costs for heavy duty vehicles: The expert panels summary of stakeholders responses'*, TNO Science and Industry for the European Commission, September 2006. http://ec.europa.eu/enterprise/automotive/pagesbackground/pollutant_emission/tno_report_euro_vi.pdf

European Commission (2006f) '*Tighter emission limits for cars after EP adoption of Euro 5 and 6*', Press Release 13 December 2006. http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/1800&format=HTML&aged=0&language=EN&guiLanguage=en

European Commission (2006g) *Preliminary draft proposal for a Regulation of the European Parliament and of the Council relating to emissions of atmospheric pollutants from motor vehicles (Euro 5).* http://ec.europa.eu/enterprise/automotive/pagesbackground/pollutant_emission/stakeholder_consultation/euro_5_draft_reg.pdf

European Commission (2006h) Impact Assessment SEC (2005) 1745: http://ec.europa.eu/enterprise/automotive/pagesbackground/pollutant_emission/sec_2005_1745.pdf

European Commission (2006i). *Preliminary draft proposal for a Regulation of the European Parliament and of the Council relating to the type-approval of hydrogen powered motor vehicles*. Version 2, 13 July 2006
http://ec.europa.eu/enterprise/automotive/pagesbackground/hydrogen/consultation/call

European Commission (2007) '*Results of the review of the community strategy to reduce CO_2 emissions from passenger cars and light commercial vehicles'*, COM(2007) 19 final.http://ec.europa.eu/environment/co2/pdf/com_2007_19_en.pdf

European Parliament (2006) *Text adopted by the European Parliament December 2006.* http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P6-TA-2006-0561+0+DOC+XML+V0//EN

EXTERNE (2003a) '*External costs of transport in Externe'*, IER-Germany, 31 May 1997. http://externe.jrc.es/trans.pdf

EXTERNE (2003b)' *Vol. 9 of Fuel cycles for emerging and end-use technologies, transport & waste.* http://www.externe.info/

FEHRL (2006) '*Final report S12.408210 tyre/road noise: volume 1'*, FEHRL, BAST, TRL, TUV Nord, VTI. http://ec.europa.eu/enterprise/automotive/projects/report_tyre_road_noise1.pdf

Fürst, S, Dub, M, Gruber, M, Lechner, W and Müller, C (2005). *Safety of hydrogen-fuelled motor vehicles with IC engines*. Paper presented at the International Conference on Hydrogen Safety, Pisa, Italy, 8-10 September 2005

Health Commission (2003) '*Noise and health: making the link'*, The London Health Commission, August 2003. http://www.londonshealth.gov.uk/pdf/noise_links.pdf

HFP (2005) '*Strategic research agenda'*, Hydrogen & Fuel Cell Technology Platform, July 2005. https://www.hfpeurope.org/uploads/677/686/HFP-SRA004_V9-2004_SRA-report-final_22JUL2005.pdf

Hyways (2006) *Latest scenarios from the 'Hyways' research programme*, unpublished. December 2006.

Hyways (2006a) '*Hyways: A European roadmap'*.
http://www.hyways.de/docs/Brochures_and_Flyers/HyWays_External_Document_02FEB2006.pdf

INFRAS (2004)'*External costs of transport'*, INFRAS, October 2004.
http://www.infras.ch/downloadpdf.php?filename=UpdateExternalCosts_FinalReport.pdf

Joint Research Centre (2003) '*Dynamics of the introduction of new passenger car technologies'*, Institute for Prospective Technological Studies and Joint Research Centre of the European Commission, Report EUR 20762 EN, June 2003. ftp://ftp.jrc.es/pub/EURdoc/eur20762en.pdf

Joint Research Centre (2006) '*Well-to-wheels analysis of future automotive fuels and powertrains in the European context'*, European Commission Joint Research Centre, Concawe and EUCAR, version 2b, May 2006. infoWTW(at)jrc.it

MNP (2006) *'The impacts of Euro 5: facts and figures'*, Netherlands Environmental Assessment Agency, February 2006. http://www.rivm.nl/bibliotheek/rapporten/500043002.pdf

Neij, L (2003) '*Experience curves: a tool for energy policy assessment'*, IMES/EES report No. 40, Department of Technology and Society, Environmental and Energy Systems Studies, Sweden, 2003. ISBN 91-88360-56-3.
http://www.iset.unikassel.de/extool/Extool_final_report.pdf#search=%22experience%20curve%20Extool%22

Ricardo (2006) *Ricardo press release* June 2006.
http://www.ricardo.com/media/pressreleases/pressrelease.aspx?page=40

Statutory Instrument 1638. (2006) *Explanatory memorandum to the motor vehicles (type approval and approval marks) (fees) (amendment) regulations 2006.* http://www.opsi.gov.uk/si/em2006/uksiem 20061638 en.pdf

UNECE (1995) *Agreement concerning the adoption of concerning the Adoption of Uniform Technical Prescriptions for wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions*. http://www.unece.org/trans/main/wp29/wp29regs.html

UNECE (2003a) *Proposal for a new draft regulation: uniform provisions concerning the approval of: specific components of motor vehicles using compressed gaseous hydrogen; vehicles with regard to the installation of specific components for the use of compressed gaseous hydrogen.* (TRANS/WP.29/GRPE/2003/3).
http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/grpedoc_2004

UNECE (2003b) *Proposal for a new draft regulation: uniform provisions concerning the approval of: specific components of motor vehicles using liquid hydrogen; vehicles with regard to the installation of specific components for the use of liquid hydrogen* (TRANS/WP.29/GRPE/2003/14).
http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/grpedoc_2003

UNITE (2002) '*Marginal cost case study 9b: heavy goods vehicle for Finland'*, Draft Version 1.0, UNITE project for European Commission 5th Framework – Transport RTD, April 2002.
http://www.its.leeds.ac.uk/projects/unite/downloads/MCCS-9B.pdf

www.storhy.net StorHy (Hydrogen Storage Systems for Automotive Application) is an integrated Project within the EU 6th Framework Programme coordinated by MAGNA STEYR Fahrzeugtechnik AG & Co KG

Annex A Results of literature review

During the literature review sources were primarily identified through the International Transport Research Documentation (ITRD) and Elsevier Science Direct. In addition to this various internet sources were used along with published material from the European Hydrogen and Fuel Cell Technology Platform (N2NET), The European Integrated Hydrogen Project Phase II (EIHP2), Clean Urban Transport for Europe (CUTE) and other international sources known for their expertise in utilising hydrogen in transport.

A.1 Environment

Environmental issues were investigated through a review of a number of the reports produced during the trial projects such as Clean Urban Transport for Europe (CUTE). Furthermore, cooperation of the car manufacturers across Europe also adds important information to the assessment of impacts of hydrogen fuelled vehicles on the environment. It is already widely recognized that use of hydrogen in vehicles presents no negative impact on the environment because the vehicle exhausts only water and heat. Table A1 lists significant and in-significant impacts. It is paramount to assess the whole life cycle analysis of the hydrogen fuelled vehicle before the right impacts on the environment are presented. If the hydrogen is not produced in a sustainable way, negative impacts of the production process will overcome positive impacts of the hydrogen fuelled vehicle itself.

Table A1: Significant and insignificant impacts

Hydrogen as a vehicle fuel has significant impacts on:	**Hydrogen as a vehicle fuel does not have significant impacts on:**
Air quality/human health	Soil quality
Greenhouse gas emissions; Mobility and the use of energy	Waste generation
Noise	Biodiversity, fauna and flora; animal and plant health, food and feed safety
Material assets; renewable and non-renewable resources	Population
Water quality	Cultural heritage including archaeological and architectural heritage
Likelihood of environmental risk	Landscape
The environmental consequences of firms' activities	

A.2 Safety

This review of safety issues relating to hydrogen powered vehicles has identified a number of aspects of safety which differ from those of conventionally fuelled vehicles. These differences arise because the characteristics of hydrogen are very different to hydrocarbon based fuels. This section identifies the differences between the fuels and the implications these have on design requirements and overall safety.

A.2.1 Hydrogen characteristics

The principal reaction characteristics of hydrogen, gasoline and natural gas are shown in Table A2.

Table A2: Reaction characteristics of hydrogen, natural gas and gasoline

Variable (Units)	Hydrogen	Natural gas	Gasoline
Lower Heating Value (MJ/kg) *The lower heating value (LHV) is the amount of energy generated when water is the product. The higher heating value (HHV) is the amount of energy generated when steam is the product.*	120	50	44.5
Auto-ignition Temperature (°C) *This is the lowest temperature at which a material will ignite without an external source of ignition.*	585	540	228-501
Flame Temperature (°C)	2045	1875	2200
Limits of Flammability in Air (Vol. %) *If the percentage of flammable material in the air is between the minimum and maximum limits, the presence of a flame or a source of ignition is likely to lead to rapid combustion or explosion.*	4-75	5.3-15	1.0-7.6
Minimum Ignition Energy (µJ) *This is the lowest possible energy that will result in the ignition of a flammable mixture by an electrical discharge*	20	290	240
Limits of Detonation in Air (Vol. %) *These define the range of composition within which detonations have been observed in laboratory and field experiments*	13-65	6.3-13.5	1.1-3.3
Theoretical Explosive Energy (kg TNT/m3 gas) *The equivalent mass of TNT to achieve explosion energy*	2.02	7.03	44.22
Diffusion Coefficient in Air (cm2/s)	0.61	0.16	0.05
Gas or Vapour density relative to air (at standard temperature and pressure)	0.07	0.6	2.0-4.0

The characteristics of hydrogen which have the most significant implications for the safety of vehicles are:

- The temperature at which hydrogen ignites without an external source of ignition is higher than that of gasoline or natural gas.
- The minimum energy that will result in the ignition of a flammable mixture by an electrical discharge is substantially lower for hydrogen than gasoline or natural gas. Given the electrical systems on vehicles this could present a significant increase in risk unless design militates against it.
- There are limits on the concentration of a flammable substance in air in which it can ignite when a source of ignition is introduced. Outside of the range there is either not enough fuel or not enough oxygen for the reaction to occur. The lower limit for hydrogen (4%) is higher than gasoline (1%) so a greater amount, by volume, is required before ignition can occur. However, the upper limit for hydrogen is much higher (75%) than for gasoline (7.6%) or natural gas (15%), therefore, where a volume becomes too concentrated for gasoline or

natural gas ignition at a relatively low level, the range over which hydrogen presents a risk is much greater.

- Detonation is the process of supersonic combustion in which a shock wave is propagated forward. It is much more destructive than a subsonic deflagration explosion. The range of concentration of hydrogen in air which will result in detonation is very large. The detonation range is almost 75% of the flammability range, meaning that there is a high likelihood that an explosion will be a detonation.
- The diffusion coefficient of hydrogen is much higher than gasoline or natural gas so it will disperse faster.

It can be concluded that the leakage of a hydrogen system in an open space may be safer than gasoline in the same environment, as a consequence of:

(i) The higher diffusion coefficient of hydrogen; and

(ii) The lower flammability limit of hydrogen is above that of gasoline.

A.2.2 Fire/ explosion

As hydrogen ignites and explodes over a greater concentration range the fire and explosion risk may be greater if a release is uncontrolled.

The University of Miami conducted a comparison of an intentionally ignited hydrogen tank release to a small gasoline fuel line leak. The pictures shown in Figure A.12 are from 60 seconds after ignition, with the hydrogen fire on the left and the gasoline fire on the right. It was reported that after 100 seconds all of the hydrogen was gone and the car's interior was undamaged having only increased in temperature by 2^{o}C. The gasoline car continued to burn for several minutes and was completely destroyed. (www.hydrogenassociation.org / US Department of Energy)

Hydrogen **Gasoline**

Figure A.12. Hydrogen and gasoline cars 60 seconds after ignition

Watanabe *et al* (2005) reported experiments with the ignition of leaks from automotive hydrogen, natural gas and gasoline tanks mounted in vehicles. The tanks were of the size and pressure that would be fitted in a typical car. It was observed that the fire from the hydrogen release was short in duration and radiated less heat to the surrounding area. The spread of flames was comparable to gasoline and less than natural gas. The authors concluded "From the results of these tests, it can be said that a fire in a 35MPa high pressure hydrogen tank-mounting vehicle would not be very much higher in hazard compared with existing vehicle fuels of gasoline and natural gas." Additionally, multiple tests with hydrogen tanks placed in different fire types (wood, oil, propane burners and vehicle) found that the hydrogen tanks consistently released pressure via the safety valves, rather than bursting due to excess pressure. It was noted that in a vehicle fire the high pressure hydrogen tank is less likely to be exposed to direct flames, but is gradually heated up by the rise in surrounding temperature.

Hydrogen flames are near invisible to the human eye and produces little radiant heat. This could present an increased risk to emergency services and/or others who could unintentionally enter a hydrogen fire. However, it is likely that a vehicle hydrogen fire will burn out quickly, or will also include the combustion of other materials which will produce a visible flame and radiant heat.

Therefore, it can be concluded that a properly designed hydrogen storage system, which incorporates a reliable pressure release system, does not have an overall fire safety disbenefit when compared with a conventionally fuelled vehicle.

A.2.3 Impact protection

The research into the fire and explosion safety of hydrogen reported in the previous section requires that the hydrogen leaks in a controlled manner through pressure relief valves.

To ensure that this happens it is necessary for the hydrogen storage system to withstand any impact that the vehicle is involved in. It is necessary to both avoid penetration of the storage tank and excessive internal pressure.

Organisations such as ENGVA have presented results of extensive testing performed on CNG storage cylinders, including bonfire, explosion, high velocity penetration and drop test. These tests have shown that tanks can be constructed to provide high integrity levels. CNG containers operate at a lower pressure than hydrogen, but are similar in design and requirements.

BMW (Fürst *et al*, 2005) reported impact test of hydrogen power versions of their 7-series model. The vehicle contained a liquid hydrogen tank mounted between the rear wheels, and pipe work carrying hydrogen to the internal combustion engine. The hydrogen fuel system was designed in accordance with the proposed UNECE regulation. The car was tested under USNCAP frontal impact conditions (100% overlap, rigid barrier, 56km/h), during which the hydrogen tank and mountings were subjected to accelerations up to 50g. A car was also subjected to the FMVSS 301 rear-end crash, where a mobile barrier strikes the rear of the vehicle at 80km/h and 70% overlap. The vehicle must provide sufficient strength and energy absorption to prevent damage to the tank. Leakage after the impacts was monitored to determine whether dangerous hydrogen levels are reached. It was reported that leakages remained below dangerous levels.

Mituishi *et al* (2005) conducted crush tests on cylinders for pressurised hydrogen applications. A 2.5 tonne mass was dropped from 2m onto various cylinder designed with different internal pressures. This research concluded that "… under the conditions of the automobile crash test method, the high pressure tank filled with fuel maintains a sufficient rigidity, and the possibility of a tank rupture occurring is extremely low." The overpressure which occurred when cylinders ruptured during the tests was sufficient to cause minor damage within the immediate area, but was significantly below the level to cause major damage or injury to people.

Within this literature review no research was identified which considered the impact effects on hydrogen storage containers of a lower standard than that required by existing or proposed legislation.

Research into hydrogen storage tank impact integrity indicates that a well designed tank is capable of withstanding the conditions that are likely to arise in a road accident. This confidence is supplemented by previous work which has shown the integrity of CNG storage tanks. Therefore, a well designed hydrogen system would provide no greater hazard than an existing fuel system. However, a poorly designed storage system would not guarantee this level of protection and it is not currently possible to quantify the risk.

A.2.4 Vehicle storage

It has been previously indicated that one of the key characteristics of hydrogen that reduces its risk is the high dissipation rate in open air, largely due to its low density. Research has been conducted to determine whether a hydrogen release within an enclosed space, such as a tunnel or garage, will result in hazardous conditions.

Mukai *et al* (2005) performed computational fluid dynamic (CFD) simulation of the diffusion of a vehicle hydrogen leakage in a tunnel, underground car park and multi-storey car park. The hydrogen leakage rate assumed was 133L/min, which is the energy equivalent of the allowable gasoline leak after an impact in FMVSS301 (Fuel System Integrity standard). Each location scenario was analysed with one and two vehicles leaking for 30 minutes. The only situation modelled in which the lower flammability limit was exceeded was a leak occurring at the bottom of a multi-storey car park. In this case there was a brief period when the area immediately behind the vehicle, and to the height of the roof above, exceeds the limit, but this dissipates quickly.

Based on this research the risk of dangerous hydrogen levels being reached is dependent on the geometry of the enclosed space and leakage rate. However, it suggests that the high diffusion coefficient of hydrogen means that the danger is limited even in an enclosed space.

Fürst *et al* (2005) considered the level of ventilation required in a standard single vehicle garage to prevent hydrogen building up above the lower flammable limit. It was deemed that 60g/hr of hydrogen may be leaked due to a fault in a stationary vehicle, or through liquid hydrogen evaporation. In a fully sealed garage it was found that the safe levels were quickly exceeded, but in a garage with typical gaps around the door critical levels were not reached. A gap with area of $0.024m^2$ was found to be sufficient to prevent critical levels being exceeded.

The research indicated that there are circumstances under which the hydrogen leaked from an enclosed vehicle will cause critical flammability levels to be reached. However, the high diffusion coefficient of hydrogen means that these situations should only occur infrequently.

A.2.5 General safety issues

Further issues which could have implications on the safety of hydrogen vehicles have been identified during this literature review:

- Electric (e.g. hydrogen fuel cell) vehicles will be much quieter than current vehicles, so would give little or no warning of their approach to other road users. This could potentially increase the risk of an injury accident, particularly to vulnerable road users.
- If appropriate materials are not selected, hydrogen can cause significant deterioration in fuel system components by diffusing into steel and other metals, causing embrittlement. As a result, the metal will break or fracture at a much lower load or stress.
- Fuel cell vehicles operate at high voltages so there are issues of electrical shock, isolation and ignition. These risks exist during either operation or maintenance.
- Different procedures for dealing with fires may be required, e.g. do not extinguish a hydrogen flame unless necessary as it could spontaneously/ explosively reignite.
- It has also been hypothesised that the mass distribution and stiffness of vehicles may change from that of current vehicles to incorporate the new technologies (Hennessey et al, 2005). This may have an effect on the protection to occupants and other road users.

A.2.6 Bus related issues

Currently hydrogen fuel is used more extensively in the bus industry than in any other sector of the automotive industry. Projects, such as the Clean Urban Transport for Europe (CUTE), are already using hydrogen powered buses in commercial operation. A consequence of this is that the bus industry has been able to identify several issues many of which also apply to cars, but some of which are specific to buses.

DaimlerChrysler have been involved in the development of hydrogen fuel cell powered buses. During the process twelve elements were identified as being key to the vehicle safety:

1. Vehicle design and safety in crashes:

Crash types identified were: bus roof, rollover, front and rear

Electrical equipment, hydrogen system and mechanics should be examined after any impact

2. Safety of personnel where voltages exceed 24V
3. Protection of personnel against escaping hydrogen

    Tank safety

    Protection where there is leakage into the vehicle

    Detection of leaks

    Protection when blowing out hydrogen during purging of fuel cells

    Safety when refuelling

4. Safety of the electronic systems

    EMC

    Electrical and electronic systems in explosive atmospheres

5. Fault detection

    Self-monitoring by the systems

    Safety in networked systems

6. Reactions to faults and indications when faults occur

    Fault storage and repair instructions

    Notification of fault to the driver

    Emergency operation

    Emergency shut-down

7. Regular checking of the equipment
8. Safety when parking fuel cell vehicles with compressed hydrogen accumulators
9. Protection against unauthorised operation of the vehicle
10. Safety rules for the vehicle and its maintenance

    Protection against leakage of hydrogen during repair work

    Controlled drainage of the tank

    Protection of workshop personnel against electric shocks

    Safety instructions in the vehicle

    Training of workshop personnel

    Requirements of workshops

11. Safety when transporting the vehicle – towing
12. Safety instructions for emergency services

Xcellsis provided the fuel cell technology to the Eurobus project. Design features incorporated to maximise safety include:

- Physical separation of high voltage wiring from fuel components, wherever possible.
- Critical hydrogen components installed out of designated crash zone (1.1m above ground, 0.4m inboard).

- Structural integrity of roof structure similar to CNG bus.
- 10g fore-aft, 5g lateral, 4.5g vertical acceleration load requirements.
- Protection provided for storage tanks (not detailed).
- Tanks and piping certified to 350 bar operating pressure.
- Bus meets technical aspects of UNECE Regulation 100 and Directive 73/23/EEC for protection against electrical shock.
- High voltage cable runs are minimised and cables are double insulated and shielded.
- To minimise risk from escaping hydrogen, components are mounted on the roof, with hydrogen lines separated from air intake lines as far as possible.
- Leak detectors and excess flow valves are fitted throughout the system.
- When purging the system (to eliminate water and impurities from the fuel cell) a hydrogen purge dilution system is fitted to ensure purged fuel is exhausted below the lower flammability limit.
- Parking hydrogen vehicles indoors:
    - Prevent the formation of ignitable concentrations of hydrogen
        - Eliminate the possibility of hydrogen being leaked within a facility
        - Increase the ventilation rate to diffuse leaked hydrogen to well below its flammable limit
- Remove all sources of ignition in proximity to the hydrogen system including:
    - Electrical systems, eg. Lighting and power outlets
    - Infrared eg. fuel-fired heaters
    - Spark-producing operations, eg. Welding, grinding
    - Personnel activities, eg. No smoking

A.2.7 Discussion

Safety has been investigated by many organisations using a combination of testing and numerical simulation methods. In all circumstances identified, only systems which are compliant or exceeding the standards currently available (such as ISO requirements for pressure vessels) were considered. The consequence of this is that the safety assessments do not identify the implications of a hydrogen system which is of a lower standard. It may be possible for such a system to be introduced if comprehensive legislation is not introduced and the additional risks cannot be quantified at this time.

If the hydrogen system is designed and constructed to a sufficient standard it has been found that:

1. When hydrogen is leaked in a controlled way from a storage system it is considered to be no more dangerous than gasoline or natural gas. Hydrogen has much wider flammable and detonation ranges than the alternatives, but also has a lower energy density, a higher lower flammable limit and dissipates much faster.
2. In experiments it took as long for a properly designed hydrogen tank to vent in a vehicle fire as it took for the seals on a gasoline tank to fail.
3. There was no evidence of the hydrogen tanks used in any of the reported experiments exploding. This was due to their design and the incorporation of pressure relief valves.
4. Tests concluded that properly designed tanks are capable of withstanding the energy of regulation type vehicle impact. The integrity of hydrogen systems in high severity impacts

has not been quantified by research. There is no requirement for conventional fuel systems to be designed to survive higher severity impacts, but the consequences of such impacts is well known. The effect of placing hydrogen systems in such high severity impacts is not known. It has been assumed that hydrogen systems follow the same relationship as conventional systems with regards to risk at in higher severity impacts. Further research would be required to determine the accuracy of this assumption.

Normal venting and liquid hydrogen boil-off will lead to critical levels of hydrogen in an enclosed space. However, the ventilation from the gaps around the door in a typical garage was found to be sufficient to provide enough air transfer to remain below critical levels. High rate leakages in tunnels and multi-storey and underground car-parks were found to rarely exceed critical levels due to the high diffusion coefficient of hydrogen.

Therefore, it can be concluded that a hydrogen fuel system which is designed and constructed to standards equivalent to those implemented in existing research would have no significant safety disbenefit compared to conventional hydrocarbon fuelled vehicles. Due to a lack of research the risks from the introduction of unregulated hydrogen systems are unknown.

Annex B List of literature reviewed

Automotive and Parts, *Hydrogen powered vehicles- face to face interview with Dr. Rosa T. Young*, Industry & Economics, 16 March 2006

Breakthrough Technologies Institute (2003). *Fuel cells and hydrogen: the path forward*, January 2003

Clean Urban Transport for Europe (CUTE), *Summary of achievements*

DaimlerChrysler, *New technology brochure*

DaimlerChrysler, *Progress in hydrogen fuel cell powered vehicles in action*, 2006

DaimlerChrysler AG, *FCs and alternative powertrains* (EP/FAB), by Dr. Dietmar Beck

Derwent, D. *Environmental impacts of* H_2, July 2004

Derwent, R. *Global warming consequences of a future hydrogen economy*, 2004

Derwent, R., *Global warming consequences of a future hydrogen economy*, The Royal Society of Chemistry, 2004

DTI, *Our energy challenge- securing clean, affordable energy for the long-term*,

Dutton, D G, *Working Paper No. 17*, April 2002. Energy Research Unit (ERU), CLRC Rutherford Appleton Laboratory, Tyndall

Dutton, G. *UK hydrogen futures to 2050- The THESIS model*, July 2004

Ecological City Transport System (ECTOS), *An approach to socio-economic & environmental studies accompanying a demonstration of a public transport system using fuel cells and hydrogen as a fuel and running a commercial hydrogen fuel station*, December 2002

Ecological City Transport System (ECTOS), Contract: EVK4-CT-2000-00033, April 2003

Ecological City Transport System (ECTOS), Contract: EVK4-CT-2000-00033, July 2005

Ecological City Transport System (ECTOS), Contract: EVK4-CT-2000-00033, February 2005

Ecological City Transport System (ECTOS), Contract: EVK4-CT-2000-00033, delivery 11, 2004

Ecological City Transport System (ECTOS), Contract: EVK4-CT-2000-00033, delivery 12, 2004

Ecological City Transport System (ECTOS), Contract: EVK4-CT-2000-00033, delivery 17, 2006

Ecological City Transport System (ECTOS), Contract: EVK4-CT-2000-00033, delivery 19, 2006

Ecological City Transport System (ECTOS), Contract: EVK4-CT-2000-00033, delivery 4, 2003

Ecological City Transport System (ECTOS), Contract: EVK4-CT-2000-00033, delivery 7, 2003

European Commission, *Hydrogen energy and fuel cells*, 2003

European Hydrogen and Fuel Cell Technology Platform, *European vision for the 7th FP and the relevant R&D&D strategy*, Feb 2006

European Hydrogen and Fuel Cell Technology Platform, *Joint Technology Initiative Process update at EU level*, Feb 2006

European Hydrogen and Fuel Cell Technology Platform, *Strategic overview*, June 2005

European Integrated Hydrogen Project-Phase 2 (EIHP2), *Final technical report*, April 2004

European Integrated Hydrogen Project-Phase 2 (EIHP2), *Safety*, March 2003

Fuel Cell Today, *Fuel cell and hydrogen activity: Europe and Japan*, January 2006

Fürst, S, Dub, M, Gruber, M, Lechner, W and Müller, C (2005) *Safety of hydrogen-fuelled motor vehicles with IC engines*. Paper presented at the International Conference on Hydrogen Safety, Pisa, Italy, 8-10 September 2005

Hennessey, B et al (2005) *NHTSA's four year plan for hydrogen fuel cell and alternative fuel vehicle safety research.* Paper 05-0034 of the International Conference on Hydrogen Safety, Pisa, Italy 8-10 September 2005

Hormandinger, G, N. and Lucas, J D. *Is clean enough? The influence of environmental externalities on markets for fuel cells in transport*, January 1996

HyCARE, *Hydrogen energy, chances and risk for the environment,* December 2004

HYWays, *Assumptions, visions and robust conclusions from project Phase 1*,

IEA , *World Energy Outlook 2004*. International Energy Agency, Paris, France.

IEA , *World Energy Outlook 2005: Middle East and North Africa Insights*. International Energy Agency, Paris, France.

IEA, *Hydrogen production and storage*, 2006

IEC, *Fuel cell technologies*, 2006

IEE, *Fuel cells- an energy and environment fact file*, January, 2003

ISO, *Business plan- hydrogen technologies*, September 2004

ISO, *Cooperation between the UN-ECE/GRPE and hoc WG on Hydrogen vehicles- onboard storage systems and ISO*, November 2002

ISO, *Daily use of hydrogen: safety, codes and regulations*, 2003

Johansson, B, and M. Ahman (2002), *A comparison of technologies for carbon-neutral passenger transport*. Transportation Research, Part D, v 7, n 3 pp 175-96

Kentzler, M, *Decision makers' progress in hydrogen infrastructure*, March 30 2006. DaimlerChrysler

Letters, Science, Vol 302, 21 November 2003,

Maack, M H, *Implementing the hydrogen economy*, November 2004

McConnell, V P, *Finding safe heaven in hydrogen and fuel cell systems*

Mituishi , H, Oshino, K and Watanabe, S. *(2005). Dynamic crush test on hydrogen pressurized* cylinder. JARI Research Journal Vol. 27, No. 7. (2005)

Mukai , S, Suzuki, J, Mitsuishi, H, Oyakawa, K and Watanabe, S. (2005). *CFD simulation of diffusion of hydrogen leakage caused by fuel cell vehicle accident in tunnel, underground parking lot and multistory parking garage*, Proceedings 19th International Technical Conference on the Enhanced Safety of Vehicles. Paper Number 05-0293 (2005).

Musil, D, *Fuel cells- current status and prospects for the future*, 30 March 2006. Ballard Power Systems,

Neue Strasse 95, 73230 Kirchheim/Teck-Nabern, Germany

OECD, *Special Issues on climate change- climate change policies: recent developments and long term issues*, 2003

Panagiotis, G and Sonke, B, *Development of sustainable urban transport system investigation (SUSI)- a decision support system for the usage of alternative fuels in public transportation*, 2005

Pridmore and A.L. Bristow, Institute for Transport Studies University of Leeds and Tyndall Centre for Climate Change Research, *Tyndall Working Paper No. 19*, April 2002

Rosyid, O.A., *System-analytic evaluation of the hydrogen cycle for energetic utilization,* Otto-von-Guericke-University Madgeburg, Germany, 2006

Shell, *Safety considerations in retailing hydrogen*, November 2002

Tyndall Centre *Technical Report No. 18*, January 2005

Tyndall Centre, *Hydrogen energy technology*, April 2002

Tyndall Centre, *The development of large technical systems: implications for hydrogen*, March 2002

Tyndall Centre, *The hydrogen energy economy: its long-term role in greenhouse gas reduction*, January 2005

Tyndall Centre, *The hydrogen energy economy: its long-term role in greenhouse gas reduction*, January 2005

Tyndall Centre, *The role of hydrogen in powering road transport*, April 2002

Tyndall Centre, *UK hydrogen futures to 2050*, February 2004,

UKERC, *Report on the ESRC/UKERC Seminar on the future economics of hydrogen*, February 2006

USFCC, *Fuel Cells for Mobility*, 2005

Van Mierlo, J.; Timmermans, J.-M.; Maggetto, G.; Van den Bossche, P.; Meyer, S.; Hecq, W.; Govaerts, L.; Verlaak, J. (2004) *Environmental rating of vehicles with different alternative fuels and drive trains: a comparison of two approaches*. Transportation Research, Part D: Transport and Environment. Vol. 9D, no. 5, pp. 387-399. Sept. 2004

Watanabe, S, Tamura, Y and Suzuki, J.(2005) *The new facility for hydrogen and fuel cell vehicle safety evaluation*. Paper presented at the International Conference on Hydrogen Safety, Pisa, Italy, 8-10 September 2005.

Internet sources:

US DoE (2006). http://www1.eere.energy.gov/hydrogenandfuelcells/did_you_know.html

http://www.msm.cam.ac.uk/doitpoms/tlplib/fuel-cells/pem_efficiency.php

http://physchem.ox.ac.uk/MSDS/glossary/autoignitiontemperature.html

http://physchem.ox.ac.uk/MSDS/glossary/flammable_limit.html

http://www.galcit.caltech.edu/EDL/projects/JetA/Glossary.html

http://www.galcit.caltech.edu/EDL/public/flammability.html

http://www.diracdelta.co.uk/science/source/d/i/diffusion%20coefficient/source.html

http://www.diracdelta.co.uk/science/source/f/i/ficks%20laws/source.html

http://www.hydrogenassociation.org/index

Annex C Review of legislation

This section reviews a number of standards and regulations for hydrogen vehicles which have been implemented or proposed around the world. Current EU Directives which would require modification to allow compliance of hydrogen vehicles have also been identified.

The draft proposal for an EU regulation (European Commission 2006i) is planned to have the same technical requirements as the proposed UNECE regulations (2003a, 2003b) described below. The United Nations Economic Commission for Europe (UNECE) hosts the World Forum for Harmonization of Vehicle Regulations (WP 29), which includes a Working Party on Pollution and Energy (GRPE). This group has developed separate proposed regulations for vehicles using liquid and compressed gaseous hydrogen.

The technical requirements of the proposed UNECE regulations are incorporated in the Preliminary draft proposal for a Regulation of the European Parliament and of the Council relating to the type-approval of a hydrogen powered motor vehicle.

C.1 UNECE Proposal for a new draft regulation (TRANS/WP.29/GRPE/2003/14):

Uniform provisions concerning the approval of specific components of:

1. Specific components of motor vehicles using liquid hydrogen
2. Vehicle with regard to the installation of specific components for the use of liquid hydrogen

This regulation applies to the installation of specific components integrated in the hydrogen system of M and N category vehicles. It sets requirements for:

- Hydrogen containers
- General components
- Pressure relief devices
- Lines incorporating pressure relief devices
- Hydrogen valves
- Heat exchangers
- Fuelling connections or receptacles
- Pressure regulators
- Sensors
- Flexible fuel lines

This regulation is extensively based on existing standards and regulations, particularly those produced by the European Committee for Standardization (CEN standards).

- The hydrogen storage container must be designed in accordance with the CEN for cryogenic vessels, which sets out design rules.
- The materials, welding operations and chemical compatibility requirements are based on CEN standards.
- Pressure and leakage tests are defined
- The container must resist fire for five minutes, however the test conditions are not defined

Components in contact with hydrogen are required to meet ISO standard for hydrogen compatibility. Additionally, components in contact with cryogenic temperatures should meet standards for this use.

Components are required to have a maximum allowable working pressure (MAWP) at least 1.5 times the set pressure of the upstream pressure relief device.

- Pressure relief devices - CENs and pressure & temperature requirement
- Hydrogen valves – CENs and pressure & temperature requirement
- Heat exchangers – pressure & temperature requirements
- Fuelling connections or receptacles – CENs and pressure & temperature
- Pressure regulators – temperature & pressure
- Sensors – temperature & pressure
- Flexible fuel lines - CENs and pressure & temperature

There are specific requirements for the use of hydrogen within motor vehicles:

- The hydrogen system shall be installed such that it is protected against damage, such as damage due to moving vehicle components, collision, grit or due to the loading or unloading of the vehicle or the shifting of those loads.
- No component of the hydrogen system, including any protective materials that form part of such components, shall project beyond the outline of the vehicle.
- No component of the hydrogen system shall be located near the exhaust of an internal combustion engine or other heat source, unless such components are adequately shielded against heat.
- The ventilating or heating system of passenger compartments and places where leakage or accumulation of hydrogen is possible shall be kept apart so that hydrogen is not drawn into the vehicle.
- When the vehicle is ready for use the lowest part of the hydrogen container shall not reduce the ground clearance of the vehicle. This shall not apply if the hydrogen container is adequately protected, at the front and the sides and no part of the hydrogen container is located lower than this protective structure.
- A container shall be mounted so that no damage occurs when:

  M1 & N1: +/- 20g in direction of travel, +/- 8g perpendicularly

  M2 & N2: +/- 10g in direction of travel, +/- 5g perpendicularly

  M3 & N3: +/- 6.6g in direction of travel, +/- 5g perpendicularly

C.2 UNECE Proposal for a new draft Regulation (TRANS/WP.29/GRPE/2003/3):

Uniform provisions concerning the approval of specific components of:

1. Specific components of motor vehicles using compressed gaseous hydrogen
2. Vehicle with regard to the installation of specific components for the use of compressed gaseous hydrogen

14.1.11:

"*In the event of hydrogen leakage or venting, hydrogen shall not be allowed to accumulate in enclosed or semi-enclosed spaces*."

14.1.12:

"*Hydrogen components that could leak hydrogen and that are mounted within the passenger or luggage compartment or other non-ventilated compartment shall be enclosed by a gas tight housing ...*"

14.2.4:

"*A container shall be mounted so that no damage occurs when:*

M1 & N1: +/- 20g in direction of travel, +/- 8g perpendicularly

M2 & N2: +/- 10g in direction of travel, +/- 5g perpendicularly

M3 & N3: +/- 6.6g in direction of travel, +/- 5g perpendicularly

Valves and lines should be designed such that isolation valves minimise loss of fuel in the event of damage.

The electrical components of the hydrogen system shall be protected against overload.

Safety instrumented systems shall be fail-safe or redundant."

Annex 7A:

"*The service conditions do not include external loads that may arise from vehicle collisions, or integration of the container into the vehicle, etc. Containers need not be designed for continuous exposure to mechanical or chemical attack, e.g. leakage from cargo that may be carried on vehicles or severe abrasion damage from road conditions*"

Material, manufacturing, inspection. batches and testing of containers is design prescriptive, using existing CENs and ISO Standards.

There is testing of both materials and constructed containers.

Tests include:

- Bonfire – container at nominal working pressure subjected to 590^{o}C until pressure drops to 1MPa, without rupture
- Penetration – container at nominal working pressure has at least one sidewall penetrated by an armour piercing bullet, without rupture
- Impact damage (some containers only). The follow sequence must not result in rupture
  - Dropped from horizontal at 1.8m
  - Dropped on each end from at least 1.8m
  - Dropped at 45^o angle with CoG at 1.8m
  - Should be allowed to bounce
  - Pressure cycled between <2MPa and 1.25 nominal working pressure for three times the calculated number of filling cycles

C.3 Review of type-approval Directives

Existing type-approval documents have been reviewed to determine whether amendments will be required to allow the use of hydrogen fuelled vehicles.

70/156/EEC (and subsequent amendments) on the approximation of the laws of the Member States relating to the type-approval of motor vehicles and their trailers

To be granted type-approval a vehicle must meet the technical requirements of the appropriate Directives listed within the top-level Directive.

Article 8 of the Council Directive No 98/14/EEC (amendment of Directive 70/156/EEC) includes exemptions for new technologies or concepts incompatible with separate directives. In this case, the Member State should provide a report containing:

- The reason why the technologies prevent the vehicle or component from complying with the requirements of the relevant(s) Directive(s)

- A description of the areas of safety and environmental protection concerned and the measures taken
- A description of the tests and their results that demonstrate at least an equivalent level of safety and environmental protection as is provided by the requirements of one or more of the relevant separate Directives
- Proposals for amendments to the relevant separate Directives or new separate Directive(s) as applicable.

This clause may allow for new technologies, such as hydrogen vehicles, to obtain type approval if the requisite level of safety can be demonstrated to the type-approval authority.

Directive 70/156/EEC contains the documentation which must be completed for type-approval. This documentation only makes provision for internal combustion / electric/ hybrid power sources so would need to be revised to allow fuel cell powered vehicles.

Below are the EC Directives which are required by the type-approval Directive and which could be relevant to hydrogen powered vehicles.

70/220/EEC: Emissions

Relates to measures to be taken against air pollution by gases from positive-ignition engines of motor vehicles in the M and N classes.

2005/55/EC: Emissions (M and N class)

Vehicle emissions are assessed under a number of test conditions to ensure that they are within the prescribed levels. The Directive has been updated to make provision for liquefied petroleum gas (LPG) and natural gas (NG) powered vehicles

Methods of testing emissions appropriate to hydrogen vehicles may need to be included. Alternatively, an exemption from emissions testing may be appropriate for hydrogen vehicles.

70/221/EEC: Fuel tanks/ rear protective devices (M and N class)

This Directive prescribes tests that must be performed to prove the integrity of the fuel tank and system. Provision is only made for tanks for liquid fuel, where "*'Liquid fuel', means a fuel which is liquid in normal ambient conditions*."

LPG and CNG vehicles are not covered by this Directive, but are required to meet the requirements of UNECE Regulation 67 or 110 (described later). 70/221/EEC is not appropriate for hydrogen vehicles and would need to be modified accordingly.

72/245/EEC: EMC (M and N class)

The EMC Directive specifies the requirements relating to the radio interference (electromagnetic compatibility) of vehicles. Hydrogen vehicles should be required to meet the same EMC standards. This Directive may require revision to ensure that all parts of the system are considered.

80/1269/EEC: Engine power (M and N class)

This Directive prescribes the test that must be performed to determine the power of an internal combustion engine. The Directive has been amended to include provisions for NG and LPG fuelled vehicles, but would require further modification to allow hydrogen fuelled internal combustion engines.

93/91/EEC: Interior fittings of motor vehicles (identification of controls)

The Directive details the symbols which shall be used to display warnings and information to the driver. This Directive would not need to be changed to allow the introduction of hydrogen vehicles, however, standardised symbols related to the hydrogen system may be useful once the systems become more prevalent.

96/27/EC: Side impact and **96/79/EC: Frontal impact (M1 class only)**

The side and frontal impact Directives contain the same requirement for the maximum rate at which fuel can leak after the impact test is conducted, section 3.3.5 and 3.2.6 in the side and frontal Directives respectively. The fuel tank must be at 90% of the full load mass for the test.

"*The fuel tank must be filled with water up to 90% of the mass of a full load of fuel as specified by the manufacturer with a ±1 % tolerance*."

"*In the case of a vehicle propelled by liquid fuel, no more than slight leakage of liquid from the entire fuel system may occur during or after the impact. If after the impact there is continuous leakage of liquid from any part of the fuel system, the rate of leakage must not exceed* 5×10^{-4} *kg/s; if the liquid from the fuel-feed system mixes with liquids from the other systems and the various liquids cannot easily be separated and identified, all the liquids collected are taken into account in evaluating the continuous leakage*."

A leakage rate for fuels which are gaseous at ambient conditions is required as there is no maximum acceptable leakage rate at present. A more appropriate fluid, such as helium, for filling the tank before the test is also required.

2001/85/EC (vehicles with eight or more seats in addition to the driver's seat):

There is a stability test for vehicles with more than eight passenger seats. The vehicle is positioned on a tilt table which is then tilted to 28 degrees from the horizontal. This test requires mass equivalent to each passenger to be fitted in the vehicle, and where the vehicle is equipped to carry luggage on the roof equivalent mass must be fitted. No provision is made for vehicles with fuel storage on the roof, so there is no requirement on the quantity of fuel that must be in the tank(s). This may need to be modified to ensure that the vehicle is tested in its most onerous operating condition.

Adherence to equivalent UNECE Regulations is a recognised alternative to compliance with Directives. These regulations also contain some additional requirements which must be met by the appropriate vehicle types.

2004/3/EC: carbon dioxide emissions and fuel consumption

Vehicle fuel consumption and carbon dioxide emissions are assessed under test conditions. This Directive has been updated to make provision for liquefied petroleum gas (LPG) and natural gas (NG) powered vehicles. Methods of testing hydrogen vehicles would need to be devised and incorporated within this Directive.

2005/64/EC: Recyclability

The proportion of a vehicle which must be recoverable, reusable or recyclable is detailed within this Directive. It may be necessary to consider whether the proportions which are currently set for conventional vehicles should also be applied to hydrogen powered vehicles. The Directive also contains a list of components which are deemed to be non-reusable which may need to be amended to include some components of the hydrogen system, such as the safety critical parts.

C.4 UNECE Regulation 66: Strength of superstructure (for carriage of >22 passengers)

This Regulation applies to single-deck large passenger vehicles to ensure that the superstructure is strong enough to protect the passengers in the event of rollover. Three routes are available to meet the requirements of this regulation; full vehicle rollover test, rollover test on representative body section or numerical methods. The alternative methods are designed to reduce costs in this low-volume production sector, without reducing safety. The Regulation states:

"The basic principle is that the equivalent approval test method must be carried out in such a way that it represents the basic rollover test specified in Annex 5. If the equivalent approval test method chosen by the manufacturer cannot take account of some special feature or construction of the vehicle (e.g. air-conditioning installation on the roof, changing height of the waist rail, changing roof height)

the complete vehicle may be required by the technical service to undergo the rollover test specified in Annex 5."

Some of the hydrogen powered buses currently in use have the fuel system fitted to the roof of the vehicle. It would be necessary for such buses to undergo a full vehicle test.

It may also be necessary to include an assessment of the integrity of the fuel system after the rollover test to ensure that it leakage would not occur under such conditions.

C.5 UNECE Regulation 67: LPG vehicles and UNECE Regulation 110: CNG vehicles

UNECE Regulations 67 and 110, for LPG and CNG are analogous to the requirements included in the proposed UNECE Regulations relating to hydrogen systems which store fuel in either the liquid or gaseous phases. Both of these regulations are design prescriptive in parts using ASTM (American Society for Testing and Materials), BS, CEN and ISO standards extensively to dictate materials and construction types that can be used. For instance, Regulation 67 has a requirement on the shape of the torispherical ends on the storage container, wall thickness, weld position, weld type and material specification. Regulation 110 does not place requirements on the container shape, but retains requirements for the materials.

In addition to the generic pressure vessel requirements, both Regulations contain the following (Section 17.4):

When the vehicle is ready for use the fuel container shall not be less than 200 mm above the road surface.

The fuel container(s) or cylinder(s) must be mounted and fixed so that the following accelerations can be absorbed (without damage occurring) when the containers are full:

Vehicles of categories M1 and N1:

(a) 20 g in the direction of travel

(b) 8 g horizontally perpendicular to the direction of travel

Vehicles of categories M2 and N2:

(a) 10 g in the direction of travel

(b) 5 g horizontally perpendicular to the direction of travel

Vehicles of categories M3 and N3:

(a) 6.6 g in the direction of travel

(b) 5 g horizontally perpendicular to the direction of travel

A calculation method can be used instead of practical testing if its equivalence can be demonstrated by the applicant for approval to the satisfaction of the technical service.

There is no requirement on the duration which the acceleration must be applied for, or what type of test should be used.

The acceleration levels are consistent with those applied in the LPG and CNG regulations.

No evidence supporting the selected acceleration levels was identified. The acceleration levels applied are lower than can be experienced within many crash situations, e.g. peak B-pillar acceleration in EuroNCAP frontal impacts are often greater than 30g. The EuroNCAP test set-up was selected as being representative of a ‘typical’ accident, therefore it can be concluded that in a significant proportion of impacts the system will be subjected to a higher deceleration.

Vehicles which are subject to the frontal or side impact Directives will be exempt from the acceleration test. Initially hydrogen vehicles may be in low production volumes which are exempt from the impact tests.

C.6 Society of Automotive Engineers (SAE International)

SAE International has produced a document *J2578 Recommended Practice for General Fuel Cell Vehicle Safety* which is intended to provide introductory mechanical and electrical system safety guidance when designing fuel cell vehicles on public roads.

The SAE guidance document is supplemented by an extensive list of other documents including; SAE publications, Federal Motor Vehicle Safety Standards (FMVSS), International Electrotechnical Commission (IEC), and ISO publications, among others.

The guidance outlines general vehicle design issues which must be considered such as electromagnetic compatibility and design for safety:

"*4.1.1.2 Isolation and Separation of Hazards – Isolation and separation of hazards are approaches used to prevent cascading of failures and preclude unwanted or unexpected interactions. Ignition sources should be isolated from hazardous fluid systems*."

"*4.1.1.3 Critical Control Function – Safety-critical control systems should be designed such that a single hardware or software failure will not cascade into a hazardous condition. This may include isolation, separation, redundancy, supervision, and/or other means*."

The guideline suggests that a fuel cell vehicle should meet applicable regulatory requirements for crashworthiness. With regard to fuel system integrity it is recommended that FMVSS 301 (Fuel System Integrity) and FMVSS 303 (Fuel System Integrity for CNG) be used as the basis for tests. These standards require the following impacts to be conducted:

- Frontal collision into fixed barrier at 30mph (48 kph)
- Rear impact from a moving barrier at 30mph (48 kph
- Lateral impact on either side at 20mph (32 kph)
- Contoured barrier impact at 30mph (48 kph)

For vehicles using liquid fuel FMVSS 301 is applied. During the tests the fuel tank is filled with water (or an equivalent non-flammable fluid) and must not leak more than "one ounce [28 grams] of fluid per minute" after the impact.

For compressed hydrogen, J2578 suggests the following modified version of FMVSS 303 (these modifications are to be more representative of a hydrogen fuel system rather than natural gas):

- Tests conducted with fuel storage container filled with helium to service pressure
- For 60 minutes after the above impacts the pressure drop in the system must not exceed the higher of:
    - 5.2% of service pressure

    or

    - 2640kPa for a system pressure of 24820kPa
    - 2800kPa for a system pressure of 34470kPa
    - 3730kPa for a system pressure of 68950kPa

Under the above impacts the automatic fuel shutoff(s) and electrical disconnect(s) should be actuated.

J2578 also suggests that the hydrogen fuel system design should:

- have a fail safe shutoff to prevent discharge due to single point failure
- manage potentially flammable atmospheres
- manage potential ignition source in flammable atmospheres
- be monitored for any system failure

Fuel cell vehicles typically contain high voltages so the system design should consider:

- high voltage wire
- high voltage connectors
- high voltage isolation
- high voltage dielectric withstand capability
- access to live parts
- system fault monitoring

Hydrogen discharge from the vehicle during normal operation should be such that the surroundings do not reach 25% of the lower flammability limit. Discharges should be less than 50% of the lower flammability level at the point of release from the vehicle. A monitoring system should be installed to confirm the discharges are not above this level. The discharges into the passenger and other compartments also must not result in 25% of the lower flammability limit being reached.

C.7 Japanese Regulations

In March 2005, the Japanese authorities issued revisions to their vehicle regulations to make provision for hydrogen powered vehicles. The Regulations which have been amended or introduced are listed in Table C1.

Table C1: Japanese safety regulation that applies to motor vehicles

Article	Content
11-1-1	Announcement that prescribes details of safety regulations for road vehicles
11-1-2-1	Details of safety regulations that apply to designated motor vehicles; newly used for operation
11-1-2-2	Details of safety regulations that apply to motor vehicles, except for designated motor vehicles
11-1-2-3	Details of safety regulations that apply to in-use motor vehicles
11-1-3-1	Details of safety regulations that apply to type-approved motor-driven cycles to be newly used for operation
11-1-3-2	Details of safety regulations that apply to motor-driven cycles to be newly used for operation, except for type-approved motor-driven cycles
11-0-1-3	Destructive testing
11-0-1	Definition of terms
11-0-17-2	Electrical system
11-1-4-17	Technical standard for fuel leakage in collisions
11-1-4-38	Measurement procedure for proximity stationary noise level
11-1-4-84	Technical standard for windshield wiping and washing systems for passenger motor vehicles
11-1-4-86	Technical standard for defrosting and demisting systems
11-1-4-100	Technical standard for fuel systems of motor vehicles fuelled by compressed hydrogen gas
11-1-4-101	Technical standard for protection of occupants against high voltage in fuel cell vehicles

In addition to the modifications to existing regulations, two new documents have been introduced which provide additional information for hydrogen systems. The most important features of these new regulations are outlined below.

Attachment 100: Technical Standard for fuel systems of motor vehicles fuelled by compressed hydrogen gas.

- Applies to fuel system – hydrogen system, fuel cell system, and other parts related to fuel as well as power generation by the fuel in fuel cell vehicles. Whilst fuel cell systems are specified this standard also applies to systems which use an internal combustion engine powered by hydrogen.
- The container must meet the specification of the *Safety Regulations for Containers*.
- The main supply valve which stops supply from each gas container must be operable from the driver's seat and must fail safe in the event of power disruption.
- There must be a pressure relief valve which must not emit into the passenger compartment or towards electrical sources.
- Gas containers, piping, etc, shall not be placed in the passenger compartment, luggage compartment or other places where ventilation is not sufficient, unless specific conditions are met.
- The container must be secured in such a way to prevent movement or damage under acceleration. The acceleration, the highest of which is 20g, is dependent on vehicle mass and number of passengers. The attachments have to survive a lower acceleration level.
- For impact testing the container must be filled with helium to at least 90% of the general-use pressure. Temperature and pressure to be monitored for 60 minutes after collision and leakage rate must be below 131NL [normal litres] per minute.
- At least one hydrogen gas leakage detector which warns the driver shall be installed. The location of the detector is specified.
- The system shall be subjected to an airtightness and ventilation test, purged gas test, and leakage detector test.

Attachment 101: Technical Standard for protection of occupants against high voltage in fuel cell vehicles.

- Provides technical regulations for protection against electrical shock for fuel cell vehicles and applies to the entire power train where the voltage is greater than 60V DC.
- All energised components shall have solid insulation, barrier or enclosure. To protect against indirect contact barriers and enclosures must be attached to ground.
- There must be a device to monitor the insulation resistance which must warn the driver if the insulation resistance drops below a preset value.
- There must be a device to cut off the power supply before any current leakage reaches a level dangerous to the human body.
- The system shall be tested for protection against direct contact with components, insulation resistance, the function of the monitor for insulation resistance, and leakage shut-off.

C.8 ISO Standards for hydrogen vehicles

The International Organization for Standardization (ISO) established Technical Committee 197 which is concerned with standardisation in the field of systems and devices for the production, storage, transport, measurement and use of hydrogen. Operating below the technical committee are a number of working groups, including:

- WG 1: Liquid hydrogen - Land vehicles fuel tanks
- WG 5: Gaseous hydrogen - Land vehicle filling connectors
- WG 6: Gaseous hydrogen and hydrogen blends - Land vehicle fuel tanks
- WG 10 : Transportable gas storage devices - hydrogen absorbed in reversible metal hydride

Technical Committee 22 for road vehicles has a sub-committee for electrically propelled road vehicles, which has produced standards for hydrogen fuel cell vehicles.

Several standards have been developed by these technical committees, the most relevant of which are detailed below.

ISO 13984:1999 Liquid hydrogen – Land vehicle fuelling system interface

The standard specifies the requirements to ensure that the refuelling systems on a vehicle are designed to minimise the risk of fire and explosion. Nine other ISO Standards, which cover inspection, examination and testing of cylinders, tubes and joints, are referred to in this standard.

Piping which comes into contact with liquid hydrogen must be austenitic stainless steel, or a material proven to be equivalent in performance.

Piping, valves, fittings, gaskets and sealants shall be suitable for liquid and cold gaseous hydrogen service.

Permanent joints must be welded or brazed.

The burst strength of all pipes, valves, fittings and hoses shall be at least four times the design pressure of the storage tank and at least four times the pressure they will be subjected to in normal service.

Formulae for deriving the pipe section thickness are given.

Formulae for calculating the effect of thermal cycling on the fatigue life are given.

A pressure-relief valve must be fitted to any part of the system that can be isolated by valves and must discharge at or below the design pressure of the section. The pressure relief valves must be tested and set point tested at least every 30 months.

ISO 23273-1:2006 Fuel cell road vehicles – Safety specification – Part 1: Vehicle functional safety

This is a standard which provides an overview of the environmental and operational features required from the system. The issues are mainly related to the fuel cell system, however, all aspects of the hydrogen fuel system would need to be compliant.

Environmental and operational conditions:

- Requirement that all electrical assemblies on fuel cell vehicles, which could effect safe operation of the vehicles, should be tolerant of electromagnetic compatibility (EMC).
- Should not emit electromagnetic emissions above national or international standards.

Operational safety:

- a main switch, accessible and operable by the driver, to disconnect power and shut off fuel supply
- two deliberate and distinct actions to go from off to drivable
- one action to go from drive to off
- driver should be notified when the power system is ready for driving
- Switching between forward and reverse shall require either two separate actions or one if it can only occur at stop or low speed

- Crashworthiness of vehicle should meet applicable standards
- Electric and hazardous fluid systems should fail safe
- Systems should be such that shutdowns can be performed safely when faults are detected that could lead to hazardous conditions

ISO 23273-2:2006 Fuel cell road vehicles – Safety specifications – Part 2: Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen

This standard applies to fuel cell vehicles which are fuelled by compressed hydrogen. SAE J2578 (described above) is recommended as guidance throughout this standard.

The fuel system shall be equipped with:

- a fire protection system incorporating one or more temperature-triggered pressure relief device
- a main hydrogen shut-off valve that shall be closed when the energizing power to the valve is lost, and which shall also be closed when the vehicle fuel cell system is not operating
- a hydrogen shut-off system
- an excess flow valve

Discharge into all vehicle compartments under normal operation and single failure conditions shall not lead to any hazardous conditions.

Hazard analysis in relation to hydrogen shall be performed considering primarily the interface between the components and systems, as established during assembly of the vehicles. This analysis may use an FMEA (failure mode and effect analysis), an FTA (fault tree analysis), or other appropriate method, and shall determine potential single hardware and software failures or conditions which could form a hazard. These methods are well established in analysis of electrical and electronic systems.

ISO/TR 15916:2004 Basic considerations for the safety of hydrogen systems

This is a general technical report which covers safety issues concerned with gaseous and liquid hydrogen in all applications. It highlights many of the general issues which need to be considered when developing a hydrogen system, such as fire, explosion, pressure hazards, embrittlement, and health hazards.

C.9 Legislation issues

C.9.1 European-wide vs national regulation

Within the EU, policy can be introduced at either EU level or by individual member states. This corresponds to Options 2 and 3, respectively, within this Impact Assessment. If implemented at EU level a new EU Regulation would be adopted and existing Directives and Regulations which are affected would be amended.

One of the major complications of individual member states introducing their own legislation is incompatibility of requirements between countries. For instance, in the first phase of the EIHP project it was concluded that it "is very clear that it is impossible to meet all the requirements of each country with a single vehicle design. [Example: The automatic shut off valve for the BMW CNG vehicle was placed according to German law at the safest place in the vehicle, which is outside the passenger compartment, below the vehicle floor, but above the rear axle. This was not acceptable for the authorities of the Netherlands. They require the safety valve to be mounted directly onto the CNG container. A particular requirement for the crash protection of this important safety valve in the Netherlands however does not exist.]." Such national variations would prove to be a serious barrier to mass introduction of hydrogen vehicles, because different designs could be required for all countries the vehicles are to be sold in. The cost of producing multiple designs would also be much higher.

The position of industry on the matter of legislation is demonstrated by Fürst (2005) who reported the opinion of BMW that “All hydrogen vehicles should comply with these standards. The relevant activities have already been commenced all over the world. It is important for the activities currently being undertaken in the USA, Japan and Europe to be coordinated and unified. Hydrogen safety must not prove to be a differentiating competitive feature.”

The literature review (Annex A) identified that the current understanding of hydrogen fuel safety is based on systems meeting requirements equivalent to the existing or proposed legislation. The risks of systems which do not meet this level of protection have not been assessed previously.

C.9.2 Design-based vs performance-based legislation

The considered view is that hydrogen safety should be covered by some form of regulation. Standards and regulations can be implemented using one of two possible approaches. Standards and regulations can either be ‘design based’ or ‘performance based’ or a combination. Design based standards specify exactly how the regulation must be met. Performance based regulation specifies only the required outcome, which provides freedom to design different ways to achieve that outcome. In general, the majority of UNECE and EC regulations tend to be performance based, to permit innovations where possible. Standards such as ISO tend to be highly design prescriptive.

The existing UNECE regulations for LPG and CNG vehicles are Regulations 67 and 110 respectively. These Regulations use a combination of design and performance based criteria. Material specifications are given for acceptable storage container materials and required components. However, in these Regulations the fuel storage tank must also pass a series of performance tests.

It is expected that design based regulations can be implemented more quickly as it may take more time to set out the requirements in a performance based regulation. Performance based regulations may require that new test methods be developed.

Design based regulation can be limiting, preventing an alternative design or specification that could give better performance. New technology, which was not suitable when the regulation was introduced, may offer benefits beyond the requirements. When such developments occur, it is necessary for the regulation to be updated. Alternatively, local approval authorities may be given authority to grant approval, if a new technology is shown to be of equivalent performance. The granting of local approval can, however, lead to inconsistencies in what is deemed to be of equivalent performance.

C.9.3 Discussion

The principal safety issues identified with hydrogen powered vehicles were identified in the literature review as:

- Fire / explosion
- Impact protection
- Release in enclosed area
- Bus specific issues
- General safety issues, e.g. high operating voltages and material embrittlement

All of the existing and proposed legislation attempts to address these safety issues.

The European Integrated Hydrogen Project (EIHP) reported that there is general agreement world-wide that the proposed UNECE regulations contains the necessary technical content, They have also been harmonised with ISO and SAE documents, while retaining the UNECE's performance-based requirements philosophy.

Annex D Questionnaire

Questionnaire on Legislative Options.
Sent to stakeholders involved in the H_2 Working Group

jleben@trl.co.uk
July 2006

Introduction

The European Commission has contracted TRL to prepare an assessment of the impacts of the introduction of hydrogen as a fuel for motor-vehicles. This 'Extended Impact Assessment' is focussed on safety, economic and environmental aspects.

This Questionnaire

The following questionnaire is designed to gather information regarding the costs and benefit of various regulatory options for the introduction of hydrogen powered vehicles. In particular, the safety, economic and environmental impacts of the various policy options will be assessed.

Please return this questionnaire to TRL at:
Name: Jure Leben
Email: jleben@trl.co.uk
Telephone: + 44 1344 770 0192

With a copy to the European Commission at:
Name: Ferenc Pekár
Email: Ferenc.Pekar@ec.europa.eu
Telephone: +32 2 29 81 334

If you wish to discuss this questionnaire, then please contact Jure Leben.

Responses given to this questionnaire will be treated confidentially. On Behalf of TRL Ltd and the European Commission, we would like to thank you for having taken the time to complete this questionnaire.

What Legislation will apply to Hydrogen Vehicles in Future?

The European Commission is considering three possible options for the legislation that will apply to hydrogen powered vehicles. These three options are described in the table below.

Option Number	Description of Option
Option 1	**'No Policy Change'** This would involve no further changes to vehicle legislation to accommodate the introduction of hydrogen vehicles.
Option 2	**'Legislation at EU level'** This would involve new type approval legislation at EU level, which would cover the safety of hydrogen vehicles. An EU Regulation would be adopted, and changes would be made to existing Directives that govern the construction and use of vehicles.
Option 3	**'Legislation at Member State level'** This would involve leaving individual member states to pass legislation to accommodate the introduction of hydrogen vehicles.

Commission comments on the three options

Option 1
This policy option could prove to be unacceptable, for example because:
(i) The technology and components needed in hydrogen vehicles might contravene the requirements of existing legislation, which would therefore prevent the introduction of hydrogen vehicles; or
(ii) Existing legislation may not provide adequate protection of the public.
Option 1 might in effect prove to be a barrier for the innovation and development of hydrogen technology for vehicles in the EU.

Option 2
In recent decades, legislation regarding the construction of road vehicles has been laid down within the framework of the EU type-approval system.

Assessment of option 2 will be focussed on the following issues:
(i) Effects on European automotive industry and research and development activities; (ii) Impact on the internal market of the European Union; and
(iii) Societal, safety and environmental impacts of such a measure.
If Option 2 were not adopted, there would need to be clear evidence that this would not adversely affect either:
(i) Safety; or
(ii) The internal market and costs. An adverse effect of not adopting this policy option might for example be an increase in the costs incurred by manufacturers in the approval and introduction of hydrogen powered road vehicles, or costs to businesses and consumers of purchasing and maintaining the vehicles.

Option 3

This policy option would potentially result in different legislative provisions in different Member States. It might also lead to the necessity of adopting legislation at the European level (policy option 2) at a later stage.

Assessment of Option 3 will focus on an assessment of the possible effects that this option might have on safety, the internal market and on research and development activities in the European Union.

Section 1: Questions about your Organisation

Question 1.1

Please provide contact details for your organisation in the space below.

Company Name and Address:

Name of contact person:

Email address:

Telephone number(s):

Question 1.2

Which of the following classes of vehicles do you either make or sell? Please provide ticks against each class in the box below.

M1: Passenger vehicles, comprising not more than eight seats in addition to the driver's seat.	
M2: Passenger vehicles, comprising more than eight seats in addition to the driver's seat, and maximum mass of 5t or less.	
M3: Passenger vehicles, comprising more than eight seats in addition to the driver's seat, and maximum mass exceeding 5t.	
N1: Goods vehicles having a maximum mass not exceeding 3.5t.	
N2: Goods vehicles having a maximum mass exceeding 3.5t but not exceeding 12t.	
N3: Goods vehicles having a maximum mass exceeding 12t.	

Question 1.3

Which of the following classes of hydrogen powered vehicles do you either make or sell? Please provide ticks against each class in the box below.

M1: Passenger vehicles, comprising not more than eight seats in addition to the driver's seat.	
M2: Passenger vehicles, comprising more than eight seats in addition to the driver's seat, and maximum mass of 5t or less.	
M3: Passenger vehicles, comprising more than eight seats in addition to the driver's seat, and maximum mass exceeding 5t.	
N1: Goods vehicles having a maximum mass not exceeding 3.5t.	
N2: Goods vehicles having a maximum mass exceeding 3.5t but not exceeding 12t.	
N3: Goods vehicles having a maximum mass exceeding 12t.	

Question 1.4

Has your organisation carried out safety or environmental impact analyses on hydrogen powered vehicles? Please provide ticks against each class in the box below.

M1: Passenger vehicles, comprising not more than eight seats in addition to the driver's seat.	
M2: Passenger vehicles, comprising more than eight seats in addition to the driver's seat, and maximum mass of 5t or less.	
M3: Passenger vehicles, comprising more than eight seats in addition to the driver's seat, and maximum mass exceeding 5t.	
N1: Goods vehicles having a maximum mass not exceeding 3.5t.	
N2: Goods vehicles having a maximum mass exceeding 3.5t but not exceeding 12t.	
N3: Goods vehicles having a maximum mass exceeding 12t.	

Question 1.5

On which classes of hydrogen powered vehicle has your organisation carried out crash or other safety tests? Please specify what kinds of tests have been carried out in the box below.

M1: Passenger vehicles, comprising not more than eight seats in addition to the driver's seat.	
M2: Passenger vehicles, comprising more than eight seats in addition to the driver's seat, and maximum mass of 5t or less.	
M3: Passenger vehicles, comprising more than eight seats in addition to the driver's seat, and maximum mass exceeding 5t.	
N1: Goods vehicles having a maximum mass not exceeding 3.5t.	
N2: Goods vehicles having a maximum mass exceeding 3.5t but not exceeding 12t.	
N3: Goods vehicles having a maximum mass exceeding 12t.	

Section 2: Questions about the safety implications of the three policy options

The questions in Sections 2-5 below are aimed at providing information on the safety, economic and environmental impacts of the various policy options concerning the introduction of hydrogen powered vehicles.

Please answer each question as accurately as possible, but we understand that some information may be too sensitive for you to be able to provide exact answers. However, please note that the responses will be treated confidentially.

The Tables under the answers in section 2, 3 and 5 are designed for you to enter three answers. This has been done **in case you consider that the answer is different for each option**. For example, would you incur different costs in designing hydrogen vehicles for differing national legal requirements, than for an EU wide requirement? The Table offers you the chance to provide different answers for each of the three options.

If you consider one or more of the options in this consultation to be unrealistic, we would welcome any comments that you can provide to support that view.

In your answers, please:
(i) Remember to think about all the vehicle classes N1, N2, N3, M1, M2, M3 for which you can provide information;
(ii) Think about all forms of hydrogen storage technology, e.g. gaseous, liquid, solid medium;
(iii) If your information relates to a specific vehicle class or specific form of hydrogen storage, then please make clear which class of vehicle or form of storage that is.
(iv) Where possible, try to highlight differences that will result from the three different options, rather than looking at the absolute impacts of hydrogen vehicles themselves. For example, in question 2.1 below, do the safety issues to be faced under the three options differ?

2.1. Have you identified any particular safety issues relating to hydrogen propulsion, e.g. when vessels, pipes, valves etc. are used with hydrogen? If so, what were they?

2.2. If there is any safety issue, how would the situation evolve according to the different policy options?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

2.3. How much attention was applied to safety considerations in the design and build of hydrogen vehicles? Please focus on vehicle handling and safety impacts.

2.4. How would these safety considerations evolve according to different policy options?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

2.5. Did these above mentioned issues affect the design, or was the design more oriented to functionality?

2.6. How would this situation evolve according to different policy options?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

2.7. Did the designers consider and assess the mass and Centre of Gravity affects in terms of vehicle handling, impact performance, in particular rollover? Please give details.

2.8. How would this situation evolve according to different policy options?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

2.9. Have the designers designed the hydrogen system for any sort of impact, such as may happen in a vehicle crash? If so, for what configurations and for what severities?

2.10. How would this situation evolve according to different policy options?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

2.11. Is the pipe work designed for any sort of impact, or is the cover structure designed to prevent damage to this pipe work?

2.12. How would this situation evolve according to different policy options?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

2.13. During the testing, was thermal or stress cycling assessment used on the hydrogen carrying components? If so, please specify details of the tests.

2.14. How would this situation evolve according to different policy options?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

2.15. Is the electrical system on the vehicle modified in any way to reduce risk of ignition? For example, petrol tankers require screened electrics, and also heat shielding on hot components.

2.16. How would this situation evolve according to different policy options?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

2.17. Most regulations tend to be performance based, with minimal design issues included as needed.

a) Do you think the preliminary proposal for an EU Regulation on hydrogen vehicles may be excessively design restrictive or constrain innovative design? If so, in what ways?
The EU Regulation is based on the UN/ECE documents TRANS/WP.29/ GRPE/2003/14 + Add 1 and TRANS/WP.29/GRPE/2004/3+Add.1.

b) Making the assumption that future systems will need to be type approved, through some form of testing, can you make proposals on how to encourage and approve systems that are robust and effective, so that they are fit for purpose?

2.18. What kind of impacts can the present legislative situation have on public safety, for example due to the lack of existing standards, or diverging safety standards?

Section 3: Questions about the economic implications of the three policy options

3.1 What would be the different costs of manufacturing and placing on the market of hydrogen vehicles under each of options 1, 2 and 3?

a) In your answer, please identify components or other items that might cost more, for example the fuel cell, piping, carrying out testing procedures under type approval. Please consider costs for mass production, where possible. In your answer, please monetise the effects if possible.

Option	Your answer
Option 1 ‘No Policy Change’	
Option 2 ‘Legislation at EU level’	
Option 3 ‘Legislation at Member State level’	

b) Please also identify areas where some costs to manufacturers might be lowered, for example the costs for components, or the type-approval process, under the different policy options. As a further example, the costs to manufacturers of complying with future vehicle noise ‘type approval’ regulations may be reduced, due to the low noise emissions from fuel cells. In your answer, please monetise the effects if possible.

Option	Your answer
Option 1 ‘No Policy Change’	
Option 2 ‘Legislation at EU level’	
Option 3 ‘Legislation at Member State level’	

3.2 What savings to consumers or businesses might result from hydrogen vehicles. Examples might be:
(i) Lower servicing costs due to longer maintenance intervals;
(ii) Lower costs in breakdowns, due to fewer moving parts;
(iii) Lower fuel costs, due to higher efficiency of fuel cells and internal combustion engines using hydrogen as fuel.

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

3.3. What would be the economic effects of policy options 1, 2 and 3 on your company's competitive position at EU level? Please monetise, if possible.

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

3.4. What would be the economic effects of policy options 1, 2 and 3 on your company's competitive position at international level? Please monetise, if possible.

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

<u>Section 4: Questions about the environmental implications of the three policy options</u>

4.1 Have you carried out any kind of analysis of CO_2 emission scenarios for hydrogen vehicles? Please give details.

4.2 Have you quantified the air quality benefits of hydrogen vehicles? Please give details, specifying savings in pollutant emissions/km, and overall quantity of abated pollutant.

4.3 What will be the impacts of water vapour emissions from hydrogen powered vehicles on:
a) Global warming;
b) Urban humidity levels;
c) Photochemical reactions, e.g. 'smog' and production of ground level ozone;
d) Building facades, e.g. limestone.

Taking into account that:
(i) Water vapour is emitted from some existing hydrogen powered vehicles at around 80C, and
(ii) Replacing the entire fleet of vehicles with hydrogen powered vehicles may increase the mass of water released into the atmosphere of an urban area by up to 150%.

4.4 Do you consider that condensers may be required in vehicles, for example to recover waste heat and generate electricity, or to capture water emissions?

4.5 Have you carried out a 'lifecycle analysis' for hydrogen powered vehicles? Please give details.

Section 5: Question about three policy options

The questions in Sections 5 below are aimed at providing information on the best policy options concerning the introduction of hydrogen powered vehicles and if the timing is right for the introduction of the hydrogen fuelled vehicle regulation.

Please answer each question as accurately as possible, but we understand that some information may be too sensitive for you to be able to provide exact answers. However, please note that the responses will be treated confidentially.

5.1 Do you think that it is too early for the introduction of regulation for hydrogen fuelled vehicles?

5.2 Which of options 1-3 would you prefer? Why is your chosen option better, in your opinion?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

<u>Section 6: General Questions about the three policy options</u>

6.1 Please provide an overall assessment of the costs and benefit of policy options 2 and 3 in comparison with policy option 1.

6.2 In which year are you likely to be able to offer hydrogen vehicles on a commercial basis, assuming policy options 1, 2 and 3?

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	
Option 3 'Legislation at Member State level'	

6.3 You are invited to submit comments on the Commission's proposed Regulation until 15th September 2006 at:

http://ec.europa.eu/enterprise/automotive/pagesbackground/hydrogen/consultation/call.htm

--END--

Annex E Selected responses to Questionnaire

The following answers are the most interesting ones from the questionnaire that was produced by TRL for the European Commission and was distributed among H_2 Working Group and other stakeholders.

Question 2.1
"Safe and simple handling of vehicles for non-experts on public roads. Reliability of hydrogen components for the life cycle of a vehicle."

- "Aspects with regard to vehicle and surroundings safety in normal use:

  1. Material and component characteristics and system integrity:
     Mechanical properties, road hazards exposure, hydrogen system integrity (normal operation)
  2. Endurance:
     Lifecycles, requalification; ageing
  3. Refuelling:
     Operability and simplicity in operation, compatibility and safety of the fuelling
  4. Intentional hydrogen releases:
     Purging, boil-off, permeation (incl. losses, e.g. connections)
  5. Controls and display (incl. H_2-sensors)

- Aspects with regard to vehicle and surroundings safety in crash situations and defects, damages:

  1. Material and component characteristics and system integrity:
     Damage tolerance, mechanical properties, road hazards exposure, hydrogen system integrity (post-crash)
  2. Crashworthiness:
     Differences to existing conventional vehicles
  3. Leakage
  4. Fire safety:
     Protection, prevention
  5. Explosion protection:
     Pressure and fire explosion
  6. Emergency medical rescue:
     Marking and installation position of parts
  7. Controls and display (incl. H_2-sensors)

- Aspects with regard to the safety of electric and electronic systems of hydrogen and fuel cell vehicles including electromagnetic compatibility".

Question 2.2

Option	Your Answer
Option 1 'No Policy Change'	For short transition period until type approval is possible on basis of international regulation: Single approvals on basis of technical drafts and CNG regulations
Option 2 'Legislation at EU level'	Medium term: Legislation at EU level must come into force ASAP. Long term: Global technical rules on UN platform must be supported.
Option 3 'Legislation at Member State Level'	Not desired by global vehicle manufacturers.

Option	Your answer
Option 1 'No Policy Change'	Not acceptable, because some of the H_2/FC specific safety aspects are not covered by current legislation.
Option 2 'Legislation at EU level'	In a first step the safety of onboard storage systems should be covered by an European Regulation. Up to now the requirements for electric vehicles are given by ECE Regulation No. 100 "Uniform provisions concerning the approval of vehicles with regard to specific requirements for the construction, functional safety of battery electric vehicles". This Regulation can serve as a basis to lay down requirements for hydrogen and fuel cell vehicles. This concerns provisions with regard to electric shock as well as gaseous emissions of vehicles with such powertrains which might be emitted during charging and discharging of the batteries. For that purpose Germany currently elaborates a proposal for an amendment of ECE-R 100 in its national committee for vehicle electronics. Special requirements with regard to the safety aspects of complex electronic vehicle control systems can be found e. g. in annex 18 of ECE-R 13 (braking). With regard to electromagnetic compatibility and interference the corresponding Directive 72/245/EEC was updated two years ago (2004/104/EC). This Directive has also to be fulfilled by hydrogen and fuel cell vehicles. At present it is not necessary to amend this Directive due to the safety of hydrogen and fuel cell vehicles.
Option 3 'Legislation at Member State level'	Not acceptable, because different requirements (design or performance based) and different safety levels will be a hurdle for the market introduction of H_2/FC vehicles.

Question 2.2

"Even if part certification is required for almost all parts forming the compressed hydrogen gas fuel supply system as in the preliminary draft proposal for a Regulation of the European Parliament and of the Council relating to the type-approval of hydrogen powered motor vehicles publicized in July 2006, we believe that hydrogen fuel cell vehicle safety cannot be assured".

"The groundwork for the GTR is currently about to take off. We believe that we should proceed with discussion of European regulations matching in pace with this".

Question 2.4

Option	Your answer
Option 1 'No Policy Change'	No change of vehicle development principles
Option 2 'Legislation at EU level'	No change of vehicle development principles
Option 3 'Legislation at Member State level'	No change of vehicle development principles

Question 2.6

"Choosing the legislation at the EU level would avoid competitive disadvantages for some manufacturers"

Question 2.7

"General comment: Construction and design oriented requirements should be avoided, because this is a hurdle for innovative technology development. To the extent possible requirements should be performance based".

Question 2.11

"A higher sense of safety in the public can be expected if standards are established"

"Different safety policies and safety levels. No legal certainty for international car manufacturers."

"No quantifiable impact on public safety"

Question 3.1

Option	Your Answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	Global Technical Rules on UN platform have wide range of acceptance in all relevant markets. Costs for international approvals are lower compared with national approvals.
Option 3 'Legislation at Member State Level'	

Option	Your answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	Lowest administrative costs for type approval in 25 member states
Option 3 'Legislation at Member State level'	

"As in option 3, the establishment of regulations with differing contents among each country in Europe will invite delays in development time and higher costs of parts for hydrogen/fuel cells vehicles due to having to adapt to each regulation. This will become a demerit to the users of a hydrogen/fuel cell vehicle".

"To secure safety in vehicles registered and sold in the EU, it is preferable that standardized safety regulations be established. Therefore, option 2 should be selected".

"Each motor vehicle company has established independent safety standards and is investing effort in the design and manufacturing of motor vehicles securing sufficient safety. Therefore, this would only make part of the certification costs unnecessary. Not much of a significant difference can be found in economic implications in comparison to option 2 and option 3".

Question 3.2

Option	Your Answer
Option 1 'No Policy Change'	
Option 2 'Legislation at EU level'	Certification and type approval of hydrogen vehicles are not possible before international regulations are set into force.
Option 3 'Legislation at Member State Level'	

Question 3.4

Option	Your answer
Option 2 'Legislation at EU level'	General: Some higher costs, but much higher benefits.
Option 3 'Legislation at Member State level'	General: Extreme costs, by different safety levels.

Option	Your answer
Option 2 'Legislation at EU level'	Legal certainty and economic benefits
Option 3 'Legislation at Member State level'	Legal certainty

Question 4.2

Option	Your Answer
Option 1 'No Policy Change'	Development of hydrogen cars is constrained because type approval is not possible. Environmental advantages will be delayed.
Option 2 'Legislation at EU level'	As soon as type approval is possible, serial production for relevant markets will start. Environmental advantages will appear (dependent on the clean production of hydrogen)
Option 3 'Legislation at Member State Level'	Development of hydrogen cars is constrained because type approval is not possible. Environmental advantages will be delayed.

Option	Your answer
Option 1 'No Policy Change'	No impact
Option 2 'Legislation at EU level'	No impact
Option 3 'Legislation at Member State level'	This option will be a hurdle for the market introduction of H_2/FC vehicles. As a consequence it will hinder the environmental benefits from H_2/FC vehicles in the field.

"Because hydrogen fuel cell vehicles are currently still being researched and the number of vehicles placed in the market is few, it is believed that it is too early to quantitatively discuss the specific improvements relating to the environment".

Question 5.2

"It is difficult to predict the beginning of the popularisation of these vehicles".

Question 5.3

"It's rather late for an EU-Regulation because Japan and USA have already developed national regulations."

"It is urgent to introduce as a first step a European Regulation regarding the safety of H_2 onboard storage systems as an important basis for harmonized approval of H_2/FC vehicles".

"In a second step, a concept for whole vehicle type approval should be developed. This should be in line with the ongoing activities for the development of a Global Technical Regulation (HFCV) under UN-ECE".

Question 6.1

Europe should proceed with its own debates while viewing the groundwork of the GTR in the UN-ECE/WP29 so as to establish European Regulations harmonized with the contents of the GTR, in other words, globally harmonized and should amend existing European Regulations in accordance with that timing.

Annex F List of Directives, Regulations and Standards

The following is the list of all Directives, Regulations and Standards that were analysed during the project:

- Framework Directive: EU Directive 70/156/EEC
- Emissions: 70/220/EEC (M and N class)
- Diesel smoke: 72/306/EEC
- Identification of controls: 78/316/EEC
- Fuel consumption: 80/1268/EEC
- Engine power: 80/1269/EEC
- CO_2 labelling: 99/94/EC
- Electric vehicles: ECE R100
- Fuel tanks: 70/221/EEC- rear protective devices (M and N class)
- Side impact: 96/27/EC
- Frontal impact: 96/79/EC (M1 class only)
- 2001/85/EC (vehicles with eight or more seats in addition to the driver's seat)
- 2005/64/EC: Recyclables (M1 and N1 class)
- UNECE Regulation 66: Strength of superstructure (for carriage of >22 passengers)
- UNECE Regulation 67: LPG vehicles and UNECE Regulation 110: CNG vehicles
- ISO 13984:1999 Liquid hydrogen – Land vehicle fuelling system interface
- ISO 23273-1:2006 Fuel cell road vehicles – Safety specification – Part 1: Vehicle functional safety
    - ISO 23273-2:2006 Fuel cell road vehicles – Safety specifications – Part 2: Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen
    - ISO/TR 15916:2004 Basic considerations for the safety of hydrogen systems

Annex G Definition of vehicle categories

Category M- Power driven vehicles having at least four wheels and used for the carriage of passengers

Category	Definition
M1	Vehicles used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.
M2	Vehicles used for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass not exceeding 5 tonnes.
M3	Vehicles used for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes.

Category N- Power driven vehicles having at least four wheels and used for the carriage of goods

Category	Definition
N1	Vehicles used for the carriage of goods and having maximum mass not exceeding 3.5 tonnes.
N2	Vehicles used for the carriage of goods and having a maximum mass exceeding 3.5 tonnes but not exceeding 12 tonnes.
N3	Vehicles used for the carriage of goods and having a maximum mass exceeding 12 tonnes.

Annex H Sources of information about the rate of introduction of hydrogen vehicles

H.1 What do we know?

We have looked at several sources of information on the likely rate of introduction of hydrogen vehicles into the road fleet. Some of these are discussed below.

H.2 Tremove database

The TREMOVE database is not currently set up to include any hydrogen vehicles in its forecasts of the fleet mix, up until 2020. This database would potentially have been very valuable, since it models the composition of the fleet, and not just the proportion of new vehicle sales in each year. It also models emissions.

The TREMOVE database provides predictions of the stock of vehicles in the EU27 member states in future years, (European Commission, 2006b). The prediction is for 243 million cars. The predicted stock of N1 vehicles is 23 million in 2020. These figures correspond to annual new vehicle sales of around 23 million. So hydrogen vehicles will only make up 1% of annual category M1 and N1 sales once the total number sold per annum is 230,000.

The EU 'Tremove' database is currently only set up to provide predictions of the following types of vehicle:

(i) Cars- conventional gasoline, hybrid gasoline, CNG, conventional diesel, hybrid diesel.

(ii) Light duty vehicle- gasoline, diesel.

(iii) Heavy duty vehicle- diesel.

(iv) Coach- diesel

(v) Bus- diesel, CNG

This is important for two reasons. Firstly, it is not just a simple step for the project team to request a run of the Tremove model, in order to obtain an accurate prediction of the future market share of hydrogen vehicles. Secondly, the operators of the Tremove database have updated the database to version 2.40 of September 2005. This included biofuels as one new element of the model. However, the operators of the model either did not see the need for a prediction of hydrogen vehicles' market share by 2020, or were unable to provide this.

In order to benefit from the Tremove database, we consider firstly the total number of passenger cars that will be sold in future years. Table 9 of EU2006b provides the following predictions for the different types of car sales in 2010, 2015 and 2020.

Table H.1. Car sales in 2010-2020

Year:	Conventional Petrol (%)	Hybrid petrol (%)	CNG (%)	Conventional diesel (%)	Hybrid diesel (%)	LPG (%)
2010	47.3	6.1	13.9	32.4	0	0.4
2015	43.2	9.9	14.3	27.0	5.3	0.4
2020	37.1	14.8	15.7	24.5	7.6	0.3

Source: Table 9, page 37 of 2006b

Clearly, this Table does not predict any significant share of the car market for hydrogen vehicles. The only information that is of use is the prediction of 22.4% of vehicles being hybrids by 2020. This percentage would have been reached 22 years after hybrid vehicles were first put on sale in Europe in 1998.

The 22.4% prediction itself looks to be very optimistic. Hybrid car sales have risen to only 0.25% of new car sales in the EU25 member states by 2006, from their start in 1998. The leap to 6.1% shown for ‘hybrid petrol’ in 2010 looks optimistic, compared to the progress made in 1998-2006.

It is important to analyse the hybrid sales figures, in order to understand how relevant the hybrid experience is for possible sales of hydrogen vehicles. The market growth of hybrids to 0.25% in 2006 was achieved with:

(i) Widespread availability of gasoline and diesel fuel for these hybrid vehicles, i.e. the fuelling infrastructure was already in place all over the EU25. A person buying a hybrid vehicle in 1998 could be sure that it could be used, or re-sold, in any location in the EU25. So these vehicles offered a high degree of ‘utility’ to consumers.

(ii) There was a very high level of public familiarity with both petrol and diesel fuel. This is important, because economists consider the vehicle market to be more ‘conservative’ than some other consumer markets.

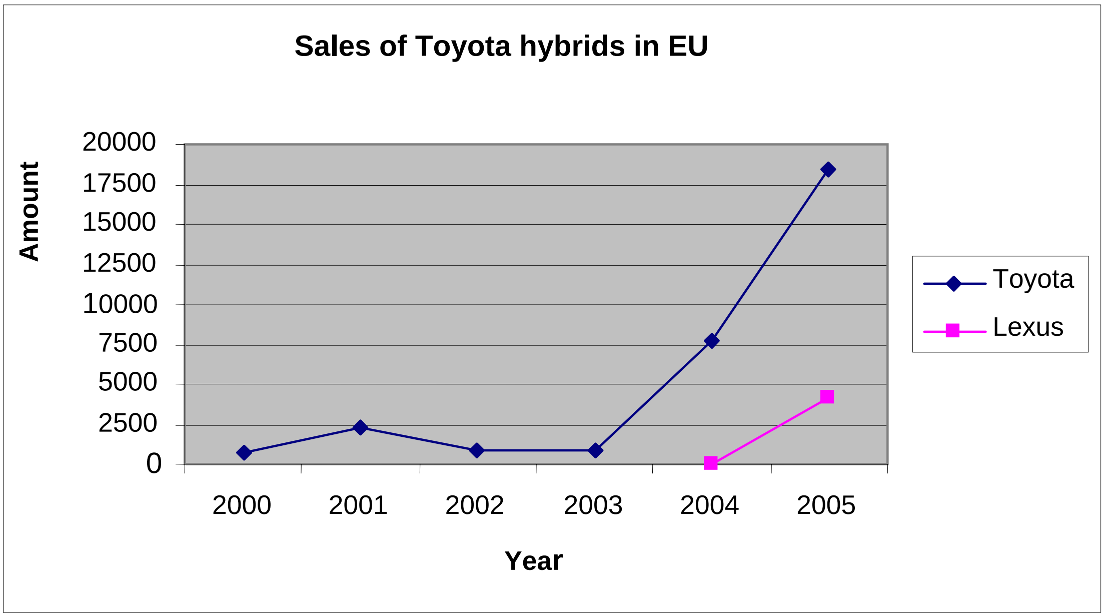
(iii) Hybrid vehicles were cheaper to run than the vehicles with which they had to compete during 1998-2006. Hydrogen vehicles will need to demonstrate clear environmental and economic benefits over the competing petrol, diesel and hybrid vehicles that are on sale in the years 2006-2030. However, these competing vehicles have far lower environmental impacts than the vehicles with which hybrid vehicles themselves had to compete from 1998-2006.

There seems therefore to be no prospect that hydrogen vehicles might achieve sales comparable to the 22.4% for hybrids, in the 22 years after their introduction. Assuming 2007 as the first year of commercial availability of hydrogen cars, this gives us an absolute upper boundary of sales through to the year 2029.

H.3 Industry figures

Several car manufacturers were approached, with a request to provide predictions of the rate of adoption of hydrogen vehicles in the EU27. Manufacturers did not wish to reveal this information.

Toyota supplied sales figures for petrol electric hybrid vehicles in the years 2000-2005, see figure H.1 below. These figures include the vast majority of all petrol electric vehicles sold in the EU25 in the period concerned. They illustrate both the relatively slow rate of adoption of these vehicles, and the inaccuracy of the IPTS2003 estimate for 2005.



Source: Toyota, personal communication 2006

Figure H.1. Toyota hybrid sales figures for EU25 2000-2005

The most reliable figures would be those held by industry. Vehicle manufacturers will base their capacity to produce hydrogen vehicles on expected sales. However, the TREMOVE database could also be modified to include estimates of the numbers of hydrogen vehicles. If this were done, it should include separate estimates for hydrogen powered internal combustion engine vehicles, and fuel cell powered vehicles.

H.4 EU Joint Research Centre predictions

The European Commission's Joint Research Centre has published a report on trends in new vehicle technology. This document describes the results of a model that '*aims to describe the dynamics of the passenger car market and the introduction of new technologies in the sector*', (Joint Research Centre 2003, page iv).

Table H.2: Predictions of fuel cell and hybrid car sales

Year	New hybrid car sales in EU15		New fuel cell car sales in EU15	
	Thousands	% of new car market	Thousands	% of new car market
2005	255	2	4	
2010	1552	10	13	
2015	2918	19	223	1
2020	3945	27	1611	11

Source: Tables 8-6 and 8-9 of Joint Research Centre 2003

The predictions in Table H.2 are already at variance with observed figures, even though they were published in 2003. Although the report points out that it is designed to illustrate the dynamics of the passenger transport market, the authors of Joint Research Centre (2003) do consider the predictions to be accurate.

Whereas Joint Research Centre 2003 predicted 255,000 hybrid vehicles in the EU15 by 2005, the actual number was less than 40,000 for the whole EU27, and the percentage closer to 0.25%. Joint Research Centre (2003) predicted 4,000 fuel cell vehicles in 2005. In reality, hydrogen vehicles were not on commercial sale in 2005. The latest industry predictions are for around 100 to be leased in 2007 worldwide.

The key issue here is that the predictions in Table H.2 for 2015 and 2020 for hydrogen vehicles look highly unlikely, given the slow progress to date. Importantly, these were based on the views of industry staff who are familiar with development trends. Even given this, the figures are clearly not usable.

Annex I Comments from 'Preliminary Impact Assessment study of the Commission services on the Hydrogen and Fuel Cell Joint Technology Initiative'

Page	Section of the report	Statements from the HyWays report	TRL Comments
1	Qualitative Assessment	Certain hydrogen pathways can substantially avoid many of the negative externalities of today's fossil based energy systems (harmful pollutants, CO2, noise), but are typically more expensive to produce and operate. This underlines the need for enlightened policy that rewards fuel cell and hydrogen systems in proportion to externalities avoided by specific pathways. This can significantly affect market penetration.	Implementation of Hydrogen economy will present great investments from the industry and governments. Support from the government, and creating policies which will support faster implementation and development, are very important.
3	Table 2: Competition in the internal market	Must ensure hydrogen distribution networks are developed ab initio with open access and not bundled with producers	Construction and management of the infrastructure is very important. Clear procedures and supply chains need to be identified for efficient implementation.
3	Table 2: Operating costs and the conduct of business	No direct effect on existing businesses other than emergence of competing technology – unless policy thresholds were adapted in an anti-competitive way	TRL presented this also in the report. EU wide regulation will open the markets and help to develop the technology in EU countries.
4	Table 2: Consumers and households	"optimising household energy utilisation"	Hydrogen will in the first stage present applications for public transportation and stationary electricity production. Many countries are already considering use of stationary applications in their households.
4	Table 2: Specific regions and sectors	• Main sectors affected will be energy producers, utilities, industrial gas companies, OEMs in the auto, LDV, bus and two-wheeler sectors, small and large energy equipment manufacturers, auxiliary power units, portable and hand held devices, and to a lesser extent, trucks, guided rail vehicles, ships and aircraft (though these may be an important premium market); • Other sectors include more "niche" applications fork lifts, neighbourhood vehicles, wheelchairs, pleasure craft, golf-carts; • Transport, industrial and domestic *end-users* of energy; • Regions most affected will be those that host the above manufacturing industries or their suppliers – they have to adapt or compete with new fuel cell technologies – this is both a threat and an opportunity; • Regions with conventional or alternative energy resources and capacities	Hydrogen economy will present challenge for all the sectors across the economy and industry. Working together with government to create supporting policies will help to overcome the implementation problems.

		will be affected – hydrogen being a secondary carrier creates opportunity for cleaner conventional energy sources and (especially stranded) renewable energy- this in an era when limitations on peak energy production may threaten energy security. The JTI monitoring and assessment framework should continuously review the potential for progressive mobilisation of sustainable fuel cell and hydrogen based energy systems throughout the regions of Europe – as potentially very serious threats to civilisation such as climate change and energy security become better understood.	
5	Table 2: The macro-economic environment	Econometric modelling indicates the potential for a significant increase in economic growth – in the order of +0.5%GDP by 2030 ~= 0.5t€ for EU25[1]; effect is likely to be more as model does not take account of stationary natural gas fuelled fuel cell systems As fuel cells and hydrogen displace existing technologies the scope for new employment is estimated at 500.000; with another 500.000 substituted; 1 million jobs could be lost if EU fails to acquire this technology and has to import it[2]; The economic losses that could arise from disruptions to energy supply and climate change are potentially several trillions of euros[3] – the results of inability to plan, resource, and build sufficient alternative energy capacity, natural disasters, desertification, civil unrest and even resource wars; hydrogen and fuel cells are part of the portfolio of technologies that will be needed to combat these most serious threats	Predictions for the future need to be taken in to account with a precaution. Introduction of hybrid cars can be taken as an example. 6 years after the first car was on our roads, there was 0.2% of hybrids on our roads.

[1] Results from MATISSE project based on assumption that EU maintains same external balance of trade in hydrogen and fuel cell technologies as it currently has for conventional technologies; HyWAYs project shows a 0.2% increase in GDP for EU10 in 2050 – both compared to the reference case of no hydrogen vehicles; stationary hydrogen fuelled fuel cell systems are not predicted to make a big impact; model does not take into account potential of natural gas fuel cell systems

[2] Results from HYWAYs socio-economic model

[3] Stern review on the economics of climate change, HM Treasury, 2006; http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/sternreview_index.cfm

9	Table 4: Employment and labour market	As fuel cells and hydrogen displace existing technologies the scope for new employment is estimated at 500.000; with another 500.000 substituted; 1 million jobs could be lost if EU fails to acquire this technology and has to import it4; Significant new education and retraining will be needed as some traditional skills associated with design, manufacture, installation, repair and maintenance of equipment, infrastructure and safe operation will be replaced by different requirements No perceived effect on the functioning of labour market	Europe should invest more in the development of Hydrogen technology, which will bring independency from USA and Japan. Many permanent jobs will be replaced by different requirements. This will only bring a new job description and not loss of jobs.
9	Table 4: Public health and safety	Positive impacts on health, longevity and overall security resulting from positive contributions to improving air quality and mitigation of climate change – as described in table 3. Modest reduction in road transport noise through quieter, near silent propulsion Operational safety of vehicles and equipment leads to safety risks of a distinctly different nature compared to conventional combustion technologies Public perception of safety of hydrogen is poor and surveys show that the public has a poor understanding of risks – making incorrect associations with the hydrogen bomb; in fact hydrogen is in some ways safer and in some ways more dangerous than conventional energy carriers, all of which carry risk; merchant hydrogen is routinely handled in massive quantities in the petro-chemical, fertilizer, and space industry and has an excellent safety record There are safety risks and these need to be managed; the JTI will place considerable emphasis on analysis and monitoring safety associated with all aspects of the hydrogen value chain International regulation and safety standards are required for stationary, transport and portable applications of hydrogen and fuel cells – the JTI will co-ordinate European pre-normative research efforts and participation in international standards-making	Benefits from Hydrogen vehicles will come only if production, distribution and end use is done the most sustainable possible. Safety of the Hydrogen vehicles is the same as the safety of the conventional vehicles and this need to be presented to the general public.

[4] Results from HYWAYs socio-economic model

Annex J Option 3: Monetisation of benefits

Table J 1: Value of noise reductions due to hydrogen fuel cell vehicles in categories M1 and N1

Year:	Proportion of stock that is hydrogen powered	Resulting noise reduction from all traffic @ 0.02dB(A) per percentage (db(A) per annum)	Value of reductions in noise @ 5.8 billion€ per dB(A) (million € per annum)	Value of noise reductions after discounting (million € per annum)
2017	0.006%	0.00012	1	0
2018	0.02%	0.0004	2	2
2019	0.04%	0.0008	5	3
2020	0.1%	0.002	12	7
2021	0.1%	0.002	12	7
2022	0.2%	0.004	23	13
2023	0.4%	0.008	46	25
2024	0.6%	0.012	70	36
2025	0.8%	0.016	93	46
Total				**138**

Table J 2: Value of NOx reductions due to hydrogen vehicles in categories M1 and N1

Year:	Distance driven by hydrogen vehicles in each year (billion vehicle kilometres)	NOx reductions @ 0.045g saving per km (tonnes NOx)	Value of NOx reductions (million €)	Value of NOx reductions after discounting (million €)
2017	0	16	0.1	0.0
2018	1	53	0.2	0.2
2019	2	105	0.5	0.3
2020	6	263	1.2	0.7
2021	6	263	1.2	0.7
2022	12	526	2.3	1.3
2023	23	1051	4.6	2.5
2024	35	1577	6.9	3.6
2025	47	2102	9.3	4.6
Total				**13.7**

Table J 3. Value of particulates reductions due to hydrogen vehicles in categories M1 and N1

Year:	Distance driven by hydrogen vehicles in each year (billion vehicle kilometres)	Particulates reductions @ 0.005g saving per km (tonnes particulates)	Value of particulates reductions (million €)	Value of particulates reductions after discounting (million €)
2017	0	2	0.0	0.0
2018	1	6	0.1	0.0
2019	2	12	0.1	0.1
2020	6	29	0.3	0.2
2021	6	29	0.3	0.2
2022	12	58	0.6	0.4
2023	23	117	1.3	0.7
2024	35	175	1.9	1.0
2025	47	234	2.6	1.3
Total				**3.8**