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1 Executive Summary

In 2000 the transit authorities of Amsterdam, Barcelona, Hamburg, London, Luxembourg, Madrid, Porto, Stockholm and Stuttgart decided to participate in a joint fuel cell bus and hydrogen fleet test to significantly enhance the development of Clean Urban Transport for Europe - CUTE. They joined with leading infrastructure companies such as BP, Norsk Hydro, Shell and Vattenfall, and with DaimlerChrysler and its bus subsidiary Evobus. In order to strengthen the development of the new technology and to support the efforts of the transport companies, in 2001 the European Commission decided to support this project with one of the largest budgets ever for a single research and demonstration project.

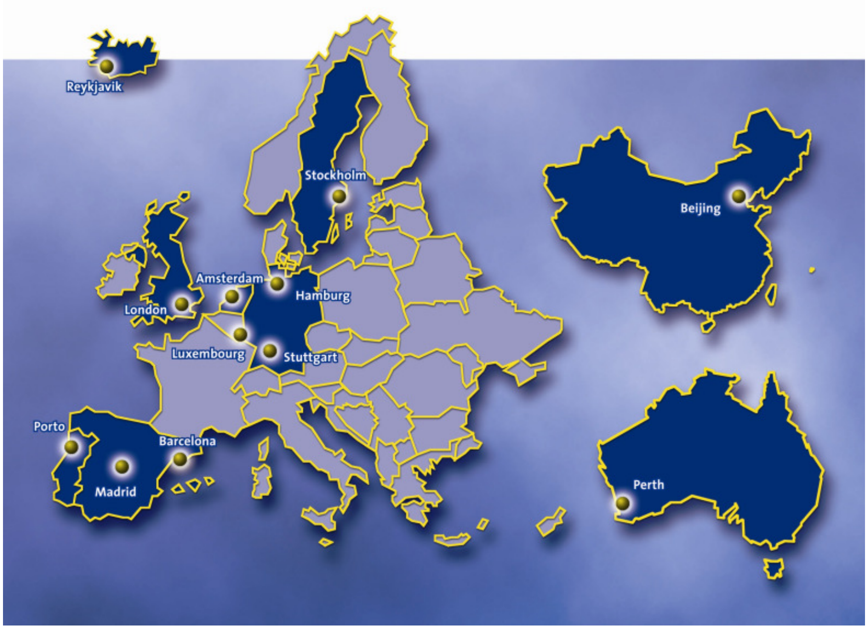

Figure 1-1: Participating cities in CUTE and associated projects in Reykjavik (ECTOS), Perth (STEP) and Beijing

The aim of the CUTE project was to develop and demonstrate an emission-free and low-noise transport system, including the accompanying hydrogen production and -refuelling infrastructure. This combination of these new technologies shows the greatest potential for the reduction of global greenhouse gas emissions and improving the quality of the atmosphere and life in densely populated areas, while conserving fossil resources. It also has the potential to strengthen the technological competitiveness of the European economy. The establishment of similar projects in the cities of Reykjavik (Iceland) in 2001, Perth (Australia) in 2002 and Beijing (PR China) in 2004 (Figure 1-1) shows the global importance of these new technologies in addressing environmental problems from the use of fossil fuels, and overcoming diminishing fossil resources.

The main challenges and objectives which have been addressed in CUTE include:

- Demonstration of 27 fuel cell powered Mercedes-Benz Citaro buses over a period of two years in the above mentioned European metropolitan areas in order to gain knowledge on the operational practicability of the fuel cell technology under real live conditions.
- Design, construction and operation of the necessary infrastructure for hydrogen production and refuelling stations. The hydrogen was produced partly on-site, partly off-site from different sources such as water (electrolysis), natural gas (steam reforming) and different processes in oil refineries.

- Development of the necessary knowledge to certify the fuel cell buses as well as the hydrogen infrastructure for safe operation in the participating European countries.
- To build up a knowledge base on the environmental performance of the new transportation system through the life cycle assessment approach and to compare the fuel cell technology with conventional technologies such as diesel- and compressed natural gas powered buses.
- Increasing public knowledge and acceptance of fuel cell and hydrogen technology through the operation of the fuel cell buses in inner city areas

The Mercedes-Benz Fuel Cell Citaro Bus

The backbone of the innovative transportation system was the Mercedes-Benz Fuel Cell Citaro. A specially designed fuel cell prototype was developed, using the latest fuel cell technology of Ballard Power Systems, Vancouver (Figure 1-2). It was based on the 12 m series diesel Citaro, which features a standing platform in the left rear area for integration a standard engine and an automatic transmission. The roof of the body shell was reinforced to cater for the 3 tonnes extra weight of the fuel cell drive train which was placed on the roof.

Figure 1-2: The Mercedes-Benz Fuel Cell Citaro

The main drive train components can be seen in Figure 1-3. Because of the limited previous experience with the new technology and the financial risk of the project, the fuel cell design and architecture focussed on maximising the reliability and availability of the vehicle by using as many series components as possible. Two fuel cell stacks were mounted on the roof of the bus. They provided a total power of about 300kW to the electric motor and all the auxiliaries, giving the vehicle a comparable driving performance to a diesel powered bus while providing the same level of passenger comfort with facilities such as air conditioning. The hydrogen storage system was able to store about 44 kg of hydrogen at a pressure level of up to 350 bar. This gave the vehicles a range of approximately 200 to 250 km, depending of the driving conditions.

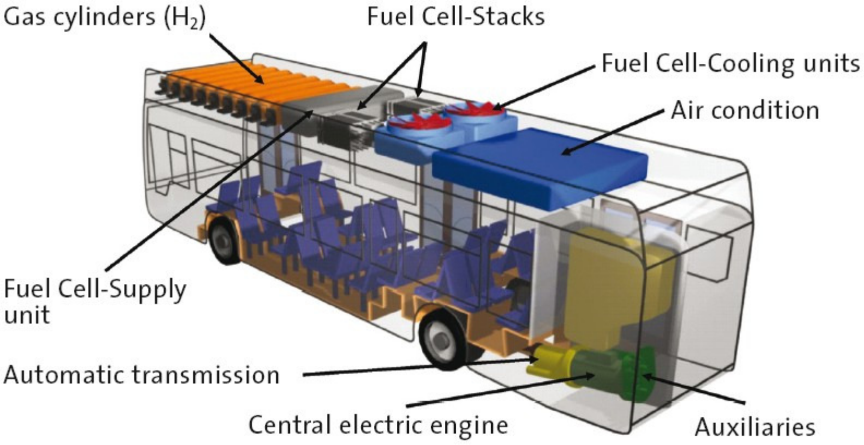

Figure 1-3: Main drive train components of the Fuel Cell CITARO

The hydrogen infrastructure

In order to maximise the total learning from CUTE, it was decided to provide hydrogen in a range of different ways. On site hydrogen production plants used different types of electrolysers and steam reformers, and hydrogen was also trucked-in. The different arrangements are shown in Figure 1- 4. New types of compressors had to be installed to dispense the hydrogen at the required high pressure. Large storage systems had to be included as up to 120 kg per day were expected to be refuelled. London used a liquid hydrogen storage system in order to gather knowledge on this phase.

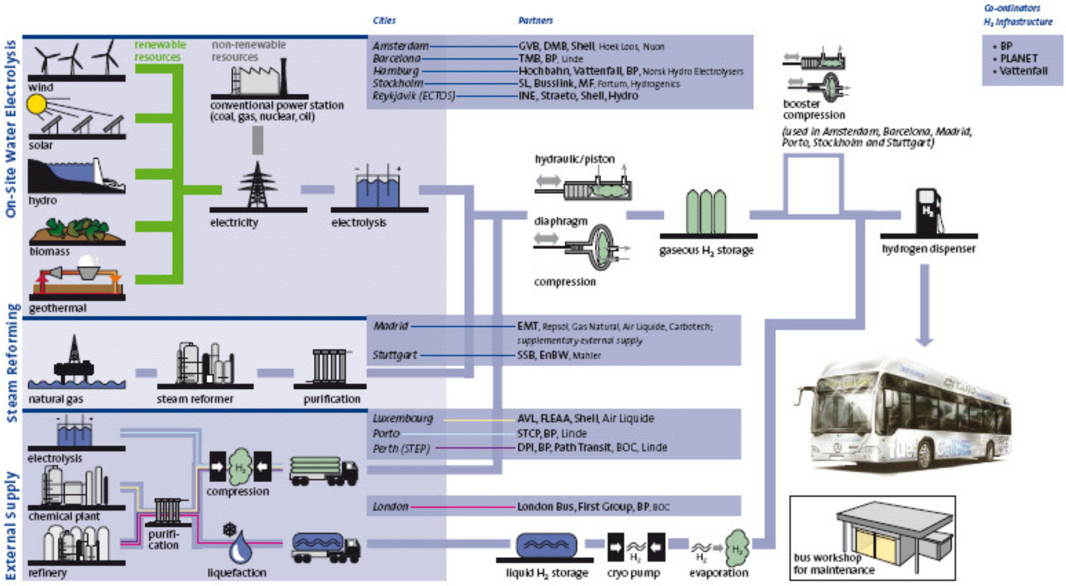

Figure 1-4: Overview of the hydrogen infrastructure set-up for CUTE and the associated projects in Reykjavik and Perth

Results:

CUTE has been a great success. The fuel cell buses and some aspects of the hydrogen infrastructure gave surprisingly high levels of availability. The project also demonstrated that the vision of a future transportation system based on fuel cells and hydrogen can become a reality when all the optimisation potentials identified in CUTE are realised and transferred into series production.

More than 4 Mio. passengers were transported and directly experienced fuel cells. This extraordinary level of exposure is far greater than all other fuel cell projects currently running added together.

The distance driven and the number of operating hours of the bus fleet are perhaps the most impressive figures from the CUTE project. They document the huge step forward that was taken in CUTE with regard to the lifetime and durability of the Fuel Cell system. Never before has a hydrogen technology project demonstrated such an outstanding operating success. Buses driven by regular bus drivers in regular traffic under normal operating conditions completed a distance of more than 20 times around the globe, producing a wealth of data and building a vast pool of experiences.

The Fuel Cell Buses:

Over the two years of operation the CUTE buses travelled a distance of almost 865 000 km in the 9 partner cities, see Figure 1-5 When the kilometres driven by the 6 additional buses operated in ECTOS (Reykjavik), STEP (Perth) are also taken into account, the Citaro Fuel Cell Buses passed the one million kilometres milestone in October 2005. The distance driven in each city ranged from some 40.000 km up to more than 140.000 km, depending on the conditions in the particular city.

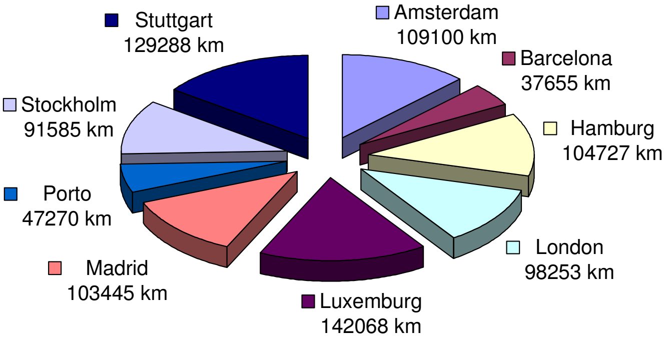

Figure 1-5: Total amount of kilometres driven in the different cities

When the bus operations within the CUTE project finished in December 2005 the twenty seven CUTE buses had been operated for over 64 000 hours on European roads, see Figure 1-6. Adding the ECTOS and STEP buses, the whole fleet operated for 75 600 hours while demonstrating their reliability, collecting information and gathering experiences on fuel cell buses. The operating hours in the different cities ranged from about 3.300 hours up to close to 10.000 hours.

The longest lifetime of a single fuel cell stack was more than 3200 operating hours. This greatly exceeded all expectations.

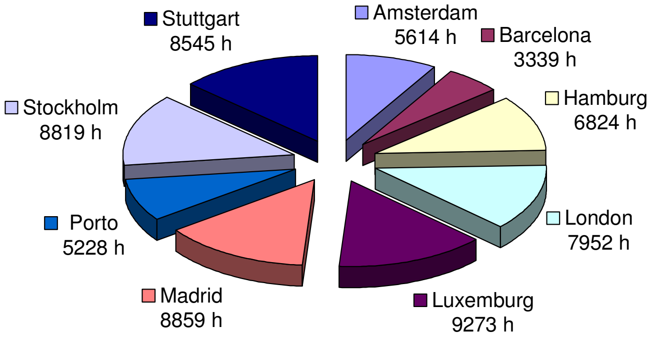

Figure 1-6: Total amount of operating hours per site, for the CUTE bus fleet

The buses performed with a better than expected reliability and availability. The data obtained also showed the optimisation potential of this prototype bus with regard to fuel consumption. Simulations showed that the fuel consumption could be reduced by up to 50 % using hybridisation and more electric drive train related technology. The fuel cell technology itself and the hydrogen components did not show any significant weak-points, but other electrical components such as the inverter need to be improved.

The hydrogen infrastructure:

All filling stations except one were operational (available) for more than 80% of the time over the two years of operation. The majority had an availability of more than 90%. Reliability in terms of successfully completed filling was generally somewhat lower. Critical components needing further development were the compressors and the refuelling interface. While electrolysers were generally reliable, the small-scale steam reformers need to be improved if the concept of an on-site hydrogen supply system is to be realised. Off-site large scale steam-reformer, often the source for trucked-in hydrogen, worked extremely well.

The CUTE hydrogen filling stations supplied the fuel cell buses with more than 192.000 kg hydrogen in more than 8.900 fillings. This is far more than in any previous trial of hydrogen-powered vehicles. The amount of refuelled hydrogen per site ranged from some 10000kg up to 29.000kg and is shown in Figure 1-7. London installed two different types of refuelling stations due to delays in construction of the original concept.

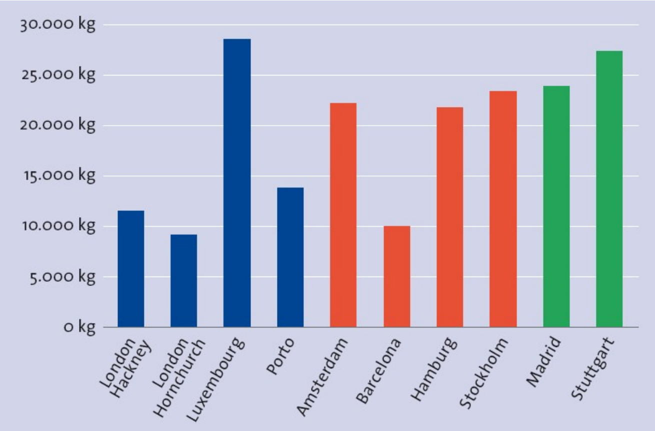

Figure 1-7: Amount of hydrogen dispensed at each side. Blue bars are sites with solely external supply, orange bars are sites with hydrogen production on-site via electrolyser, green bars are sites with hydrogen production on-site via steam reformer)

The accompanying studies provided several key findings:

- The energy efficiency of the hydrogen production and dispensing infrastructure was generally poor. This meant that the overall environmental impact of the fuel cell bus system (vehicle and fuel supply), was highly dependant on its own efficiency and on the H2- supply route chosen, particularly the source of energy input. This demonstrates yet again the importance of increasing the level of renewable inputs to stationary energy production.
- There is a need for a significant cost reduction in hydrogen production and of hydrogen refuelling stations, as well as in the fuel cell vehicles. Target costs of 2,5 to 3 €/kg of refuelled hydrogen can't be realised with today's technology.

Conclusions and Outlook

CUTE demonstrated the potential a fuel cell and hydrogen based transportation system can have for Europe. Figure 1-8 illustrates how the energy supply system for the CUTE project was changed through the application of this new technology in comparison with the situation existing currently within the public transport systems of Europe. More than 40 % of the energy for the hydrogen supply structure within CUTE came from renewable resources.

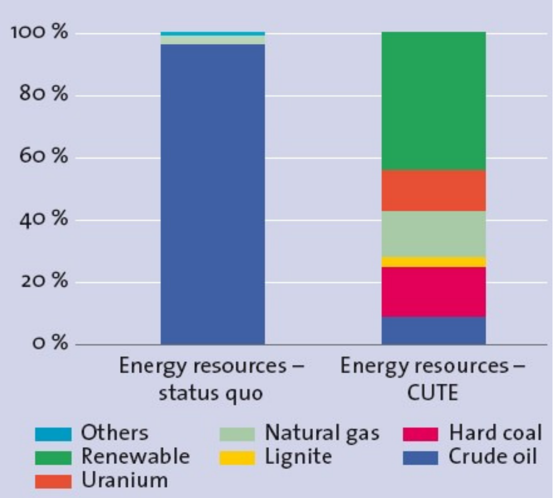

Figure 1-8: Mix of Energy Resources

CUTE has also clearly pointed to the challenges ahead and what needs to happen within the near future:

- The overall cost structure must be improved for both the fuel cell buses and for the hydrogen refuelling technology including the production of hydrogen. The prices for fuel cell buses must be significantly reduced in order to become competitive.
- The overall efficiency of the hydrogen production and distribution needs to be greatly improved.
- The durability and power density of the fuel cells has to be further enhanced, while the hydrogen storage systems need to be simplified and less expensive.
- The complete drive train of future fuel cell buses needs to be improved especially with regard to electrical components such as electric motors, high voltage battery systems and their associated control strategies.
- Community demand for the development of sustainable transport energies must become stronger in order to speed up the development and commercialisation of the technology.
- Increased community and political awareness must be translated into long term investment not only through the funding of projects such as CUTE, but also through the necessary legislative support. Currently the technology is still not mature enough to be rolled out in mass production within the next five years and this support is critical to reduce this time frame.

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List of Abbreviations

A/C	Air Conditioning
AB	Aktiebolag = PLC
AC	Alternate Current
AG	Aktiengesellschaft = PLC
AP	Acidification Potential
ASBL	Association Sans But Lucratif
AVL	Autobus de la ville de Luxembourg
Bar	Pressure unit
BE	Belgium
BP	British Petrol
CNG	Compressed natural gas
CO	Confidential
CO_2	Carbon Dioxid
COM	Communication of the European Comission
CPF	Contract Participation Forms
CS	Cost Statements
CUTE	Clean Urban Transport for Europe
DC	Direct Current
DE	Germany
DG TREN	Directorate General of Transport and Energy of the European Commission
EC	European Commission
ECTOS	Ecological City Transport System
EEV	Enhanced Environmentally Friendly Vehicle
EMT	Empresa Municipal de Transportes de Madrid
EN	European Standard
ES	Spain
EU	European Union
FC	Fuel Cell
FCB	Fuel Cell Bus
FLEAA	Fédération Luxembourgeoise des Exploitants d´Autobus et d´Autocars
GPS	Global Positioning System
GVB	Gemeentevervoerbedrijf Amsterdam
GWP 100	Global Warming Potential 100 years
H_2	Hydrogen
H_2-ICE	Hydrogen Internal Combustion Engine
HEW	Hamburgische Elektrizitäts-Werke AG
HHA	Hamburger Hochbahn AG
IND	Industry Partner
IRR	Internal Rate of Return
ISO	International Organization for Standardization
IST	Instituto Superior Tecnico
KBA	Kraftfahrt-Bundesamt, German Federal Authority for vehicles
LCA	Life Cycle Assessement
LU	Luxembourg
MDA	Milieudienst Amsterdam
MF	Miljö Förvaltningen

MIPP	Mission Profile Planning
Mk9	Product Name of Fuel Cell Type
MVV	Münchner Verkehrs- und Tarifverbund
Nebus	New Electric Bus
NL	Netherlands
NO	Norway
NO_x	Nitrogen Oxide
PDCA	Plan-Do-Check-Act
PE	Primary Energy
PLC	Public limited company
POCP	Photochemical Ozone Creation Potential
PR	Public Relations
PT	Portugal
PU	Public
Q & S	Quality & Safety
RE	Restricted
SAE	Society of Automotive Engineering
SE	Sweden
SSB	Stuttgarter Straßenbahn AG
STEP	Sustainable Transport Energy for Perth
TB	Transports de Barcelona
TQC	Total Quality Control
UK	United Kingdom
USTUTT	University of Stuttgart
WP	Work Packages

2 Introduction

2.1 Objectives / Content of the report

This Report summarises the key findings and illustrates key facts of CUTE, the world's largest fuel cell project with commercial vehicles.

The Report presents the results and experiences from more than four years of work. This involved planning, installing and operating hydrogen production and distribution infrastructure as well as hydrogen fuel cell technology. It includes lessons learned and recommendations on how to proceed in subsequent projects.

As well as summarising the technical/ engineering issues regarding the set-up and operation phase of the buses and the infrastructure, the Report also gives an overview on the social aspects of how staff involved in the project was trained. Activities undertaken to disseminate the project information to the public are also outlined.

The Report is aimed at providing a final summary of the major results of the CUTE project to both the project partners and the public.

2.2 Document Scope & Structure

This Report summarizes the key findings, lessons learned and recommendations from the operation of fuel cell buses under regular service conditions in 9 European metropolitan areas and the associated on-site hydrogen production and refuelling infrastructure. While the emphasis of the Report is on the operational phases of the CUTE project from May 2003 to December 2005, the efforts involved in certifying the buses and establishing the hydrogen infrastructure are also discussed.

The Report structure is outlined below:

- Chapter 3: Project description
  This Chapter includes
    - a brief overview of the project and its structure,
    - a timeline of the project (project meetings, delivery dates, conferences etc.),
    - an overview of project cost and
    - how the project was coordinated (technical and financial management aspects)
- Chapter 4: CUTE Assessment Framework
  Chapter 4 describes the methodology and tools used for assessing the whole project.
    - Project objectives and description of the CUTE Assessment Framework
    - an introduction to the data sheets (called Mission Profile Planning (MIPP) Data Sheets) which were developed to collect all necessary data from the operation of the fuel cell buses and of the H_2-infrastructure
    - the phase 1 assessment procedure and the evaluation conducted after 18 months by the official evaluators of the European Commission (EC)
    - data collection and monitoring, e.g. measurement trials conducted at the different cities, and the evaluation of the data in monthly evaluation reports.

- Chapter 5: Findings and results
  The chapter is divided into 8 sections which are based on the Executive Summaries of the 8 other CUTE Deliverables:
  - Infrastructure (D1)
    This section gives an overview of the hydrogen infrastructure. It also presents experiences during operation and discusses the performance of the different sites (e.g. efficiencies, losses, optimisation potentials).
  - Economic evaluation of the hydrogen infrastructure (D6)
    The hydrogen costs are an important part of the overall cost of public transport. This section gives an overview of the hydrogen cost incurred during the CUTE project and discusses future economic scenarios.
  - Quality and safety (D3)
    Quality and safety aspects are always major issues when a new disruptive technology is intended to be introduced. This chapter describes the way these issues were handled during the CUTE project.
  - Admission of System components (D9)
    Certification of the infrastructure and of the fuel cell buses was an important activity within CUTE, especially for the first two years. The challenges and the key findings of the certification process are described in this section
  - Fuel Cell Bus operation (D2)
    The overall performance is discussed, including operational hours and kilometres driven of the Fuel Cell (FC) buses as well as influencing factors such as climatic/ geographic.
  - Environmental evaluation of FC bus system (D5)
    One of the key reasons why fuel cell technology should be introduced in the future is its environmentally friendliness and the possibilities to be independent from fossil fuel that are created. CUTE is the first large scale FC demonstration project where the bus and fuel cell manufacturer "opened" their production plants in order to conduct a full life cycle inventory of the major competing technologies. This chapter provides the key findings of the environmental assessment of the total life cycle of the FC bus system including the provision of hydrogen (H_2).
  - Training and education – the human dimension of CUTE (D4)
    This chapter provides an overview of the training/ education materials developed and the activities carried out.
  - Exploitation and dissemination of project results (D7)
    Dissemination materials developed by the different sites as well as their activities are presented in this section.
- Chapter 6: Conclusions
  This chapter gives an overview of the general experiences, and recommendations that will increase the efficiency and performance of future projects.

2.3 Disclaimer

Despite the care that was taken while preparing this document, the following disclaimer applies: The information in this document is provided as is and no guarantee or warranty is given that the information is fit for any particular purpose. The user thereof employs the information at his/her sole risk and liability.

3 Project Description

3.1 The contribution of CUTE to Clean Transport Energy

The Commission's Green Paper "A European Strategy for Sustainable, Competitive and Secure Energy" (March 2006) identifies hydrogen and fuel cells among the portfolio of technologies that could address the common energy problems. This technology is identified as having the potential to provide solutions for issues such as energy supply security, while reducing local air pollution and increasing employment.

The Green Paper advocates investing in hydrogen and fuel cell development and deployment. It calls for large-scale integrated actions with the necessary critical mass, and mobilising private business, Member States and the Commission in public private partnerships. The work of the industry-led European Hydrogen and Fuel Cell Technology Platform can be seen as the first building blocks for such actions. The basis and motivation to use the fuel cell and hydrogen technology as one pillar of this strategy was the success of the CUTE project.

The European Union embarked in 2001 on the most ambitious demonstration project worldwide of hydrogen and fuel cells: CUTE (Clean Urban Transport for Europe). The optimal combination of a forward-looking vision, cutting edge technology and committed teamwork has led to the success of CUTE.

Currently the road transport system's fuels are diesel and petrol. These fuels are produced mostly from imported oil and natural gas and, when burned in buses, trucks or cars, they produce emissions of greenhouse gases and air pollutants. The ever-increasing demand for transport brings as a consequence more dependence on external supplies of oil, and leads to more Greenhouse gas emissions that provoke climate change.

The vision pursued by CUTE was to develop a totally clean transport system for cities, without reducing modern society mobility standards. In particular, CUTE aimed to achieve this vision by replacing diesel and petrol with hydrogen and combustion engines with fuel cells. Hydrogen and fuel cells can introduce a paradigm shift away from the transport sector's 'addiction' to oil. Hydrogen and fuel cells can be at the heart of a zero emissions transport system that would decouple mobility from climate change and air quality concerns.

However to achieve the commercialisation of hydrogen and fuel cells for transport we will have to climb a steep uphill path, solving technological, economic and public acceptance challenges along the way.

These challenges include: producing hydrogen economically and with minimal or no negative environmental impact; handling hydrogen safely; storing sufficient energy to achieve the required vehicle range; and making fuel cells competitive in terms of cost and reliability in comparison with the traditional combustion engine.

Against this background of very exciting technical potential and significant challenges the European Union, through CUTE, has provided answers to some fundamental questions:

Is it possible to build fuel cells and fuel cell buses in series production, and get them on the road to deliver regular public transport services?

Twenty seven Mercedes-Benz fuel cell buses were produced under series production conditions in the city bus production plant in Mannheim, Germany; another nine of them for the ECTOS project in Iceland, the STEP project in Western-Australia and the Hydrogen bus project in China. These buses were certified to operate in urban public transport services in Amsterdam, Barcelona, Hamburg, London, Luxembourg, Madrid, Porto, Stockholm and Stuttgart, as well as in Reykjavik, Perth and Beijing. The buses operated quietly for more than one million kilometres over a two year period and transported more than four million European passengers while producing only some steam as tail-pipe emissions.

More than 60.000 fuel cells were produced for the original equipment of the FC buses. Later on some 10.000 more fuel cells for the replacement of the original fuel cells at the end of their lifetime. This project produced some very important key learning as this was the first time that such a large number of fuel cells had been produced.

Is it possible to build a hydrogen supply infrastructure to fuel buses, mostly based on renewable energy sources?

Nine fuelling stations were constructed in the nine cities. It was the first time that fuelling stations were installed to refuel a local fleet of buses with hydrogen at 350 bar. These stations delivered up to 100 and sometimes up to 200 kg of hydrogen every day. Hydrogen was produced both centrally and on-site through natural gas reforming, or water electrolysis. While more than 56% of the hydrogen produced on-site came from renewable sources, it has also been shown that natural gas could be another important source for future transport applications when hydrogen is needed much more broadly throughout the community.

Would the hydrogen fuel cell buses and the hydrogen supply infrastructure achieve availability rates comparable with alternative technologies?

Over the two-year trials the total system availability (bus + infrastructure) reached a rate of around 80 %. This availability, while lower than that of a comparable diesel fleet, is close to that of a CNG bus fleet. This shows that the technology is workable. Even more importantly, through the work in CUTE, lessons have been learnt which will enable availability to be improved. Availability rates at some sites at the end of the CUTE project were the same as diesel buses.

Would drivers, technicians and the general public accept these new technologies?

Many drivers tested the buses and they were highly satisfied. Many technicians developed the necessary skills to maintain the buses and the fuelling stations without any major problem. Millions of European citizens experienced this new form of clean mobility and they liked it. Some passengers were even prepared to wait for the next bus if they knew it was one of the silent and non-polluting hydrogen buses. More than 4 Mio. Passengers drove on the Fuel Cell buses and, through the explanatory banners inside the buses, learnt how this technology works and what the advantages are. These introductory experiences may also become an important factor when fuel cell passenger cars are to be introduced.

Is it safe to use hydrogen as a fuel?

No hydrogen related accident occurred over the two-year demonstration period. Hazards related to hydrogen are simply different from those related to other fuels, and they can be managed. CUTE has moved the state of the art in hydrogen and fuel cell technologies for transport a significant step forward. It has put the European industry, cities, and researchers amongst the global leaders in production and operation of hydrogen fuel cells buses, as well as in hydrogen production and distribution.

Is it necessary to build partnerships like in CUTE for future demonstration projects?

CUTE was only possible due to an unprecedented European alliance involving the automobile and energy industries, a group of pioneering cities, a group of university and research centres, and the European Commission. This large but well-structured partnership gathered together the necessary skills, resources and individuals that made possible the execution of the project. Outstanding teamwork was key to its success.

CUTE has become the flagship project of the European Hydrogen and Fuel Cell Technology Platform and has been recognised at the global level by the International Partnership for the Hydrogen Economy.

CUTE has provided unparalleled visibility for hydrogen, and helped establish its credibility as part of an alternative transport energy system to petrol and diesel. At the same time CUTE has raised new questions and challenges. After CUTE the questions are no longer *how* and *if*, but WHEN will this technology be ready; and WHAT needs to be done to render performance and costs more competitive?

The European Union has now embarked on a series of further demonstration projects grouped under the initiative “Hydrogen for Transport”. Around 200 hydrogen-powered vehicles will be demonstrated over the next three years. The aim is to improve vehicle efficiency and infrastructure reliability, to facilitate the understanding of the citizens and the decision makers regarding hydrogen, and to prepare even larger demonstration projects which will be necessary to bridge the gap between the future state of technology and the market.

The conclusion of CUTE marks a milestone in the history of clean transport energy technology and opens the way to a new era of sustainable transport systems.

3.2 Description of the project

CUTE was the most ambitious field trial of fuel cell buses and their hydrogen infrastructure ever attempted. Twenty seven Mercedes-Benz Fuel Cell Citaro buses operated in the nine participating cities. Another 6 buses ran within the associated projects ECTOS (Reykjavik/Iceland, also funded by the EU) and STEP (Perth/Western Australia). Three more buses started operation in November 2005 in Beijing, China.

The CUTE project started in November 2001 and continued until May 2006. During the first two years of the project the buses were built and hydrogen supply chains for the nine sites developed and commissioned. The first vehicle was delivered to Madrid and tested from May 2003. The operation phase officially started in November 2003.

The project has examined a wide range of issues in detail. For example, as part of the comparative assessment of the different ways of hydrogen production and supply employed, issues such as “How do the individual supply pathways perform in terms of availability, efficiency, costs, environmental benefits, safety etc.?“ and “Are the components mature?” have been examined

The performance of fuel cell vehicles has been benchmarked against conventional buses powered by diesel or natural gas. These evaluations have been carried out as both a technological issue and from the perspective of stakeholder satisfaction (transport operators, fuel suppliers, passengers, bus drivers, technicians etc.). This breadth of analysis has been an important characteristic of CUTE.

CUTE partners have conducted extensive dissemination activities in order to increase public awareness of the fuel cell and hydrogen technology, contributing to a better public understanding and therefore acceptance of the technology. The reliable day-to-day operation of the CUTE buses has demonstrated to European society the relevance of such innovative technology to helping to combat concerns such as human health, environmental protection, quality of life in densely populated areas, conservation of fossil resources and control of greenhouse gas emissions. In this way, CUTE has been a driving force for a European hydrogen pathway.

3.3 Project structure

The work programme of the project was structured into different Work Packages (WP) addressing the different tasks and objectives of CUTE (see Figure 3-1). The four main thematic areas were

- set-up and the operation of the hydrogen infrastructure,
- operation of 27 Fuel Cell Citaro buses,
- accompanying studies and
- exploitation & dissemination of the project’s findings.

The first theme addresses the supply of hydrogen. This was achieved either by on-site production or trucked in hydrogen from external sources. The construction and operation of the H_2 production infrastructure was the topic of WP 1 and 2.

Work package 3 included the provision and use of the local infrastructure necessary for the operation of the buses, consisting of a refuelling station and a bus depot.

The demonstration and evaluation of the behaviour and performance of the bus system in regular service in European inner city areas under different climatic, topographical and traffic-related conditions formed the heart of the project and was covered in the WP 4-6.
The first part of the accompanying studies contains the implementation of a Quality & Safety Monitoring system for the setting up and operation of a H_2/FC bus system (WP 7). This includes the certification and homologation of the various system components. The second part addresses the appropriate training and education of the personnel involved, as well as informing the public to give them a better understanding of this new propulsion system (WP 8).

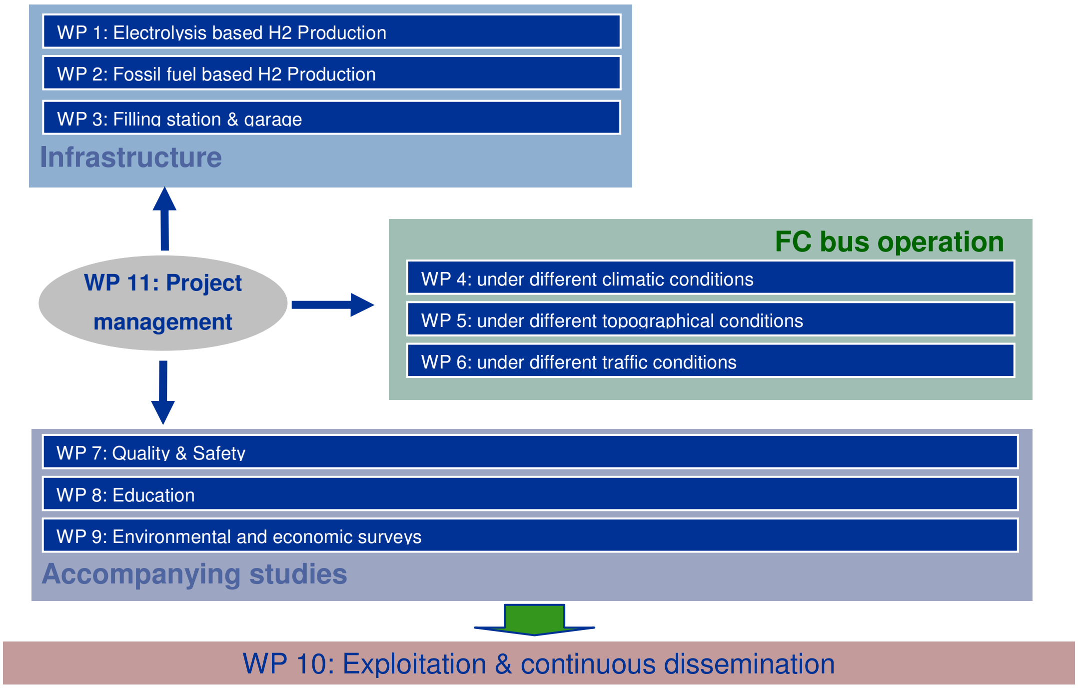


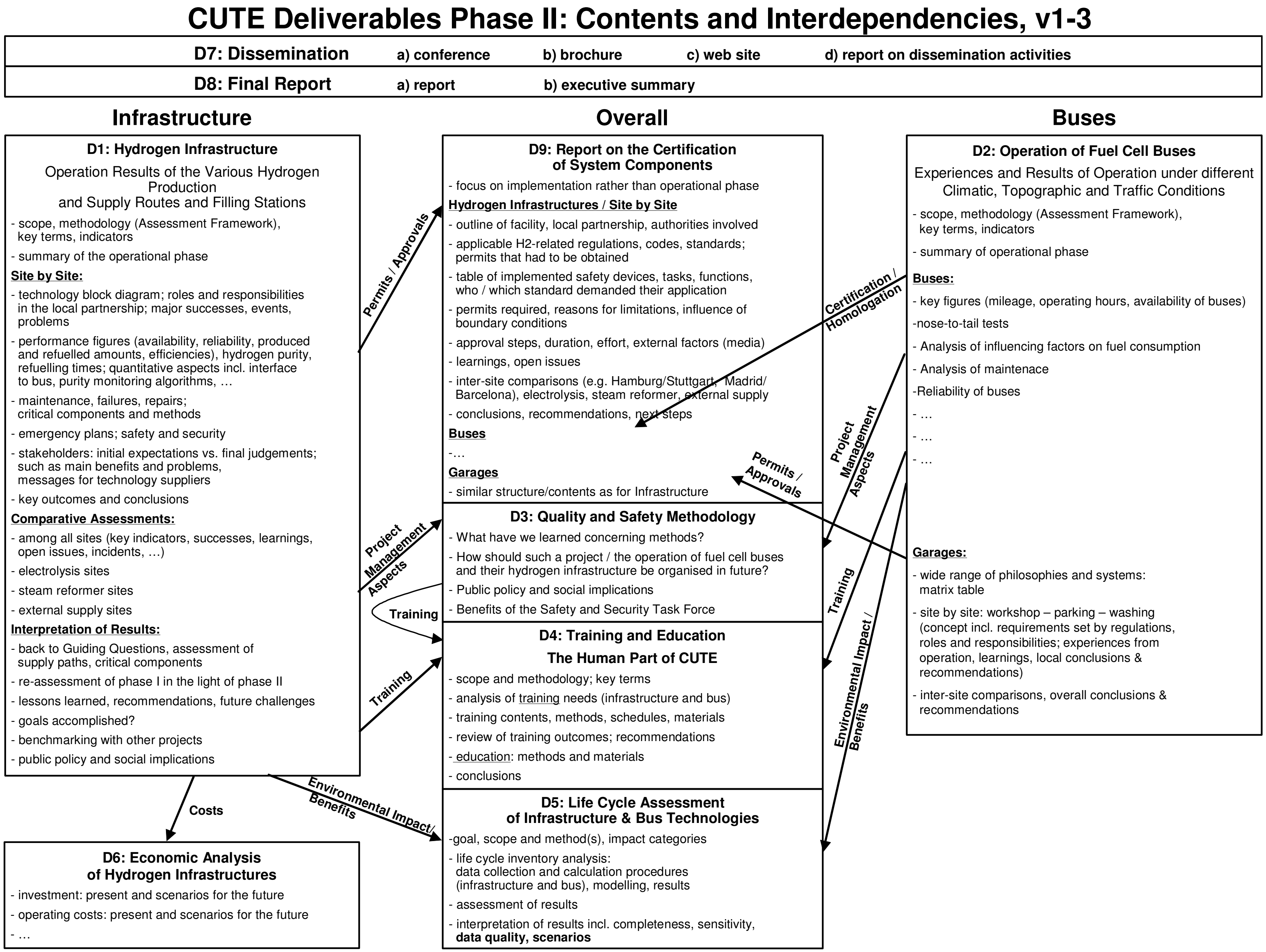
Figure 3-1: Work package structure of CUTE

In addition to the technical project content outlined above, studies on the ecological and economic effects of introducing the new technology in Europe were carried out in work package 9 in order to better assess the medium and long-term effects of the new transport system.
WP 10 and 11 consider the exploitation of the project results and the project management.

Work package outcomes and interactions

The overall project structure and the deliverables of the different Work Packages are summarised in Figure 3-2. The figure also shows the interrelations between the different deliverables.

Figure 3-2: Interdependencies between the CUTE deliverables



CUTE Deliverables Phase II: Contents and Interdependencies, v1-3

D7: Dissemination a) conference b) brochure c) web site d) report on dissemination activities

D8: Final Report a) report b) executive summary

Infrastructure

D1: Hydrogen Infrastructure

Operation Results of the Various Hydrogen Production and Supply Routes and Filling Stations

- scope, methodology (Assessment Framework), key terms, indicators
- summary of the operational phase

Site by Site:

- technology block diagram; roles and responsibilities in the local partnership; major successes, events, problems
- performance figures (availability, reliability, produced and refuelled amounts, efficiencies), hydrogen purity, refuelling times; quantitative aspects incl. interface to bus, purity monitoring algorithms, …
- maintenance, failures, repairs; critical components and methods
- emergency plans; safety and security
- stakeholders: initial expectations vs. final judgements; such as main benefits and problems, messages for technology suppliers
- key outcomes and conclusions

Comparative Assessments:

- among all sites (key indicators, successes, learnings, open issues, incidents, …)
- electrolysis sites
- steam reformer sites
- external supply sites

Interpretation of Results:

- back to Guiding Questions, assessment of supply paths, critical components
- re-assessment of phase I in the light of phase II
- lessons learned, recommendations, future challenges
- goals accomplished?
- benchmarking with other projects
- public policy and social implications

D6: Economic Analysis of Hydrogen Infrastructures

- investment: present and scenarios for the future
- operating costs: present and scenarios for the future
- …

Overall

D9: Report on the Certification of System Components

- focus on implementation rather than operational phase

Hydrogen Infrastructures / Site by Site

- outline of facility, local partnership, authorities involved
- applicable H2-related regulations, codes, standards; permits that had to be obtained
- table of implemented safety devices, tasks, functions, who / which standard demanded their application
- permits required, reasons for limitations, influence of boundary conditions
- approval steps, duration, effort, external factors (media)
- learnings, open issues
- inter-site comparisons (e.g. Hamburg/Stuttgart, Madrid/ Barcelona), electrolysis, steam reformer, external supply
- conclusions, recommendations, next steps

Buses

-…

Garages

- similar structure/contents as for Infrastructure

D3: Quality and Safety Methodology

- What have we learned concerning methods?
- How should such a project / the operation of fuel cell buses and their hydrogen infrastructure be organised in future?
- Public policy and social implications
- Benefits of the Safety and Security Task Force

D4: Training and Education

The Human Part of CUTE

- scope and methodology; key terms
- analysis of training needs (infrastructure and bus)
- training contents, methods, schedules, materials
- review of training outcomes; recommendations
- education: methods and materials
- conclusions

D5: Life Cycle Assessment of Infrastructure & Bus Technologies

- goal, scope and method(s), impact categories
- life cycle inventory analysis: data collection and calculation procedures (infrastructure and bus), modelling, results
- assessment of results
- interpretation of results incl. completeness, sensitivity, **data quality, scenarios**

Buses

D2: Operation of Fuel Cell Buses

Experiences and Results of Operation under different Climatic, Topographic and Traffic Conditions

- scope, methodology (Assessment Framework), key terms, indicators
- summary of operational phase

Buses:

- key figures (mileage, operating hours, availability of buses)
- nose-to-tail tests
- Analysis of influencing factors on fuel consumption
- Analysis of maintenace
- Reliability of buses
- …
- …
- …

Garages:

- wide range of philosophies and systems: matrix table
- site by site: workshop – parking – washing (concept incl. requirements set by regulations, roles and responsibilities; experiences from operation, learnings, local conclusions & recommendations)
- inter-site comparisons, overall conclusions & recommendations

Partners

For an ambitious demonstration project like CUTE a well balanced consortium is the key to success. CUTE involved partners from four different fields (see Table 3-1). The city partners were involved in the operation of the FC buses and hydrogen infrastructure. The industry partners supplied the FC buses (Bus Manufacturer) and the H_2 infrastructure (Infrastructure), and the academic and consulting partners (University and Consultants) conducted the evaluation of the project. Most partners were involved to some degree in the evaluation activities, and the dissemination of the results.

Table 3-1: Consortium overview

Part. No.	Organisation name	Country	Function in the project	Grouping
1	EvoBus	DE	Project co-ordination / Bus supply / Leader WP 10 &11	Bus Manufacturer Project coordinator
2	Polis Iasbl (European Cities and Regions Networking for New Transport Solutions)	BE	Member of WP 10 Dissemination and exploitation	University & Consultants
3	Hamburger Hochbahn AG (HHA)	DE	Local site manager and operator of buses in Hamburg	City partner
4	Hamburgische Elektrizitäts-Werke AG (HEW)	DE	Leader WP 1 H_2 production *via* electrolysis, Responsible for H_2 infrastructure in Hamburg	Infrastructure
5	PE Product Engineering GmbH	DE	Economical & Environmental studies	University & Consultants
6	London Bus Services Limited	UK	Transport authority in London and local site manager	City partner
7	First Group PLC	UK	Operator of buses in London	City partner
8	Gemeentevervoerbedrijf Amsterdam (GVB)	NL	Leader WP 6, Local site manager and operator of buses in Amsterdam	City partner
9	Milieudienst Amsterdam (MDA)	NL	Public Authority Amsterdam, Support to GVB	City partner
10	Shell Hydrogen B.V.	NL	Support for H_2 infrastructure in Amsterdam and Luxembourg	Infrastructure
11	BP Amoco PLC (BP)	UK	Leader WP 2 H_2 from other fuels, Responsible for H_2 infrastructure in Barcelona, London, Porto, financially involved also in Hamburg and in Stuttgart	Infrastructure
12	Transports de Barcelona (TB)	ES	Local site manager and operator of buses in Barcelona	City partner
13	Busslink i **Sverige** AB	SE	Operator of buses in Stockholm	City partner
14	City of Stockholm, Environmental and Health Protection Administration (MF)	SE	Leader WP 4, Local project manager Stockholm	City partner
15	Empresa Municipal de Transportes de Madrid (EMT)	ES	Operator of buses in Madrid and local site manager	City partner
16	Autobus de la ville de Luxembourg (AVL)	LU	Local site manager and operator of buses in Luxembourg	City partner
17	Fédération Luxembourgeoise des Exploitants d´Autobus et d´Autocars ASBL (FLEAA)	LU	Dissemination support to AVL, Luxembourg	
18	Instituto Superior Tecnico (IST)	PT	Technical and economical optimisation of hydrogen technology	University & Consultants

19	Stuttgarter Straßenbahn AG (SSB)	DE	Leader WP 5, Local site manager and operator of buses in Stuttgart	University & Consultants
20	Sociedade de Transportes Colectivos do Porto SA (STCP)	PT	Local site manager and operator of buses in Porto	City partner
21	DaimlerChrysler	DE	Bus development/ Assistant to IND1	Bus Manufacturer
22	Norsk Hydro ASA	NO	WP Leader 7 Quality & Safety, Leader Taskforce Safety & Security	University & Consultants
23	University of Stuttgart (USTUTT)	DE	WP Leader 9 Technical, economical and environmental studies, Life Cycle Assessment of different bus propulsion technologies	University & Consultants
24	Storstockholms Lokaltraffik (SL)	SE	SL is the main Stockholm project contractor	Public transport authority
25	Sydkraft AB	SE	Support WP 9 for technical and economical studies referring hydrogen supply for future European-wide fuel strategies	University & Consultants
26	MVV Verkehr AG	DE	Member of WP 8 & 10 Education& Training resp. Dissemination and exploitation	University & Consultants
27	PLANET	DE	WP leader 3 filling station & garage; support to WP leaders 1 & 2	University & Consultants
28	Statkraft SF	NO	Support WP 9 for technical and economical studies referring hydrogen supply for future European-wide fuel strategies	University & Consultants

3.4 Timeline

The timeline of the key events and achievements of CUTE are presented in Figure 3-3. The delivery of the buses to the sites and the start of operation in each city took place between May 2003 and January 2004.

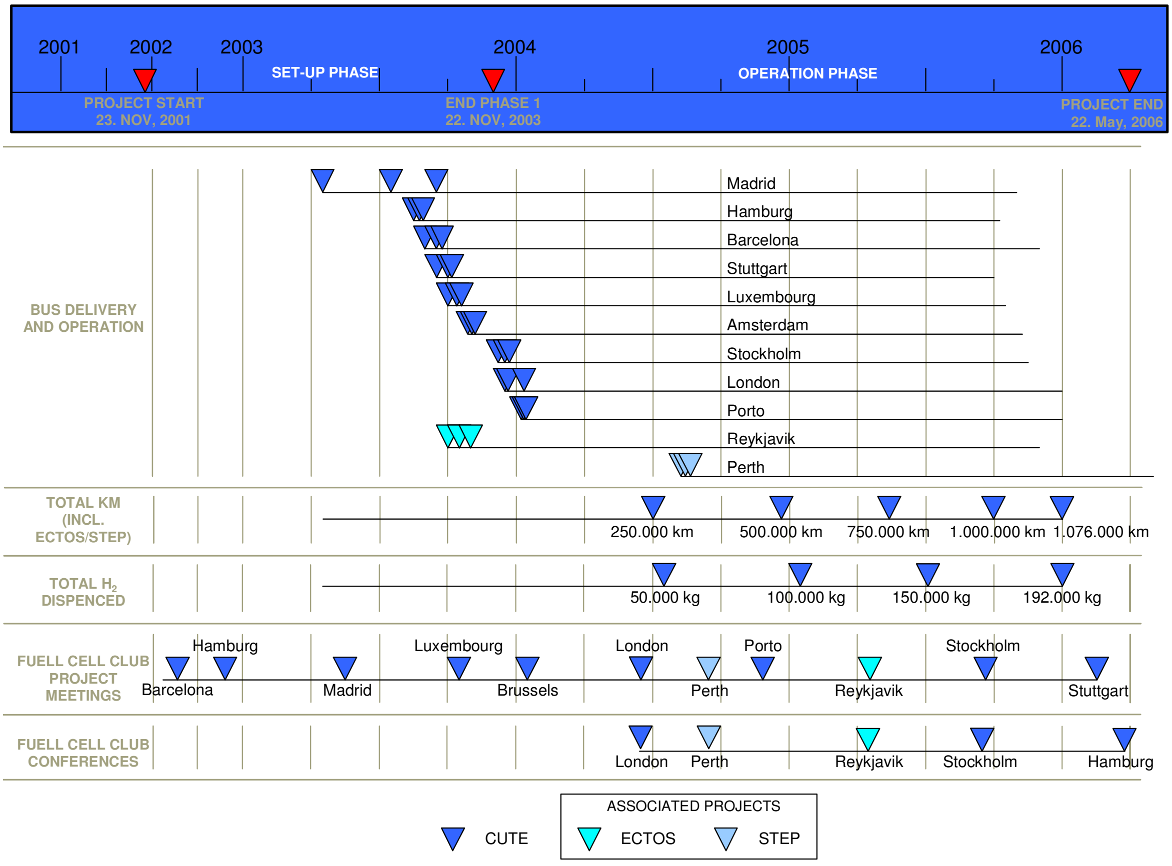


Figure 3-3: Key dates of the CUTE project

While it took approximately 18 months for the buses to travel the first 500.000 km mark, the next 500.000 km were travelled in half this time. In similar fashion, the time period for dispensing 100 tonnes of H_2 was also reduced by 50% in the course of the project, from 20 months to 11 months. Project meetings were held in all project sites and also at the sites of the sister projects ECTOS and STEP. Several conferences were held in Europe and Australia by the consortium. These served as key dissemination events on the status and outcomes of the demonstration projects.

3.5 Costs of CUTE

The CUTE project involved substantial investments, especially by the participating cities and their partners. Each site had to acquire a H_2 infrastructure (either with or without an on-site H_2 production unit) (500.000 € to 1.5 Mio. €), 3 FC buses (1.25 Mio. € each including maintenance), and a bus maintenance facility (60.000 to 1 Mio. €).

This resulted in investment costs for the hardware only of between 4 and 6 Mio. € per site. Personnel costs for running the project were another major budget item. Each site has to establish a project team including management, bus drivers, PR experts etc.

The estimated costs at the beginning of the project added up to 52.5 Mio. € with an EC contribution of 18.5 Mio. €.

Figure 3-4 and Figure 3-5 show the distribution of the estimated project costs according to the formal agreements of each partner with the Commission (Contract Participation Forms – CPF). Figure 3-4 shows the large share of the consumables, mainly the FC buses. The H_2 infrastructure was included in the Durable equipment category together with the required investments for the garage. Subcontracting was mainly assigned to technical suppliers such as engineering firms or consultants responsible for matters such as certification. Personnel and overhead costs totalled 26% of the estimated costs. Figure 3-5 gives a breakdown of the costs according to the four partner groups as defined in chapter 3.3 .It shows the large proportion of the costs met by the city partners. This was mainly due to the costs for H_2 infrastructure and FC buses.

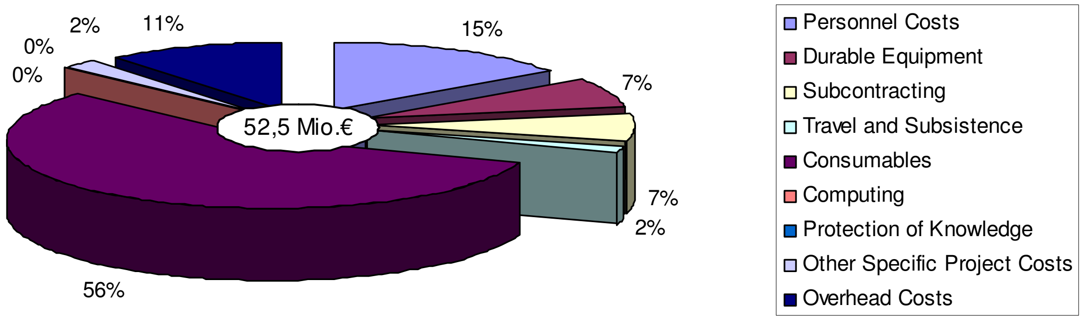


Figure 3-4: Distribution of costs by cost category according to contract (based on CPF)

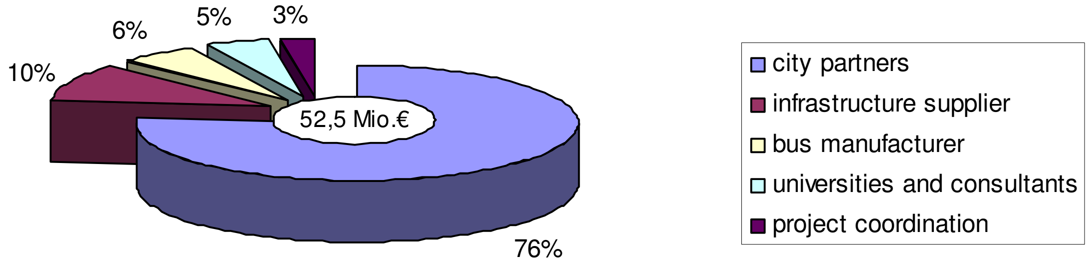


Figure 3-5: Distribution of costs by partner groups according to contract (based on CPF)

The 52.5 Mio. € was only part of the costs invested by all partners into the CUTE project. Figure 3-6 shows the deviation of actual costs (as taken from Cost Statements - CS - submitted to the European Commission) from the estimated costs for the first 48 months for the different partner groups. Positive percentage values indicate that the originally estimated costs were exceeded, and the negative values show the areas where project costs could not have been claimed for the project because of results of some activities, mainly evaluation, still being undertaken at the time of writing.

However even cost "over-runs" of 20-30% do not fully represent the overall costs incurred for CUTE. The total costs by all partners (including ECTOS) are estimated to exceed 100 Mio. €. This clearly demonstrates the level of commitment of the transport authorities, industry companies and research partners involved. In addition to the EC funding, substantial contributions were also made to each city by national and local bodies in order to make this project a reality. The time period to secure all funding across all sites for the CUTE project is estimated to be somewhere between 3 and 4 years.

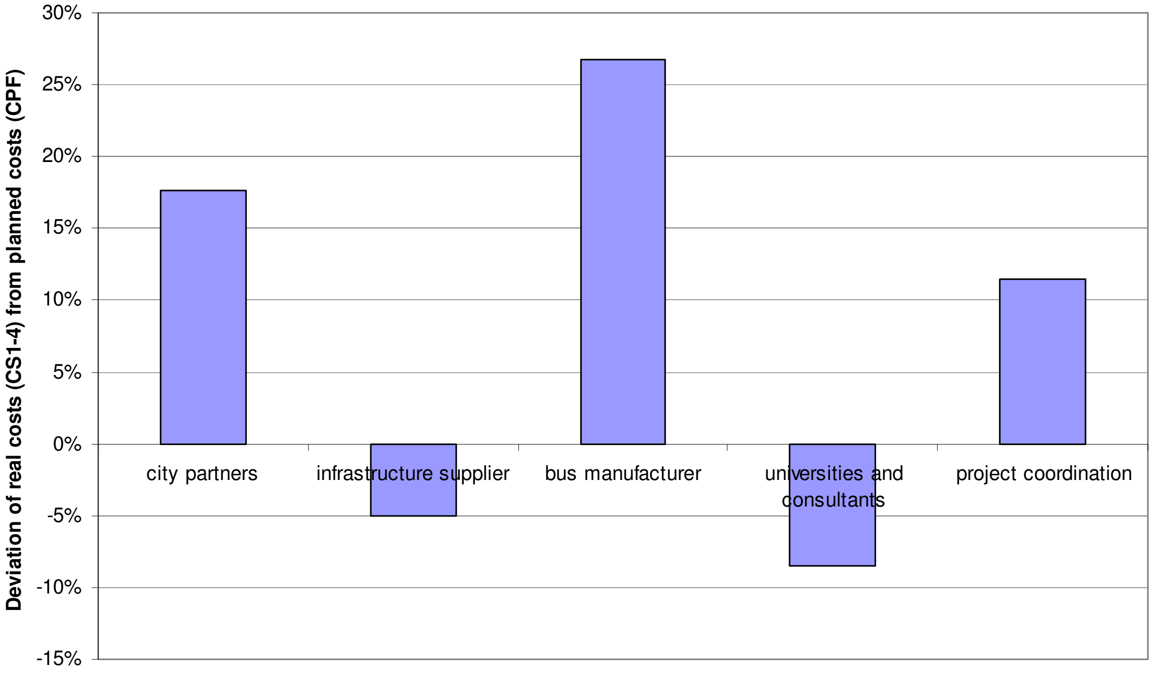


Figure 3-6: Comparison planned (CPF) – actual (CS 1-4) cost distribution

3.6 Project management aspects

The project management that was defined and established for the CUTE project is shown in the Figure 3-7.

The coordination of the project was carried out by the Project Coordinator in collaboration with the Steering Committee. The Project Coordinator reported to the European commission.

Three subgroups reported to the Project Coordinator:

- the transport companies (9 members)
- the infrastructure partners (6 members)
- the universities / consultants (6 members)

The 11 Work Packages were the responsibility of members of the three subgroups.

The Project Coordinator had technical and financial tasks. These roles, the respective tasks and the experiences collected during the project are described in the following two chapters.

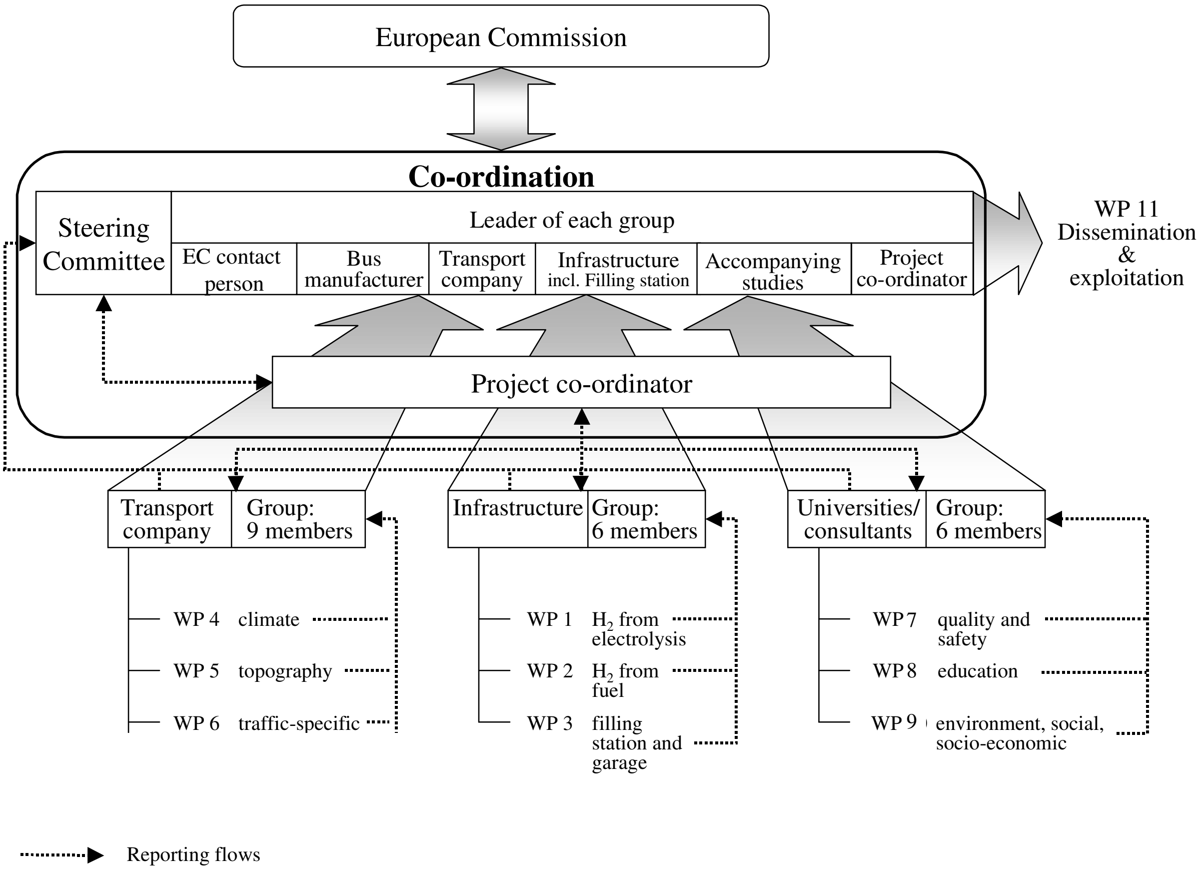


Figure 3-7: Overall project management structure

3.6.1 Technical

The responsibilities of the technical Project Coordinator were:

- Management of the consortium
- Coordination of the 11 Work Packages
- Organisation of the biannual project meetings with all partners
- Communication and reporting to the European Commission
- Project internal communication
- Interface to other EC projects
- Representation of the consortium at international level
- Coordination of bus operation
- Coordination of hydrogen infrastructure
- Data collection and data exchange between partners
- Communication/ Input with certification and regulation bodies for vehicle and H_2 infrastructure

Each of the 9 operating sites named a Site Coordinator and contact person for the site. These Site Coordinators represented the bus and infrastructure. These site coordinators were the direct contact for the Project Coordinator.

The Project Coordinator was supported internally by one person responsible for the coordination of bus fleet and one for the coordination of the infrastructure. These two coordinators concentrated on keeping the bus fleet and the infrastructure operational. They worked on the improvement of communication between the sites.

This concept of having on the one hand a centralized Project Coordinator, supported by the coordinators for the bus fleet and the infrastructure, and on the other hand decentralized site coordinators, proved to be very valuable because of streamlined but clear communication pathways.

The very ambitious technical objectives that were described in the Work Package tasks mostly needed more resources than was originally estimated. This led to problems for some partners which had to be resolved jointly by the partners, the Project Coordinator and the European Commission.

Biannual meetings were organized at the bus operation sites by the Project Coordinator. These were on a rotational basis in alphabetical order of the city names. At the meetings the overall progress of the project and at the different sites, as well as the tasks of the work packages, were discussed. This led to better communication in the project and provided outstanding opportunities for communications between the different participants. The meetings proved to be a good “monitoring tool” on the project progress for the Project Coordinator, all partners and the Scientific Officer from the European Commission.
Work Package Leader meetings and Work Package meetings were commonly held at the same time as partner meetings.

As the project meetings proved to be a good tool for monitoring the project progress, the web-site, www.fuel-cell-bus-club.com, with the member section added to this. Monthly updates of the various project data were posted to the webpage and provided all partners with the most current information on the operation of the sites.

The Project Coordinator submitted all Deliverables (see chapter 4.3.3) and further reports to the European Commission. This included reports on the project progress to the EC every six months. These centrally generated reports covered the progress in all tasks of the project, i.e. in the Work Packages, and were found to be very valuable for the supervision of the project.

The Steering Committee was established at the first partner meeting and was convened by the Project Coordinator at this meeting. Due to the well accepted project partner meetings and fruitful discussions the body of the Steering Committee was essential, but it was not necessary to hold other steering committee meetings. The Steering Committee was therefore not convened after the first meeting.

3.6.2 Financial

The responsibilities of the Financial Coordinator were:

- responsibility for all financial issues of the project to the EC
- Interface with the EC Financial Officer
- Ensuring timely submission of Cost Statements
- Facilitator and coordinator for amendment-, cost statement, mandate-processes within the project

The Cost Statement – and amendment – process was not easy to understand for partners with little experience in EC projects. This led to problems in the submission of statements, provision of mandates etc.

Cost Statements had to be submitted annually and all partners were required to hand in the documents to the Financial Coordinator who collected and submitted them to the EC. The size of the CUTE project and the short timeline for submitting the proposal led to some imprecision in the contract and the description of work. This created difficulties for some partners in presenting the costs.
The EC Cost Statement process has to be simplified, especially for big projects like CUTE involving partners with serial production. Worker and project related monitoring in a production line with

thousands of employees is neither efficient nor cost-effective. Therefore it is highly recommended that future large scale demonstration projects skip the personnel-related declaration of project work.

The amendment process for such a large partner group is extensive. To get the mandates for all partners was very time-consuming and sometimes difficult to achieve within the required time frames.

Information on depreciation timelines, processes for change of partners due to change of name etc. should have been explained in more details to the partners.

Sub-contracting of tasks to a different project partner is possible, but the costs associated with this are not eligible for funding. In instances where is in the interest of partners or the consortium that knowledge stays inside the group , but the partner does not have the capacity to carry out the actual task, it should be possible to get these costs funded as well. During the Fifth Framework program a Consortium Agreement between all partners was requested, but not mandatory. To get a contractual agreement between more than 25 partners from 9 countries proved to be very complex and could not be resolved. Therefore the project CUTE did not have a Consortium Agreement in place.

4 CUTE assessment framework

4.1 Methodology

The CUTE project was the first large scale demonstration project anywhere in the world of fuel cell public transport buses operating hydrogen production and fuel cell technologies under normal operational conditions. Prior to this project there was no "real life" knowledge or experience of either the certification processes or operation of fuel cell buses and hydrogen infrastructure, or the public acceptance of this new technology.

One important aspect of this project was to fill this information gap. It was therefore crucial to gather, analyse and evaluate the information, data and experience gained during the course of the project in a uniform and transparent way. This would ensure the rigour of the results and enable the findings to guide and support the decisions of policymakers, public transport companies/operators, developers of fuel cell buses and hydrogen infrastructure. The data produced would also provide the public with information and experiences.

The CUTE Assessment Framework was developed to assess the objectives of the project as defined in the description of work, Part B from the project proposal. The Framework provided a structured way for compiling the data gathered by the different project partners and to analyse and evaluate the technical and environmental aspects of the fuel cell bus system from a holistic perspective.

The fuel cell bus system being evaluated consisted of the hydrogen infrastructure (production, operation and end of life) and the production, operation (maintenance) and end of life of the fuel cell buses.

The CUTE Assessment Framework had to take into account the numerous partners and stakeholders involved as well as the many different aspects (technological, environmental and human experience/ acceptance) to be assessed. In order to provide a comprehensive basis for further development, the Framework was organised into the following key areas addressing the respective Work Packages (WP):

- Set up & operation of hydrogen production facilities (WP1, WP2)
- Set up and operation of the filling stations and garages (WP 3)
- Operation of the buses (WP 4, WP 5, WP 6)
- Quality and Safety for H_2 filling stations (WP 7)
- Experiences regarding training and education (WP 8)
- Environmental and economic evaluation and potential for future improvements (WP 9)
- Review of dissemination activities (WP 10)

This structure was designed to not only be suitable for the CUTE project, but also similar ongoing hydrogen demonstration projects as in Reykjavik (ECTOS), Perth, Western Australia (STEP) or California (AC transit FC bus project). It could also serve as the methodological basis for other projects of similar dimension.

Because of the complexity and dimensions of the project, various partners were involved in more than one area and similar information data needed to be assessed by different key areas. To avoid misunderstandings and misinterpretation, each of the areas follows the same structure, these were:

1. **Short description** of key area.
2. **Guiding questions**: Specific guiding questions for each key area to guide the focus of the researchers.

3. **Data collection**: MIPP[1] data sheets relevant for the WP detailing which data table/s were relevant.
4. **Indicators**: For each of the 7 areas specific qualitative and quantitative indicators were developed. The focus was on the development of quantitative indicators. If these could not be established qualitative indicators have been developed e.g. experiences from training.

The work flow of the Assessment framework, see Figure 4-1, was divided into the steps

- **Data collection and quality check**[2]: The coordination of the data collection was one of the responsibilities of the Project Coordinator. MIPP data tables were developed in order to have a common format for the data collection. These data tables included all major quantifiable aspects of the trial as well as some "more subjective" data such as passenger acceptance.
- **Analysis of data using indicators**: The submitted data were firstly subjected to a quality check for consistency, reliability and accuracy. They were then analysed focusing on the indicators defined for each key area.
- **Interpretation of the indicators**: The findings were then presented and discussed with reference to the indicators defined for the different key areas. Recommendations and projections for the investigated sectors (technology, admission, safety and environment) were based on the finding of the different work packages.

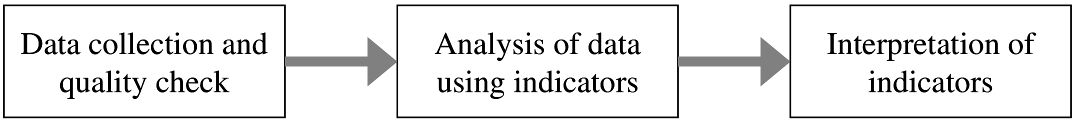


Figure 4-1: Work flow Assessment Framework

Since the application of the CUTE Assessment Framework showed that the methodology was suitable for complex projects like such as this, it has been used as the basis for the development of the Premia3 assessment framework. It has been adjusted to their specific boundary conditions and a dialogue between the two projects has been initiated.

4.2 Mission Profile Planning - MIPP

A comprehensive and transparent assessment framework is only of value if the necessary data for the assessment are available and provided in a way which meets the needs of all involved partners.

It is also important for the data handling to be organized in an efficient way. This is especially true for complex projects like CUTE or else the willingness to provide data is likely to decrease as the project progresses. The MIPP data sheets were therefore developed, based on the CUTE Assessment Framework to collect the necessary quantitative and qualitative information. This ensured a guided and structured process and provided the same data to be used by all parties.

The frequency of the data collection and submission varied according to the needs of the particular evaluation. Some were submitted monthly while others were collected and submitted on a once-off basis. Both types of data were integrated into a single data handling system.

Part 1: Continuously data gathering were submitted by way of the Mission Profile Planning (MIPP) data tables which handled the continuously monitored data needed for the assessment. The

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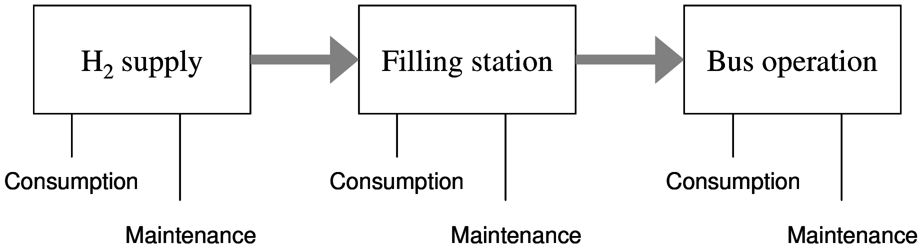
[1] MIPP: Mission Profile Planning, for more detailed information, please go to chapter 4.2

[2] Please find additional information on the measurement trials conducted and the data evaluation and quality check in chapter 4.4.2 and 4.4.4

[3] More information about this project can be found at www.premia-eu.org.

overall structure of the MIPP data tables is shown in Figure 4-2. For detailed description of the MIPP data sheets, please see Annex B: CUTE Assessment Framework.

Part 2: Data collected on a once off basis, e.g. training experiences, dissemination activities, cost data. The frequency was defined in accordance with the overall project objective requirements.



Collection frequency:	per day	per bus (if possible) and day	per bus and day

Figure 4-2: Structure of MIPP

4.3 *Phase 1 Assessment*[4]

Given the budgetary and technical risks associated with this ambitious project, it was decided at the contract signature stage to undertake an evaluation of the infrastructure development efforts (Phase 1) before moving on to the "real" demonstration stage (Phase 2) of the project.

The objective of the evaluation was to provide DG TREN-Dir D with an assessment of the results of Phase 1, which essentially covered the development of the hydrogen infrastructure. Based on this assessment DG TREN-Dir D was to decide whether to proceed with Phase 2.

This assessment hurdle was understandable when the European Commission's unique situation of allocating such large amounts of funding to one single project (5 Mio. € and 13.5 Mio. € for each phase) are considered. However as the fuel cell bus operation had to commence immediately after the approval of the Phase 1 Assessment, this contract clause left all the risks with the bus manufacturer and the bus operators. Only a substantial project group with enough financial resources is able to cope with such a limitation. Such a limitation is not acceptable for future demonstration projects and the involvement of smaller companies

4.3.1 Assessment procedure

The European Commission, DG TREN-Dir D, selected three independent experts who, together with the Project Co-ordinator and the EC Scientific Officer comprised the Evaluation Team. The three experts were responsible for performing the evaluation according to an agreed methodology which is detailed in the Final Evaluation report of Phase 1.

The assessment for the evaluation included a set of five evaluation criteria (see below) to be met by individual sites and the consortium and a scoring system to respectively quantify the level of fulfilment of the evaluation criteria. The Co-ordinator and the EC Scientific Officer

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[4] This section is based on the Final Evaluation report and the documents used in the course of the evaluation process. For more details on the evaluation results and the applied evaluation methodology please refer to these materials.

supported the evaluators with project related information. The Co-ordinator acted as the main contact person for the evaluators.

The evaluation criteria as agreed in the contract were as follows:

1. Each city/transport company had to establish a hydrogen infrastructure, either by producing hydrogen at the site or by purchasing hydrogen from a gas supplier. Each participating city had to demonstrate that the **hydrogen supply system** functioned well.
2. Each city had to establish a hydrogen filling station. Each participating city had to demonstrate that the **hydrogen filling station** functioned well.
3. The first fuel cell driven bus was delivered during the second project year. The manufacturer had to demonstrate the **performance of the bus** following the detailed specifications in the contract with the local authorities and/or bus operators.
4. The project had to develop a **specific methodology to evaluate the results for the demonstration phase** in order to demonstrate the environmental impact of the new technology in comparison with conventional propulsion systems. The methodology had to be approved by the Commission.
5. The **project- and participation- structure** for successfully accomplishing the goals for Phase 2 had to be ensured.

The evaluators and the Co-ordinator visited each site from July to November 2003 in order to check the current state of the infrastructure set-up and determine the progress of Phase 1 of the project. The evaluation itself followed a detailed questionnaire based on a set of criteria and the overall goals of the project. Each site was judged by points allocated to each criterion.

Before finalising the evaluation report the evaluation team participated in a detailed discussion with project team members in order to solve any misunderstandings and to update on the latest developments at the sites. After the submission of the report to the European Commission the Commission then decided to proceed to Phase 1. This decision was based on the successful compliance with the milestones, the evaluation report, the mid-term assessment report and overall information on the project.

4.3.2 Evaluation results and recommendations of the evaluators

The visits for evaluating the nine sites were carried out between July and November 2003. The score given to each city are shown in Table 4-1

Table 4-1: Evaluation score of the nine CUTE cities

CITY	Evaluation Marks per Criterion				TOTAL Mark	Comments
	# 1 (max. 48)	# 2 (max. 36)	# 3 (max. 12)	# 5 (max. 36)		
Madrid	47	24	12	36	**119** (max. 120)	A very well progressed, according to the timetable, clearly problem free site. Excellent effort in obtaining a long list of required licenses and permits. Dedicated and motivated team.
Barcelona	46.3	21.7	Not Applicable	35	**103** (max. 108)	A well progressing site, with efforts in producing hydrogen utilising green electricity; Bus operator with great experience with different fuels, LPG and CNG. Worth noting the differences in permitting with the Madrid site.
Hamburg	47	22	Not Applicable	34	**104.5** (max. 108)	A site that can definitely proceed to Phase II, without any apparent concerns. One of the evaluators, SDP, in a later visit experienced the refuelling of the buses and took a test-ride with one of the FCBs. The critical questions on the backup supply, permitting and H2 quality were all successfully answered during SDP's visit.
Stuttgart	47.8	24	Not Applicable	34	**106.8** (max. 108)	Another site that has achieved what was supposed to in the Phase I of the project and quite ready to move into the 2nd Phase. Has applied an interesting concept to ensure back-up H2 supply.
Amsterdam	45.3	23.3	Not Applicable	34	**104.8** (max. 108)	A team that had to fight early on unfounded and wrong media coverage about the safety of H2 technologies. It handled the matter very well and effectively. Its Phase I is completed and thus, ready to proceed with the operational phase of the buses. Is believed that the lack of back-up supply solution will not be a problem source. Very effective sponsorship of the project.
Porto	48	24	Not Applicable	36	**108** (max. 108)	Porto is been progressing very well, completed successfully Phase I and can move on with Phase II. Although an improvised refuelling process was demonstrated, the whole infrastructure is convincing as to meet the requirements. The purity of H2 has to be verified. Interestingly enough there were not any pertinent regulations for the H2 installations in Portugal.
Stockholm	46.5	24	Not Applicable	36	**106.5** (max. 108)	A site that has completed and demonstrated well what is needed for Phase I and ready to move to Phase II. The selection of the site may hinder the longevity and further expansion of the H2 infrastructure in the post-CUTE project times. Has to deal also with the route selection of the buses considering the weigh exemptions for the FCBs. A site that required the most components for the realisation of its H2 supply and refuelling depot.
Luxembourg	43	22	Not Applicable	34.5	**99.5** (max. 108)	Well-performing project site with motivated team, ready to proceed to Phase II. Back-up supply only possible through the primary supply route (CGH2 trailer delivery) via an alternative supply company.
London	36.3	22.3	Not Applicable	34.7	**93.3** (max. 108)	A site that ran from the beginning on unjust and stubborn opposition by the local authority on providing it with a permit for its "public" refuelling station. Whilst continuing fighting its case through the appropriate legal channels it has progressed on improvising an interim solution that would allow it to eventually jump into Phase II of the project, apparently without any delays. It is hoped that the interim solution will be properly functioning according to the time constraints and the project requirements. Specific recommendations should be taken aboard.

Beside the evaluation of each city the evaluators also gave recommendations on the overall project management and the assessment framework. These are listed below:

Overall project management related comments were:

- local dissemination is done with different measures and effort level; missing link between the local dissemination/information products and the project internet site
- a few cities are lacking sufficient means and a strategy to address the public concerns and inform it correctly about hydrogen technologies → successful PR campaigns can address media concerns and questions to isolate possible political animosities
- the operational permits of various sites are limited to the duration of the CUTE project → what is to be expected for a post CUTE phase?
- all sites should have harmonised billboards in place identifying the project and its sponsors (European Commission and local sponsors)
- communication between the different sites was not as extensive as one would expect → the exchange of practices and information should be promoted
- It would be useful to have harmonised training manuals both for the FCB drivers as well as the refuelling technicians in the project file (upon its completion)
- organise a meeting of the whole consortium to present the evaluation report and discuss the Assessment framework

According to the comments on the Assessment framework the evaluation should be focused on issues like (selection):

- Is the proposed scope of the assessment consistent with its goal? e.g. is the only purpose to assess the project per se, or to assess the different technologies under demonstration and to draw lessons for all the stakeholders.
- Is it possible to make comparative analyses of the different configurations and technological options?
- How to track problems (and be able to propose solutions) along the whole production to operation chain?
- How to apply this framework to other EU and international projects? i.e. currently it is closely tied to CUTE structure, work packages and deliverables

4.3.3 Restructuring the deliverables (Phase 1 to Phase 2)

As a part of the transition from Phase 1 to Phase 2 the number and content of the project deliverables were restructured.
In the original contract 50 deliverables were defined to report on the project progress and all findings of the project over the 5 year timeline of CUTE.

The progress and results of CUTE at the end of Phase 1 indicated that it would be difficult to deliver an objective representation of the project goals and the results with the original structure of the deliverables. The deliverables were therefore restructured to concentrate on the main objectives of CUTE.

The Table 4-2 shows the restructuring of the deliverables.
The original 50 deliverables were correlated with the nine new deliverables for Phase 2. The reduction to the nine deliverables allowed a streamlining of the project reports and a concentration on the key objectives without reducing the contents or objectives of the project.

Table 4-2: Deliverable restructuring

Deliv. No old	Deliverable title OLD	Deliv. No new	Deliverable title NEW	Dissemination level*)
D 1	Handbook for installing a complete H_2 supply chain via electrolysis	D1	Hydrogen Infrastructure - Operation Results of the Various Hydrogen Production & Supply Routes and Filling Stations	RE
D 2	Handbook for the operation of a H_2 production route via electrolysis			
D 3	Revised maintenance plan for the complete production facility			
.....	......			
D 13	Maintenance plan of the filling station and the garage			
D 15	Catalogue of improvements of the filling station and the garage			
D 14	Delivery of one fuel cell driven bus	D2	Operation of FC buses – Experiences & results of operation under different climatic, topographic and traffic conditions	RE
D 16	Results of operational use of FC buses as a function of the climate			
D 17	Compilation of experiences from drivers of FC buses in warm and cold regions of Europe.			
.....	....			
D 27	Guidelines for replacement of wearing parts as a function of the different traffic conditions.			
D 29	Analysis of existing regulations for the admission and certification	D3	Quality & Safety Methodology	PU
D 28	Report on admission of system components	D9	Report on Admission of system components	RE
D 30	Handbooks for the description of the applied components			
D 31	Detailed description of working procedures and working conditions for the operating and maintenance staff	D4	Training & Education – the human part of CUTE	PU
......	......			
D 34	Requirement catalogues for industrial education/training and academic research programs			
D 35	Compilation of necessary educational contents			

D 36	Report on the methodology development of the different surveys	D5	LCA of the different bus technologies	RE
D 37	Report of the environmental analysis of the fuel cell bus systems including the different production routes, the use phase and the recycling phase			
D 38	Comparison of the new propulsion technology with conventionally powered bus systems considering the primary energy, the emissions and the used resources			
D 39	Technical and economical reports	D6	Economic analysis of hydrogen infrastructure	PU
D 40	Exploitation and implementation plans	D7	Dissemination a) Final Conference b) Brochure c) Web page d) Report on dissemination activities conducted	PU
D 41	Web site presentation of the project			
D 42	Presentation material on different media for the project, conferences and workshop proceedings			
D 43	Consortium agreement	D8	Final report - Report - Exec. Summary	 PU PU
D 44	Reports (6 monthly or annual and mid-term)			
D 45	Final project report			

4.4 Data collection and monitoring

4.4.1 Workflow of data collection

The general process of data acquisition worked as follows: The relevant data were noted down daily, weekly or monthly by the station operator, the person refuelling, the bus driver, and collected by a designated person. These data sets were reported monthly to the project management, usually by the 15th of the following month. In some cases, bus data and infrastructure data from one site were gathered and forwarded by different project partners. Data submission took place *via* spreadsheets initially, with a gradual shift to using an online submission tool.[5]

4.4.2 Monthly data evaluation

The data collected *via* the MIPP sheets or later *via* the online tool were evaluated after being received from the partners. Completeness and accuracy were checked for all data that were requested in the data sheets. This was done before the end of the month.

Based on the collected data a general overview, the so called site summary, was created for all sites, i.e. the projects ECTOS, STEP and BEIJING were included in this report as well.

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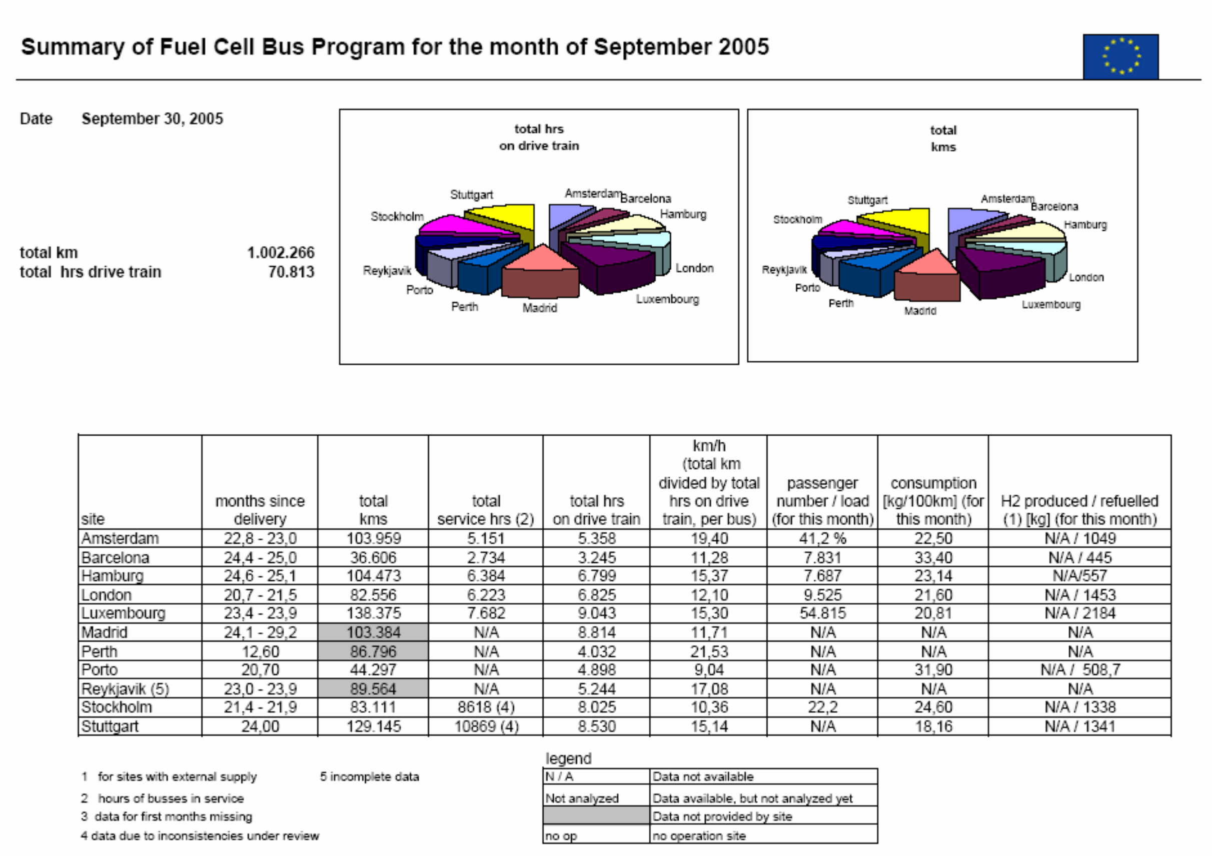
[5] Inside the project, these data tables are know as “MIPP sheets”, MIPP standing for “Mission Profile Planning”. See also chapter 4.2.

The site summary was prepared every month and consisted of

- Facts and Figures of the bus and infrastructure operation for the respective month
- Bus incidents for that respective month
- Data and bus availability (overall and by site)
- Infrastructure incidents for that respective month

All site summaries can be found in the Annex F of this report.



Summary of Fuel Cell Bus Program for the month of September 2005

Date **September 30, 2005**

total km	**1.002.266**
total hrs drive train	**70.813**

site	months since delivery	total kms	total service hrs (2)	total hrs on drive train	km/h (total km divided by total hrs on drive train, per bus)	passenger number / load (for this month)	consumption [kg/100km] (for this month)	H2 produced / refuelled (1) [kg] (for this month)
Amsterdam	22,8 - 23,0	103.959	5.151	5.358	19,40	41,2 %	22,50	N/A / 1049
Barcelona	24,4 - 25,0	36.606	2.734	3.245	11,28	7.831	33,40	N/A / 445
Hamburg	24,6 - 25,1	104.473	6.384	6.799	15,37	7.687	23,14	N/A/557
London	20,7 - 21,5	82.556	6.223	6.825	12,10	9.525	21,60	N/A / 1453
Luxembourg	23,4 - 23,9	138.375	7.682	9.043	15,30	54.815	20,81	N/A / 2184
Madrid	24,1 - 29,2	103.384	N/A	8.814	11,71	N/A	N/A	N/A
Perth	12,60	86.796	N/A	4.032	21,53	N/A	N/A	N/A
Porto	20,70	44.297	N/A	4.898	9,04	N/A	31,90	N/A / 508,7
Reykjavik (5)	23,0 - 23,9	89.564	N/A	5.244	17,08	N/A	N/A	N/A
Stockholm	21,4 - 21,9	83.111	8618 (4)	8.025	10,36	22,2	24,60	N/A / 1338
Stuttgart	24,00	129.145	10869 (4)	8.530	15,14	N/A	18,16	N/A / 1341

1 for sites with external supply
2 hours of busses in service
3 data for first months missing
4 data due to inconsistencies under review
5 incomplete data

legend

N / A	Data not available
Not analyzed	Data available, but not analyzed yet
▨	Data not provided by site
no op	no operation site

Figure 4-3: Facts and figure section of the site summary report, for the month of September 2005

The section "Facts and Figures of the bus and infrastructure operation" included the following information:

Overall project

- Total kilometres
- Total hours
- Pie charts for total kilometres and hours broken down by sites

For each site (for all three buses, averaged):

- Total kilometres
- Total service hours[6]
- Total hours on drive train[7]

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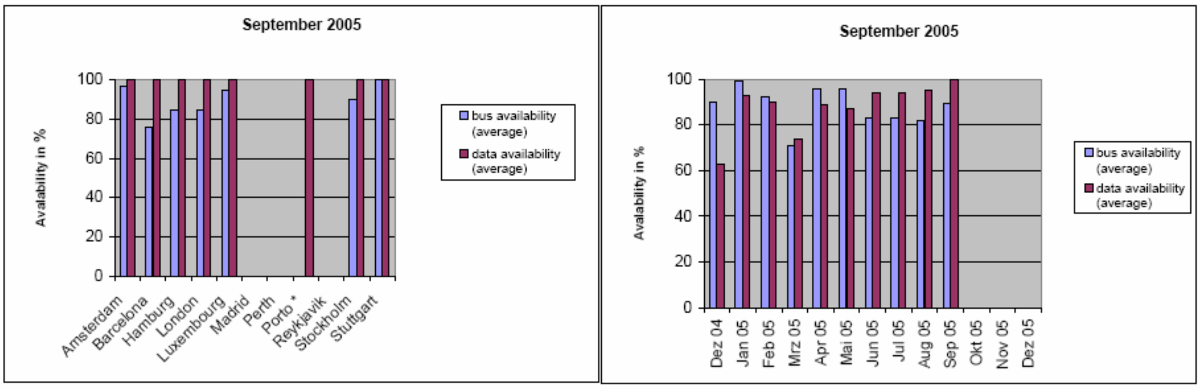
[6] Service hour: hours that the buses were actually in revenue service. This does not include trips to fuelling station, testing, etc.

[7] Drive train hours: Hours the buses were in operation including trips to fuelling station, testing etc.

- Average speed (km/h)
- Passenger number / passenger load
- Consumption (kg/100 km)
- Hydrogen produced / hydrogen refuelled

The section “bus incidents of [respective month]” summarized the issues that occurred on the buses during that month. This focused on the failure and replacement of parts of the fuel cell drive train.

The availabilities provided in the section “data and bus availability” gave an overview of the quality of data feedback by the sites and the bus operation, for the respective month and for the whole reporting period (see Figure 4-4).



bus availability: based on the data that is fed back through the MiPP sheets, e.g. bus is available (not in maintenance/repair) for 20 days out of 25 days of data, the bus availability is 80%

data availability: based on the number of days in the months the availability is calcucated for those days with input in the MiPP sheets, e.g. out of a 30 day month on 25 days data is provided, the data availability is 83%

Figure 4-4: Data and bus availability, for the month of September 2005

The “infrastructure incidents”-section listed the monthly-issues of the fuelling station in the different sites.

The site summary was sent to the partners each month together with the MIPP data evaluation sheets along with any feedback about the accuracy and completeness of their data sheets. At the same time all files were uploaded to the project website where the Work Package leaders could access them for evaluation.

The site managers and submitting partners usually provided comment on the feedback back to the Co-ordinator within few weeks.

4.4.3 Questionnaires

It soon became obvious soon to the Work Package leaders that while the data provided were a good base for their evaluations, a comprehensive assessment would also need more qualitative data. Therefore, the routine process of data collection was complemented by questionnaires filled in by the site coordinators, by other project partners, and sometimes by third parties, such as the technology suppliers. Questionnaires were used to collect information required only once, for example concerning the approval process, or to obtain the current views of partners - being stakeholders - regarding matters such as assessments, learnings and problems.

Other areas included the set-up of the infrastructure, dissemination activities, training and education, bus operation.

4.4.4 Measurement trials

In the beginning of the operation phase, the Work Package leaders of deliverable 2 “bus operation – under climatic, topographical and traffic influences” agreed that additional testing would be necessary in order to do an analysis or comparison with regard to climate, topography or traffic. Through these tests a comprehensive understanding of the energy system of the buses and an evaluation of different parameter influences on bus operation would be possible.

DaimlerChrysler, Ballard, and the Work Package leaders jointly developed a testing procedure. Some of these tests were so called drive cycle tests where the buses ran on a regular route and a test evaluator recorded data such as the number of passengers on board or any unusual event, e.g. road construction or traffic congestion. Other special tests were set up to analyse variables such as the energy system under average speed or to test the air conditioning.

Measurement trials were performed in Amsterdam, Luxembourg, London, Porto, Stockholm, Stuttgart and in Reykjavik.

From the drive cycle and other complementary tests, data measured on the bus for each test run were received from Ballard by the Work Package leaders. A confidential document provided by Ballard defined the data that would be made available for those test runs and gave background information to the energy system. These data were the basis for the analysis of the work packages. Deliverable 2 presents the results of these analyses, i.e. the influences of the different boundary conditions on the fuel consumption, and also the investigation and definition of optimisation potentials.

5 Findings and results of CUTE

This chapter presents the results and findings of the different Work Packages. It is structured according to the deliverables of the CUTE project and is based on the executive summaries of each deliverable. In order to put the findings and results into perspective with regard to the assessment framework developed, the guiding questions for each deliverable are stated at the beginning of each section. Further detailed information on the results can be found in the respective deliverables.

5.1 Hydrogen infrastructure

5.1.1 Guiding questions

To focus the results and learnings of operating a hydrogen fuel infrastructure across Europe, the following guiding questions were formulated:

- What were the main problems and learnings during planning, implementation and operation of the infrastructure (hydrogen production unit and station unit)?
- Were there permitting problems relating to safety?[8] Were there safety problems during operation?
- What were the availabilities of the hydrogen production unit and of the station unit?
- What caused the units to be out of service?
- What was the energy demand for supplying hydrogen to the buses?
- What improvements are recommended for the future?

5.1.2 Introduction

Hydrogen can be produced by different technologies using different energy sources. One unique fact of CUTE is that numerous different hydrogen infrastructure solutions were realised. At the beginning of the project, it was not known how the different hydrogen supply pathways would perform.

There were two major supply strategies as the hydrogen could either be produced on-site at the filling station, or externally by centralised plants and trucked into the station. In six of the nine cities, hydrogen supply was based on fully or partly on-site production. Amsterdam, Barcelona, Hamburg and Stockholm used electrolysers to split water into its constituents - hydrogen and oxygen. Madrid and Stuttgart employed steam methane reformers to derive hydrogen from natural gas. Over 120.000 kg of hydrogen were produced on-site with about 56 % of this being derived from “green” electricity, i.e. hydro power and combustion of solid biomass, in Amsterdam, Hamburg and Stockholm.

London, Luxembourg and Porto relied solely on hydrogen from external sources delivered by truck to the refuelling sites. The hydrogen was produced *via* electrolysis (Porto), as a by-product of a chemical plant (Luxembourg), and from centralised large-scale steam methane reforming. London effectively worked with two stations: An installation with trucked-in gaseous hydrogen storage was installed and utilised until the final unit became operational. This unit included a tank for storing liquid hydrogen - the only one in CUTE.

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[8] Matters of approval and certification are addressed in section 5.4

Figure 5-1 gives an overview on the implemented supply paths.

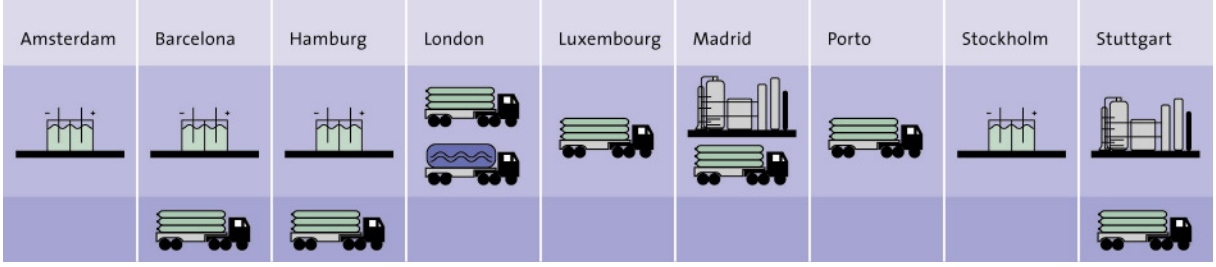

Figure 5-1: Overview of the hydrogen supply in the nine CUTE cities.

The upper row represents the usual way of supply (for example on-site electrolysis in Amsterdam, on-site steam methane reforming in Stuttgart, or external supply by truck in Luxembourg). The lower row shows the external backup supply at the sites with regular on-site generation. Some sites decided to implement this backup supply to bridge periods when the on-site productions was out of operation. London initially relied on gaseous hydrogen supply and subsequently switched to liquid delivery and storage. Madrid had a mix of on-site steam reforming and external supply on a regular basis.

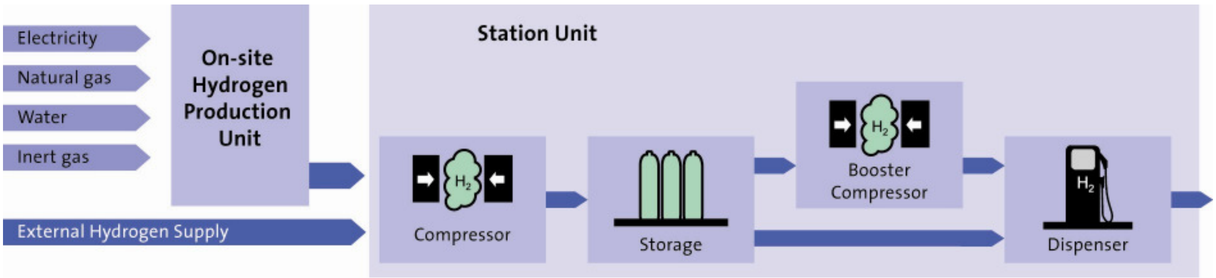

Figure 5-2: Generalised schematic of the CUTE hydrogen infrastructures.

Figure 5-2 outlines the schematic layout of a H_2 filling station in the CUTE project. Hydrogen was supplied by truck from external sources or generated on site. It was compressed, stored, and dispensed on demand to the buses. Dispensing required a pressure differential between the on-site storage and the vehicle tanks. The pressure differential resulting from the empty bus tanks allowed filling to commence and filling was completed with a booster compressor.

A more detailed description of the H_2 infrastructures in all 9 CUTE cities is given in Annex G.

5.1.3 Results

All filling stations except one were operational (available) for more than 80% of the time over the two years of operation. The majority had an availability of more than 90%. Reliability in terms of successfully completed filling was somewhat lower in general. Critical components turned out to be compressors and the refuelling interface.

The CUTE hydrogen filling stations supplied the fuel cell buses with more than 192.000 kg hydrogen in more than 8.900 fillings. This is far more than in any previous trial of hydrogen-powered vehicles (see Figure 5-3 and Figure 5-4).

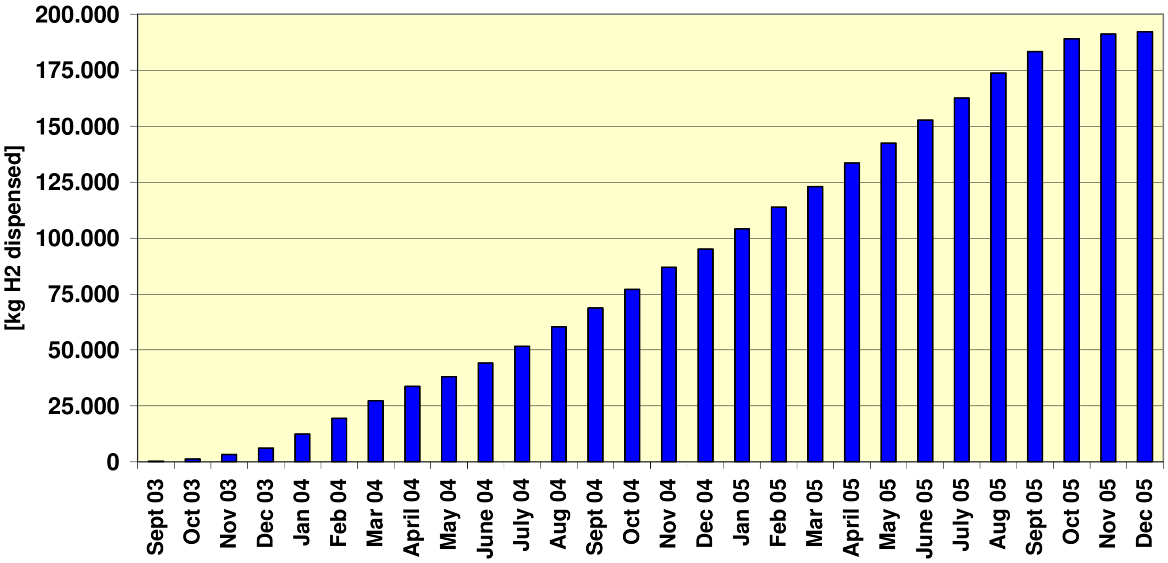

Figure 5-3: Total quantity of hydrogen dispensed in the CUTE project.

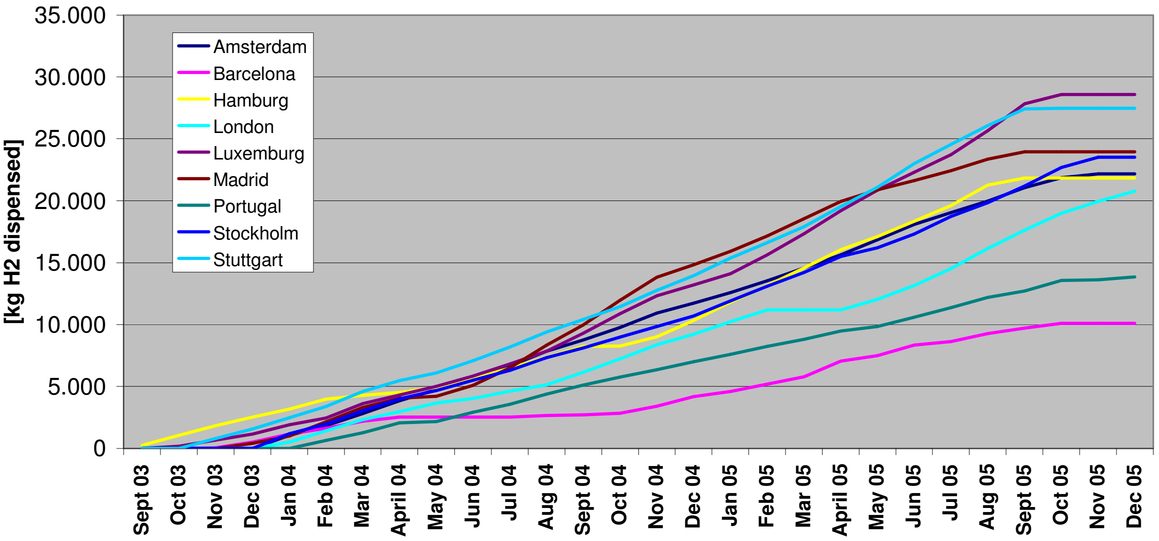

Figure 5-4: Quantity of hydrogen dispensed in the nine CUTE cities.

The hydrogen production units equipped with electrolysers met expectations well.

Hydrogen generation from natural gas was not as satisfactory: While steam reformer plants at an industrial scale have been state-of-the-art for decades, the small on-site units used in CUTE had not been widely used previously and had difficulty coping with some of challenges such as high load flexibility.

The nine sites with their different operating approaches have produced very different results that are often difficult to compare. This has meant that a definition of best practices is not possible at this stage.

5.1.4 Operators´ view

The quantitative findings from the analysis were in line with statements from the bus and station operators when they were consulted about their views on advances and issues arising from the trials.

The experiences gained were widely appreciated by the operators, despite the need for significant improvements in future. The user interface was given first priority in terms of safety. Operators were generally satisfied with the performance of the infrastructure installations. The level of their individual satisfaction reflected the availability of the particular local facility. For a similar project, most of them would choose the same site for their station again, as well as the same way of hydrogen supply and the same type of station technology.

Using hydrogen is not considered more dangerous than conventional fuels when the special requirements are complied with. Bus operators that had previous experiences with natural gas powered vehicles and refuelling installations pointed out that there were no fundamental differences between natural gas and hydrogen infrastructures.

5.1.5 Learnings

Future demonstration activities should include “fleet trials” of hydrogen production and refuelling facilities that enable experiences with technologies from one supplier to be compared under different boundary conditions, as was possible with the fuel cell buses under CUTE. A coherent concept for data acquisition and evaluation across sites and even between individual projects must be a prerequisite, not only in transport-related activities.

The issue of harmonised regulations for the approval of hydrogen refuelling installations needs to be tackled in order to assure planning reliability in all parts of the EU (and beyond) and to facilitate a cost reducing standardisation of the technology[9]. Operating experiences from CUTE and other hydrogen infrastructures need to be disseminated to approval bodies at all levels in order to avoid, for example, local authorities imposing highly over-engineered safety features because of their inexperience with hydrogen technology.

CUTE has been an important step towards sustainability in public transport but it has been only one of the first steps that are needed. With the next steps, hydrogen as a fuel has to get even closer to the day-to-day needs of bus operators. The hydrogen infrastructures used in CUTE were realistic for the supply of small fleets. Larger fleets will require the refuelling of numerous units in parallel, either with substantially reduced refuelling times and no waiting between two vehicles, or slow refuelling overnight. Refuelling at 700 bar would also help by increasing vehicle range. Concepts and components for installations such as these are not currently at hand.

5.2 Economic evaluation of the hydrogen infrastructure

5.2.1 Guiding questions

The main guiding questions for the economic evaluation of the H_2 infrastructure are:

- What are the detailed costs for the H_2 based on the infrastructure concepts implemented in CUTE (*status quo*)?
- How will the cost for H_2 develop for an increased level of market penetration using scenarios (future scenarios)?

5.2.2 Introduction

Since the hydrogen costs are a major factor influencing the overall economics of hydrogen powered transportation an economic analysis of the hydrogen infrastructure was conducted within work package 9 as part of the accompanying studies.[10]

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[9] see also section 5.4

[10] For more detailed results please see Deliverable No. 6: Economic analysis of the hydrogen infrastructure

The study addressed the guiding questions of the CUTE Assessment Framework (costs for infrastructure and fuel supply *status quo*, creation of future scenarios and costs for the future scenarios). It gives an overview of the economics of the CUTE hydrogen infrastructure based on actual cost numbers as they occurred within the project. These cost numbers represent the situation for small production capacity of on-site production units (50 Nm^3/h for steam reforming, 60 Nm^3/h for electrolyser and prototype production units) and small volume for trucked-in hydrogen.

Based on this CUTE *status quo,* a *future scenario* has been constructed intended to meet the hydrogen demand of 2015 as envisioned by the European Commission (EC). The necessary production capacity was based on

- the goal of substituting 2 % of conventional fuel by hydrogen (based on energy content; lower calorific value) as stated in the EC Whitepaper: „European Transport Policy for 2010: time to decide“; COM (2001) 370 and

- an estimated fuel demand based on the number of buses and coaches published in statistics by DG TREN, an increase of 10 % of buses every 10 years, an average fuel economy of 49 l diesel per 100 km and a yearly mileage of 60.000 km.

Using these boundary conditions 170 on-site production plants with a production capacity of 600 Nm^3/h each would be required in 2015. This implied the operation of 170 FC bus fleets throughout Europe with 73 buses each, operating with a fuel economy of 10.8 kg hydrogen per 100 km.

5.2.3 Status Quo

The economic analysis of the *status quo* was performed based on the following level of detail: Overall equipment (initial investment), maintenance, operation and site preparation cost.

Since the cost for the different categories varied between the different sites, the results are presented as average values showing the minimum and maximum range. The minimum numbers consist of the minimum cost provided by the infrastructure suppliers for each module (electrolyser/steam reformer, storage concept, compressor, dispenser and maintenance) and the minimum cost for site preparation. The maximum numbers consists of the maximum cost of each module.

As the energy consumption is independent of the non-operational cost, the same energy consumption has been considered for all scenarios. The energy consumption considered represents the average number from all sites of the total filling station (electrolyser 5.8 kWh electricity per Nm^3 hydrogen; steam reformer 7 kWh natural gas and 1 kWh electricity per Nm^3 hydrogen).

The high consumption of natural gas of the on site steam reformer was based on the fact that they were rarely operated under full load conditions leading to a significantly decreased energy efficiency of the steam reformer. To better represent an operation according to design specifications, the economics of the steam reformer was also calculated and presented for full load operation (4.7 kWh natural gas and 1 kWh electricity per Nm^3 hydrogen).

For on-site production the non-operational costs (overall equipment, maintenance and site preparation) within the CUTE project were between approximately 5 € and 9 € per kg of hydrogen produced by electrolyser and between approximately 7 € and 10 € per kg of hydrogen produced by steam reforming. The wide range of the cost numbers is due to the fact that the cost numbers for on-site production facilities are based on prototype, custom built plants (electrolyser, steam reformer, compressor and dispenser). The overall production cost for hydrogen was dominated by energy costs. As the cost for energy supply was regionally specific, the overall cost for hydrogen production could be determined using the regional energy cost, energy consumption and the range of non operational costs.

5.2.4 Future scenario

The economics of future plants with a capacity of 600 Nm^3/h have been calculated using the six-tenth factor for up scaling, cost reduction factors related to the increase of plant numbers produced, an internal return of return (IRR) of 12 % and an increase in efficiency. The electricity consumption of filling stations with on-site electrolysers has been modelled using 5.5 kWh per Nm^3 hydrogen while 4.2 kWh natural gas and 0.6 kWh electricity have been assumed for steam reforming.

The non-operational cost for the future scenario decreased to approx. 2.0 € ÷ 2.5 € for hydrogen production *via* on-site electrolyser, and to approx. 1.5 € ÷ 2.25 € per kg hydrogen for steam reforming.

Figure 5-5 and Figure 5-6 illustrate results for electricity costs of 0.07 € and 0.1 € per kWh and varying costs for natural gas. They also show that, depending on the locally prevailing costs for the energy carriers used, cost ranges can be determined within which one particular technology is preferable over another, or when the non-operational (capital) costs become decisive.

The analysis of Figure 5-6 shows that for an estimated cost for electricity of 0.1 € per kWh on site steam reforming is the preferable technology when the cost for natural gas is less than approx. 0.102 € per kWh. Production of hydrogen by electrolyser should be preferred if the cost for natural gas is greater than approx. 0.127 € per kWh. Between approx. 0.102 € and approx. 0.127 € per kWh natural gas the non operational cost is the decisive factor.

Should the electricity cost be 0.07 € per kWh as shown in Figure 5-5, on site steam reforming is the preferable technology if the cost for natural gas is less than approx. 0.078 € per kWh. Production of hydrogen by electrolyser should be preferred if the cost for natural gas is greater than approx. 0.104 € per kWh. Between approx. 0.078 € and approx. 0.104 € per kWh natural gas the non operational costs are decisive.

Because the determination of the preferable technology from an economic point of view is closely related to the cost for energy supply, it is therefore necessary to consider local boundary conditions when comparing different infrastructure scenarios.

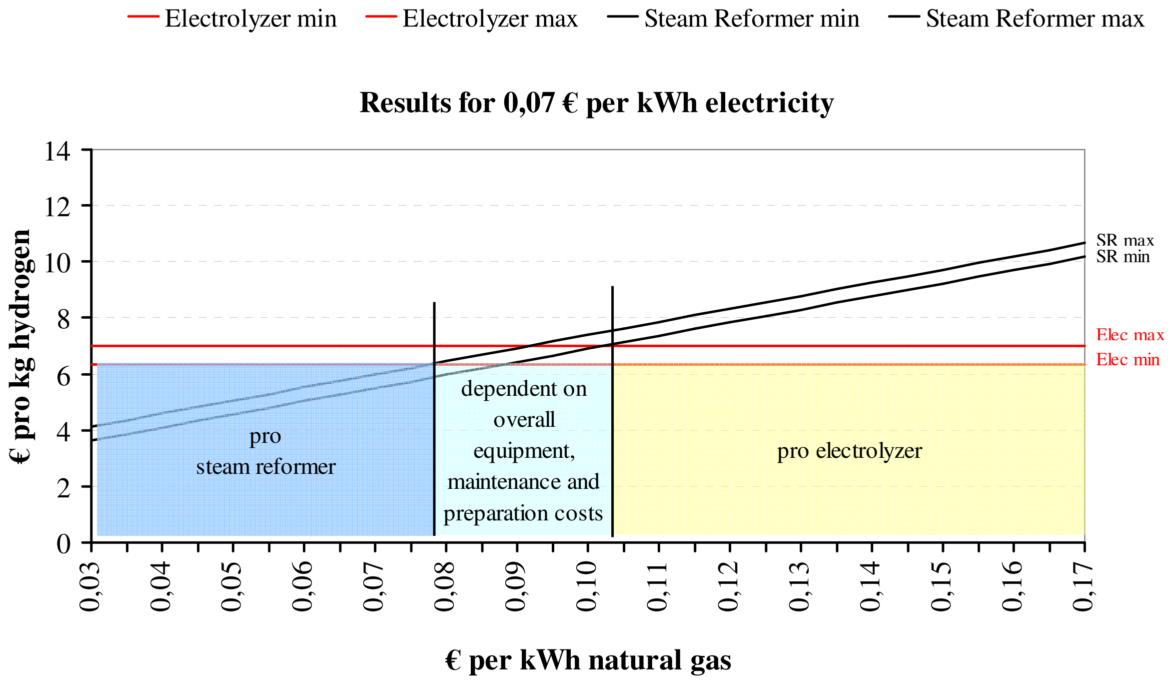

Figure 5-5: Future scenario: Reformer – Electrolyser; cost for electricity 0.07 € per kWh

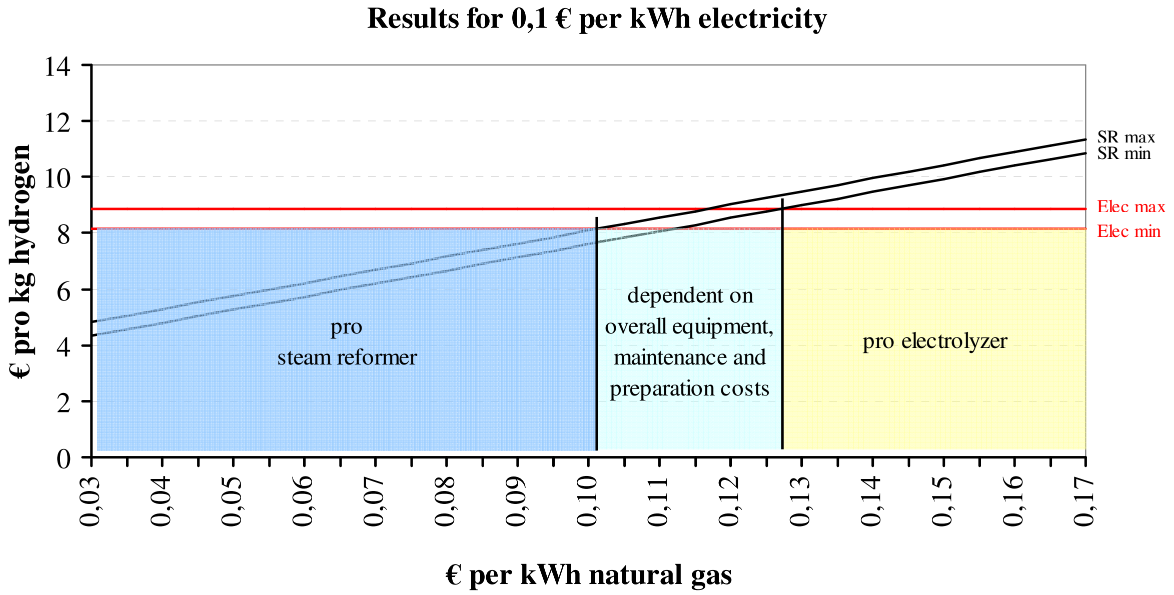

Figure 5-6: Future scenario: Reformer – Electrolyser; cost for electricity 0.10 € per kWh

5.2.5 Findings

The comparison of the *status quo* and the *future scenario* shows the contribution of the non-operational cost is likely to decrease in the future. This is due to the greater decrease of the non operational cost as a result of up-scaling and learning curve effects, compared with the decrease of operational cost resulting from an increase of energy efficiency in the future.

Status quo

- Regional boundary conditions are decisive,
- Absolute non-operational costs are independent of the utilization rate of the production unit,
- Within CUTE boundary conditions the non-operational cost is higher for steam reformer than for electrolyser hydrogen production ,
- Cost for site preparation and storage are not insignificant and
- The maintenance cost for both on-site technologies adds up to an average of 5 % to 8 % of the initial investment cost. Cost related to warranty repairs and special incidents are not included and must be discussed independently.

Future scenario

- Cost reduction potential is higher for steam reformer compared with electrolyser hydrogen production and
- No general statement favouring one of the options can be made as the overall cost is closely related to regional boundary conditions e.g. cost for trucked-in hydrogen varied by a factor of 4 between different sites.

Based on the findings of this study, it is possible to determine the cost for on site steam reformer & electrolyser hydrogen production and trucked-in hydrogen for different boundary conditions by varying the key parameters such as the cost for energy, efficiencies, capacity and number of on-site production units, maintenance and site preparation cost, IRR[11] applied to investment cost.

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[11] IRR = Internal Rate of Return

When comparing the hydrogen production costs calculated in this study with cost numbers provided by other studies it is essential to carefully consider the boundary conditions that have been applied

5.3 Quality & Safety

5.3.1 Guiding questions

For the work package on Quality and safety the following guiding questions were defined:

- What quality and safety systems are installed by the different cities?
- Is there a formal approach to Q & S issues?
- What form of risk analysis and risk control is conducted?
- What kind of quality management system is applied?
- What will be the next steps to harmonise quality and safety in hydrogen filling stations?
- What guidelines on quality and safety for future hydrogen filling stations can be developed?

5.3.2 The Task

Work Package 7 (WP7) covered Quality and Safety in the CUTE project. The purpose of the work was to develop a recommended quality and safety methodology to be used when establishing future hydrogen refuelling station. The objectives for WP 7 were:

- Development of a quality and safety methodology to be used as a basis for guidelines for future hydrogen filling stations. The methodology was to be developed based on existing knowledge and monitoring of CUTE project activities, and to focus on the anticipated future needs and requirements for transport companies.

- Documentation of technical safety requirements for the permitting, manufacturing, and usage of the technology. This included the infrastructure for the H_2 supply and its use in fuel cell powered buses in different European countries.

A draft quality and safety methodology was developed in Phase 1 of the CUTE project. The intention of WP7 was to use this methodology in collecting and assessing experiences during the operations phase (Phase 2) of the project. Development, introduction and follow up of a monitoring scheme with subsequent data collecting and processing have been key activities.

The scope was the hydrogen supply and hydrogen station illustrated below.

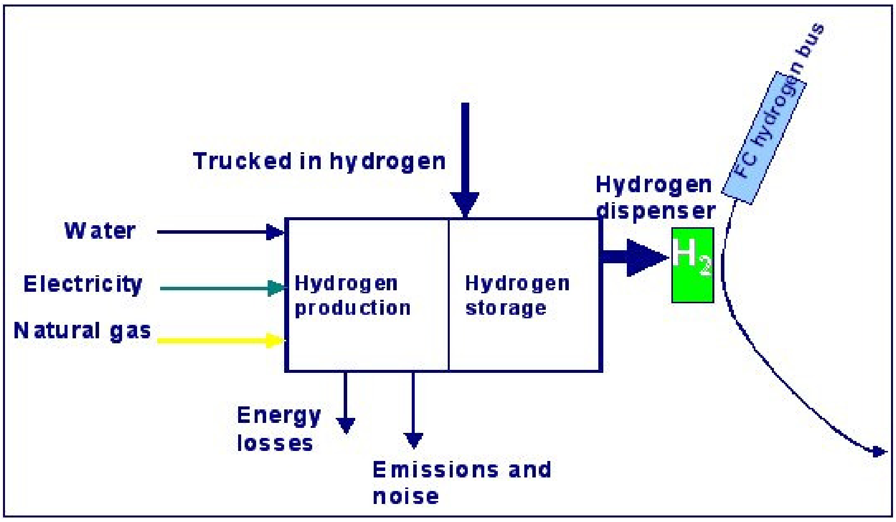

Figure 5-7: The scope of WP7, Quality and Safety Methodology

All the cities and other project partners contributed valuable feedback and input to the monitoring programme, the quality and safety approach, and to the results.

The work involving the cities was carried out through individual meetings and telephone conferences during the project and followed up in all the CUTE project meetings.

5.3.3 The Results

Quality

WP 7 followed the definition of quality as described in EN-ISO 9000:2000. High quality means satisfied customers.

A quality management methodology in line with the ISO standard is the PDCA methodology, also known as the Deming methodology[12]. The methodology comprises four basic steps: **P**lan what to do - **D**o what you have planned – Monitor and **C**heck the results of what you have done – **A**ct to correct as needed. (see Figure 5-8)

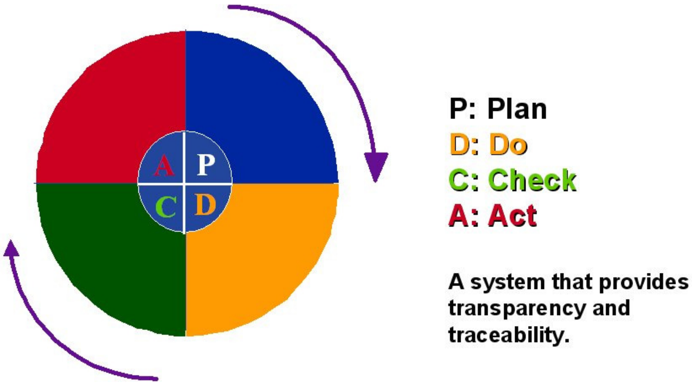

Figure 5-8: The PDCA Methodology according to Deming

The CUTE project implemented the PDCA approach. The performance of the hydrogen stations and hydrogen supply systems in Phase 2 has been evaluated and compared with the stakeholders' expectations.

In order to close any gap between the actual performance and what the stakeholders expected, quality and safety deviations were monitored and communicated. Communication of requirements and expectations between the city project groups and other stakeholders was vital. The common reporting system, the Mission Profile Planning (MIPP), and the project meetings involving all the sites proved valuable in developing a common appreciation of performance monitoring.

Continuously improved performance during the project's lifespan was a key to the project's success. To encourage quality improvement, deviations need to be recorded, followed up and appropriately handled. The experiences need to be communicated. This was done in the CUTE project.

DaimlerChrysler and Ballard used the PDCA approach efficiently during the planning and the operation of the buses.

The fuel-cell buses performed far better than expected by the project partners and stakeholders. Deviations, e.g. the transmitter failures, were closed efficiently, and the overall results were of high quality. The customers were satisfied. An extensive service and maintenance programme with on-site personnel was one of the keys to this success.

Application of the PDCA approach for the hydrogen stations improved considerably during the project's lifespan. The common incident reporting and follow-up system introduced by the Safety and Security Task Force in 2004 turned out to be a valuable tool. Deviations were reported and handled locally; modifications and improvements were carried out. Safety related deviations and incidents were discussed and followed-up within groups of project partners.

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[12] A general process methodology for Total Quality Control (TQC) introduced by the American statistics W.E. Deming in the late 1940's.

Nearly 300 deviations were reported, some 220 in the MIPP and some 65 in the Task Force reporting system. Most of the deviations reported were related to technical failures. There were a few due to human errors.

As a general comment, the quality of the hydrogen stations was not as expected. Some stations were reliable with satisfactory performance, while others suffered from operational failures and were out of operation for periods of time. The performance improved during the project's lifespan. Improved filling nozzle coupling, improved dispenser systems, improved hydrogen compressors, and improved on-site production are examples of continuous improvements.

Safety

No major accidents involving lost-time from personnel injury were reported in the CUTE and ECTOS projects (and none to date within STEP). That means that one major project target was achieved.

To control the safety risks involved with the hydrogen infrastructure, a methodology in line with risk based safety management was recommended in Phase 1. The two basic steps of this methodology are risk analysis and risk control (see Figure 5-9). Applying this methodology in design and construction emphasises inherent safety. Hazards and risk are analysed through safety risk assessments, and any need for additional safety measures is revealed.

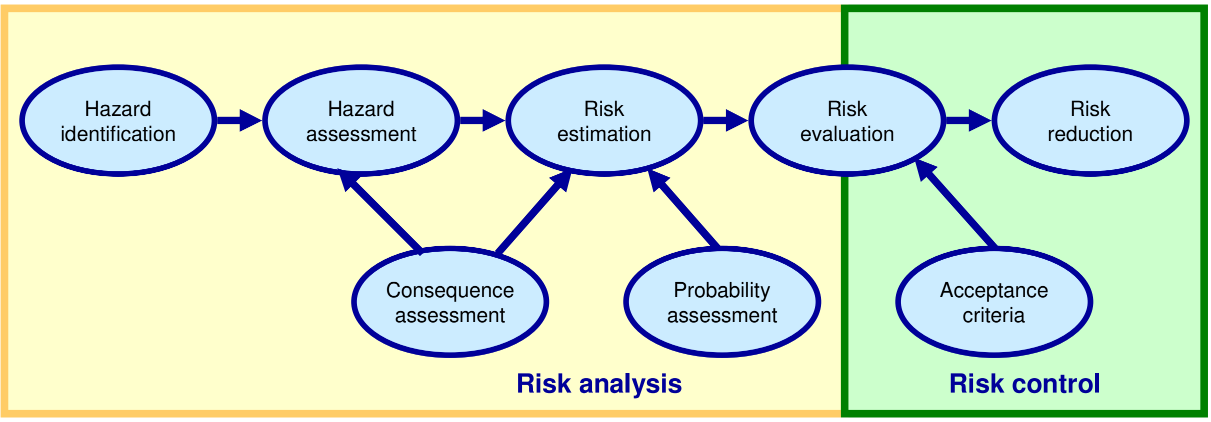

Figure 5-9: Schematic of a risk based safety management system

Risk based safety management was also applicable for operation of the hydrogen stations. The methodology was implemented in the CUTE project. The incident reporting and follow-up system approach is in line with risk based safety management, and it is also in line with the PDCA methodology.

Some 120 safety related deviations, incidents and near-misses were reported and handled locally. About 40 of them were communicated in the Task Force incident reporting system.

The establishment of the Safety and Security Task Force gave rise to major improvements in the communication of incidents and lessons learnt during the operation phase of the project. Experiences from incidents have been shared and discussed by the project partners. These discussions have enhanced the safety awareness in the project, and the overall safety level in terms of improved technical solutions, e.g. the refuelling hose, improved.

Both operators and suppliers were members of the Task Force. The contribution of Task Force members from the ECTOS (**E**cological **C**ity **T**ransp**O**rt **S**ystem) project in Reykjavik and the STEP (**S**ustainable **T**ransport **E**nergy **P**roject) project in Perth was widely recognized. The Task Force, its activities and results are presented in further detail in a separate report given in Appendix 1.

Learnings

The combination of the two methodologies for quality and safety proved successful for the CUTE project and is recommended for future hydrogen stations.

Although there have been incidents and a number of deviations from planned operation, the stakeholders were satisfied with the fuel cell buses and the hydrogen infrastructure increased during the project's lifespan. A key learning is that in order to close any gap between actual performance and what is expected, all deviations and incidents need to be recorded, corrected and communicated systematically. Another key learning is that the day-to-day follow up on operation of the hydrogen station must be designed according to the maturity of this technology and the users' knowledge. Experiences from the successful operation of the buses should be utilised for the hydrogen stations. In particular, the following elements should be addressed:

- Operational issues such as automated operation, follow up, service and maintenance
- User interface and local service system

5.3.4 Quality and Safety Methodology for Future Hydrogen Stations

The Quality and Safety Methodology recommended to be used for the establishment and operation of future hydrogen stations can be outlined as follows:

- Follow the steps of a fixed asset project in the establishment of a hydrogen station.
- Identify the main stakeholders, the authorities included, and their requirements, goals and expected performance at an early stage. Implement these expectations in the design to implement an inherently safe facility.
- Use an approach based on risk based safety management and industrial safety policy and practice to identify hazards and risks. Implement risk-reducing measures, wherever needed, to ensure a facility with tolerable risk.
- Apply recognized methods for risk analysis and risk control in all phases of establishment, operation and decommissioning of the hydrogen station.
- Apply quality management according to the ISO standard (ISO 9001:2000). Take the requirements and expectations of the customers and other interested parties (stakeholders) as a basis for the development of quality performance characteristics.
- Implement quality and safety management as an integral part of daily work. Establish a management system with procedures, instructions and checklists that provides systematic monitoring and follow-up.
- Use the results from quality and safety monitoring for continuous improvement of the hydrogen stations and appurtenant systems. The PDCA–methodology, is recommended.

5.4 Approval and Certification of System Components

5.4.1 Guiding questions

From the set of bus-related guiding questions (see section 5.5.1); one is partly relevant with respect to approval and certification:

- Are there safety problems in operation or admittance problems due to safety regulations?

Concerning infrastructure, two of the guiding questions (see section 5.1.1) are pertinent under this headline:

- Were there permitting problems relating to safety?
- What improvements are recommended for the future?

5.4.2 Introduction

This section summarises the experiences of obtaining approvals and licences for the fuel cell bus, for the hydrogen supply infrastructures and for the garages for bus maintenance.

The key challenge in these three areas was the lack of well-defined statutory or other requirements that could serve as the basis for design. In some fields, though, rules and regulations applicable to natural gas powered vehicles could serve as a guideline. In many respects, new ground had to be broken.

All licences and permits were received in time.

5.4.3 Fuel cell bus

The strategy was to seek approval based on Federal German Law and then gain acceptance of this approval in the participating countries. The resources of the program, mainly time and manpower, did not allow building of variations of the basic bus design in order to meet local requirements for specific countries. The strategy followed also supported the goal of getting operational approval without any restrictions over the time of use or the location of operation, as well as no limitations of who was allowed to operate the buses.

The homologation activities in the project were planned and agreed at early stage. The execution of the activities went through without major drawbacks. Projects of this magnitude challenge efficient communication between all parties involved. Clear paths of communication flow between central contacts must be defined and this helps to streamline the communication.

The fuel cell bus road licence was granted by the German Federal Authority for vehicles (KBA). It was the first of its kind issued for fuel cell vehicles. As planned, the other participating countries adopted the German road licence without requests for design alterations or operational restrictions.

From a technical development point of view, the lack of legal requirements specifically for fuel cell vehicles was a challenge. Discussions occurred frequently during the development process about the interpretation of general vehicle requirements. Component manufacturers would welcome better guidance being provided by international regulations. Regulations which focus on the “what” rather than on the “how” would facilitate advancing the technology. Requirements should indicate what targets have to be met, but should not narrow down technical solutions to the ones available at the present time.

The homologation for pressure vessels, including the tests required, periods of use, cycle times etc. should be standardized internationally.

5.4.4 Hydrogen supply infrastructures

The situation in terms of approvals for the hydrogen refuelling infrastructures was complex not only because of the different local approval bodies responsible for the individual sites, but also because various technologies for hydrogen supply, storage and dispensing that were selected (Figure 5-1 outlines the hydrogen supply pathways).

The objective in the approval processes was to present strong safety concepts that would be acceptable to the authorities without any existing and proven standards or best practices for the particular type of installation. This was accomplished by

- Applying well-established procedures for CNG refuelling sites or filling stations for compressed gases in general which are laid down in existing guidelines or regulations, or
- Using hydrogen codes and standards for industrial plants, or
- Employing hydrogen-related standards from outside Europe, or
- Combining the above approaches,

and adapting the specifications from these documents in an appropriate manner. This process often involved time consuming procedures.

As most of the authorities involved had not encountered hydrogen installations before and needed to be “trained” in order to be able to take decisions, close cooperation with them from an early stage was an advantage. Selecting experienced turn-key suppliers or even a station operator from industry with established quality assurance and health and safety policies also helped to increase the credibility of the undertaking in the eyes of the authorities.

The issue of harmonised regulations for the approval of hydrogen refuelling installations needs to be tackled in order to assure planning reliability in all parts of the European Union as well as globally, and to facilitate standardisation of the technology which can lead to reductions in costs. Operating experiences from CUTE and other hydrogen infrastructures need to be disseminated to approval bodies at all levels. It is important that local regulating authorities are not put in a position of wanting to refuse approval, defer decisions or impose highly over-engineered safety features because of their inexperience with hydrogen technology.

From a wider perspective, the general public also needs to be informed and familiarised with hydrogen as an energy carrier.

5.4.5 Garages

Approval of the workshops was accomplished without major obstacles, especially when the authorities were involved in the design process at an early stage. Operators sometimes felt, though, that the process of obtaining permits had been rather time consuming.

Hydrogen-related hazards were addressed appropriately. Based on the CUTE Design Handbook, individual concepts were developed locally and licensed by the relevant authorities. In some of the CUTE cities, the approving authorities even used the Handbook as a tool for checking that all necessary measures had been taken. It is important to note that there were no hydrogen related safety incidents in the garages throughout the trial.

Improvements in workplace safety should focus on equipment and procedures for carrying out maintenance on the roof-mounted components of the buses.

Harmonised regulations for constructing garages for hydrogen-powered vehicles would be welcomed by bus operators.

5.5 Fuel Cell Bus Operation under different climatic, topographic and traffic conditions

5.5.1 Guiding questions

Beside the infrastructure the focus in CUTE was on the operation of FC buses under real world conditions. For this task the guiding questions were:

- Are there major technical problems during the operation of the buses?
- Are there safety problems in operation or admittance problems due to safety regulations?
- Operating experience: Are there meaningful correlations derived from the trial regarding different topographical, climatic and traffic conditions?
    - If yes, what is the effect on the availability?
    - What is the effect on the fuel consumption?
- What will be the next steps to improve the system regarding availability, safety, energy efficiency and cost?

5.5.2 Introduction

The operation of the buses under different boundary conditions with focus on climate, topography and traffic was evaluated within Deliverable 2 which includes the work performed by work packages 4, 5 and 6.

The buses were operated for two years and covered a total distance of almost 850 000 km and operated for over 62 000 hours in nine cities with very different boundary conditions. From hot and dry in Madrid to cold and humid in Stockholm, from flat in Hamburg to hilly in Stuttgart, and from congested in Madrid to relatively traffic free in Luxembourg. The operation was highly successful without any major breakdowns or problems caused by the fuel cell technology itself and the buses have been assessed to be far more reliable than expected under European climate, topography and traffic conditions.

The main goal of the project – to demonstrate and evaluate the emission-free and low-noise transport system that fuel cell buses constitute, including the energy (i.e. fuel) infrastructure – was certainly achieved.

5.5.3 Technology overview of the Fuel cell bus

The Fuel Cell Citaro was based on the 12 meter series vehicle of EvoBus featuring a standing platform in the rear for a standing engine and an automatic transmission. As the fuel cell drive train and the air conditioning system was mounted on the roof, see Figure 5-11, the structure of the standard bus had to be reinforced to hold the additional three tons. Also the suspension had to be adapted to accommodate the greater weight and the increased tendency to roll. The length and width remained the same. The high increased to approximately 3.70 m due to the fuel cell drive train and cooling fans, see Figure 5-10. The Fuel Cell Citaro was designed focusing on reliability, and as many standardized components were used as possible. Therefore the drive train was designed to directly replace the diesel drive train.

Figure 5-10: Fuel Cell bus - Amsterdam

The HY-205 P5-1 engine was the fifth generation of the heavy-duty drive trains developed by Ballard, Vancouver (Canada). It was based on the latest Mk9 stack technology which efficiently converted gaseous hydrogen and atmospheric oxygen directly into electricity and water. The electricity generated was handled by a liquid-cooled electric motor which provided the energy for the bus traction as well as for the fuel cell engine and bus auxiliaries. The electric motor was designed to be mounted to any SAE 1 transmission flange.

The main sub systems of the fuel cell drive train, as shown in Figure 5-11, were:[13]

- Storage
  Nine carbon fibre reinforced composite 350 bar hydrogen pressure vessels with a geometric volume of 205 litres each and a total capacity of 40-44 kg at 15 °C/ 350 bar
- Fuel Cell module
  2 fuel cell stacks, consisting of 6 discrete cells rows each with a maximum output of 125 kW nominal power per stack
- Inverter
  The inverter converted DC electrical power produced by the fuel cell stacks into the controlled AC power needed by the electric motor
- Cooling system
  The liquid cooling system handled the waste heat produced by the fuel cell process. A special deionised (DI) water/ ethylene glycol mixture was used as cooling fluid.

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[13] For more information on the Fuel Cell Citaro (e. g. characteristics of the FC Citaro, functional description, detailed description of subsystems) please see Schuckert et al, “Hydrogen Supply Infrastructure and Fuel Cell Bus Technology”, Ulm 2004

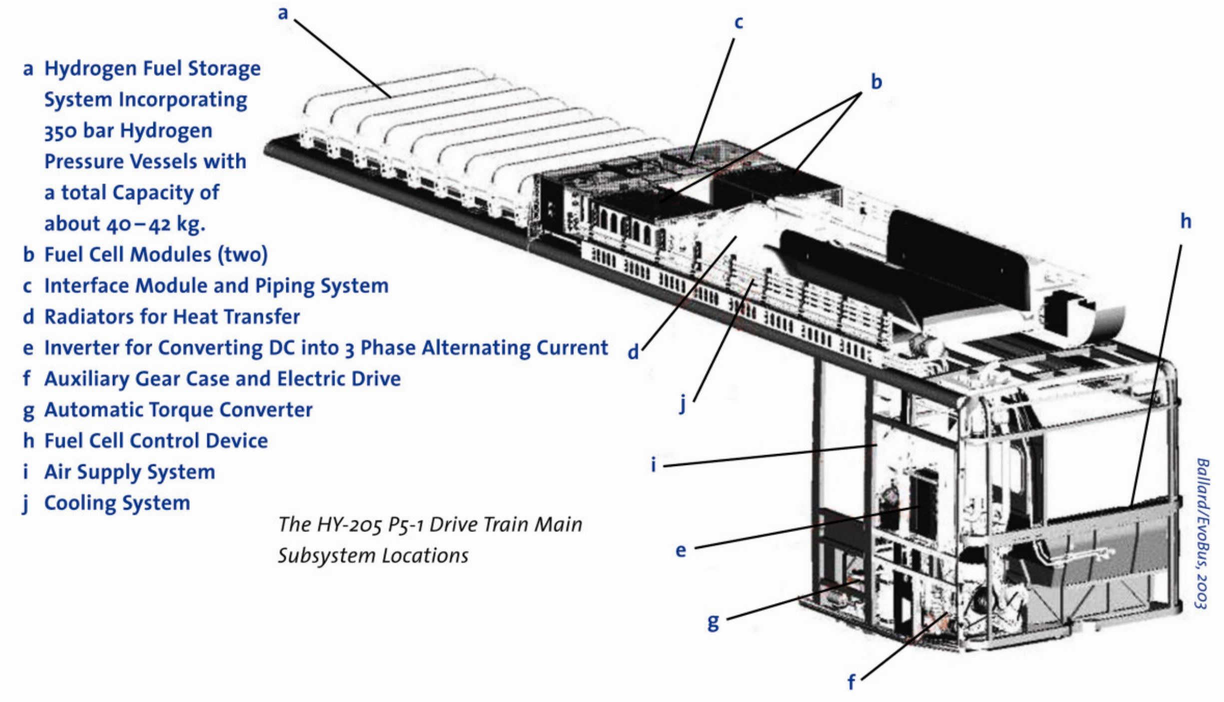

Figure 5-11: Fuel Cell specific parts and locations

The key characteristics and specifications of the Mercedes-Benz Fuel Cell Citaro are displayed in Table 5-1.

Table 5-1: Key characteristics and specifications of the Mercedes-Benz Fuel Cell Citaro

Vehicle weight * / **	14.2 / 18 or 19 tonne	
Vehicle dimensions	12.0 (l) x 2.55 (w) x 3.67 (h) m	
Max. fuel cell gross power	> 250 kW	
Max. net shaft power	205 kW	
Acceleration 0-50 km/h	~16 - 20 s	
Range	~ 200 km	
Tail pipe emissions	CO	0.000
	NO_x	0.000
	hydrocarbons	0.000
	SO_2	0.000
	particulates	0.000
	CO_2	0.000
Passenger capacity	up to 70	
Maximum speed	~ 70 km/h (electronically limited, design parameter > 100 km/h)	
Hydrogen (fuel) storage	350 bar, 44 kg	

* Vehicle in running order

** Maximum authorised; varying between cities

5.5.4 Overall results:

The distance driven and the number of operating hours of the bus fleet are perhaps the most impressive figures from the CUTE project. They document the huge step forward that was taken in CUTE with regard to the lifetime and durability of the FC system. Never before has a hydrogen technology project demonstrated such an outstanding operating success. Buses driven by regular bus drivers in regular traffic under normal operating conditions completed a distance of more than 20 times around the globe, producing a wealth of data and gaining a vast pool of experiences.

Total kilometres driven and hours operated

At the end of two years of operation the CUTE buses had travelled a distance of almost 850 000 km in the 9 partner cities, see Figure 5-12. Taking the kilometres driver by the 6 additional buses operated in ECTOS (Reykjavik), STEP (Perth) into account the Citaro Fuel Cell Buses surpassed the one million kilometres milestone in October 2005.

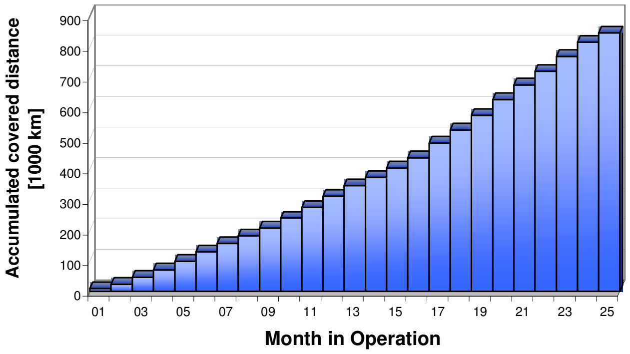

Figure 5-12: Accumulated operating kilometres per month of operation, for the CUTE bus fleet.

Total hours operated

When the bus operations within the CUTE project finished in December 2005 the twenty seven CUTE buses had been operated for over 62 000 hours on European roads, see Figure 5-13. Adding ECTOS and STEP the whole fleet had 75 600 hours to demonstrate reliability, collect information and gather experiences on fuel cell buses.

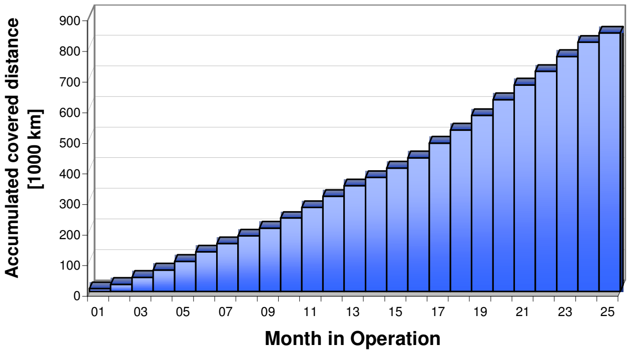

Figure 5-13: Accumulated operating hours per month of operation, for the CUTE bus fleet.

Kilometres driven per city

The buses completed an average of 94 000 km in each city. Luxembourg buses covered a total of 142 000 km within the two years of operation, followed closely by Stuttgart. Barcelona with 38 000 km, due to numerous days off caused by incidents relating to infrastructure and hydrogen supply, and Porto with 47 000 km were the cities with the lowest total distance travelled.

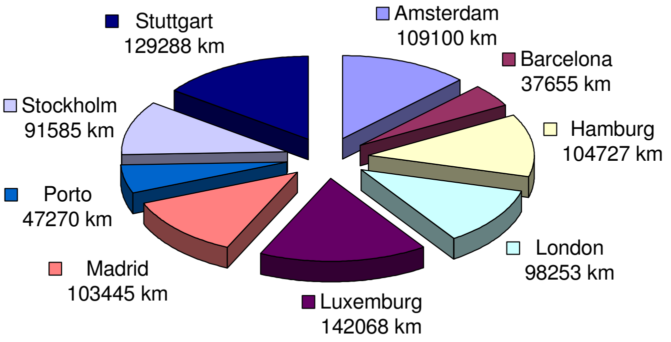

Figure 5-14: The total amount of kilometres driven in the 9 CUTE cities.

Hours of operation per city
On average each CUTE bus operated for 2 300 hours and the fleet in each city averaged 6900 hours. Luxembourg buses operated for the most hours with a total of over 9 000 hours. In Barcelona the three buses operated for almost 3 400 hours, i.e. approx. 1 130 hours each.

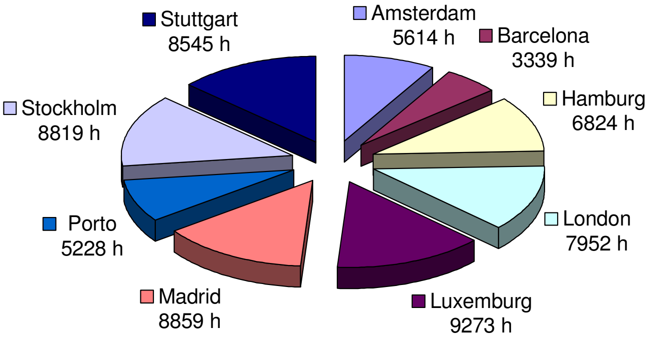

Figure 5-15: The operating hours in each CUTE city.

5.5.5 Specific Results

- The buses proved reliable and safe during operation under extreme European climate conditions, with daytime temperatures ranging from 39 ºC down to -16 ºC, and relative humidity ranging from 13 % up to 100 %. An influence on fuel consumption due to climate was found when the temperature was below 0 ºC or above 18 ºC. This was primarily due to the need to heat or cool the cabin, which is based on the provision of electricity provided by the fuel cells.
- During the two years of operation there was no obvious long-term effect of topography on the wear of the buses or the fuel cell system. The buses have therefore been assessed reliable under topographical conditions with differences in height up to 150 m and gradients up to 8.5 %. While a challenging topography would theoretically cause an increase in fuel consumption, this cannot be seen in the data gathered in the project due to overlapping effects such as driver behaviour, use of A/C and passenger loads.
- Traffic influences the bus in several ways: externally in terms of driving mode, the number of stops, traffic congestion etc. and within the bus in terms of the weight of passengers. The average speed has been shown that to be an important factor for fuel consumption. However, data from some cities indicate that the weight of the buses (including the passengers) is also an important factor that needs further investigation to be able to tell how much is due to the impact of the external traffic situation, and how much is due to different passenger loads.

5.5.6 Satisfaction

Many of the participating partners were positively surprised by the durability of the fuel cell technology and the availability of the fuel cell buses. The drivers – the main ambassadors for this new technology – were satisfied with the performance of the buses and they felt safe with the hydrogen fuelled fuel cells. This meant a lot for the attitudes of the public towards the new technology.

5.5.7 Potential for improved fuel economy

The Mercedes-Benz Citaro fuel cell buses in CUTE demonstrated an energy consumption that was higher than that of a conventional diesel bus. Higher average speeds gave generally lower fuel consumption. The fuel cell buses consumed 20-30 kg hydrogen per 100 km, which is equivalent to a fuel consumption of 65-100 l diesel per 100 km. A conventional 12 m diesel bus has a fuel consumption of 45-60 l/100 km. However, the fuel cell buses were not designed for low fuel consumption but for high reliability, a quality that they certainly possess.

The buses have great potential in terms of design for better fuel economy, both related to the fuel cell system and the driveline, as well as to adaptations of bus auxiliary systems to an electric power source.

A minimum current limitation of the fuel cell stacks in this system design reduced one of the major benefits from using fuel cells, that is the high efficiency at partial loads. This system design, in which a current is drawn constantly from the fuel cells, makes the bus consume energy when the competing technologies such as diesel engines do not, for example when coasting or decelerating. Simulations show that over 15 % fuel would be saved if the minimum current limitation were eliminated on a typical inner-city bus route in Stockholm.

The minimum current also affected the climate related loads since some of the electricity dumped was used for heating the cabin. Therefore the climate related loads would affect the overall fuel consumption more if there where no limiting current.

A pure electric driveline, without a gearbox and with electrically powered auxiliaries and with an energy storage system and the possibility to recover brake energy, i.e. hybridisation, would be of great benefit. With an electric driveline the buses would do even better in terms of external and interior noise and the overall bus design could be improved. With electrical auxiliaries the power consumption of the auxiliaries due to low efficiency and idling could be minimised, and with hybridisation, regenerative braking and other optimisations could save more than 25 % of the fuel.

Redesigning the cabin heating system to adapt it to the lower temperature of the output heat from the fuel cells would further increase efficiency. This could eliminate or at least minimise the need for electrical heating during operation in cold climates.

The fact that the fuel consumption was related to the average speed implies that actions to increase the average speed of the buses would improve the fuel economy. Such actions could be to implement special bus lanes and prioritised traffic lights, but also actions to minimise the bus stop times, such as for example automatic ticketing systems.

5.5.8 Hydrogen purity demand

The hydrogen purity is an important factor to consider. The most severe damage, causing a down time of several months in Barcelona, was because of contamination of the fuel tanks on the buses caused by impure hydrogen from the refuelling station. Actions should be taken to minimise the effect of contaminated hydrogen.

5.6 Environmental evaluation of FC bus system

5.6.1 Introduction

Assessing the environmental performances of the fuel cell (FC) bus including the provision of hydrogen (H_2) was a central element of the CUTE project.

The emission free operation of fuel cell buses means there is a shift of the environmental burdens from the bus operation to the supply of the fuel. In case This means the environmental effects of the fuel cell bus operations are determined by the production, storage and dispensing of hydrogen.

Considering this fact for the H_2/FC bus system and in order to address the need for an integrated system evaluation it is essential to consider the complete life cycle of a transport system independently of the applied propulsion technology. Thus the methodology of Life Cycle Assessment (LCA) as specified in the ISO Standard 14040 series was chosen for the environmental analysis of the Fuel Cell bus system along with its conventional competitor systems Diesel and CNG[14].

Figure 5-16 gives a schematic overview of the life cycle and the system boundaries considered for the FC bus system. Analogous boundary conditions were applied for the diesel and CNG bus system.

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[14] CNG: Compressed natural gas

The life cycle consists of three phases: production including resource beneficiation, operation and end of life. Besides this vertical break down, the system can also be grouped horizontally into the fuel supply part and the bus vehicle part.

Enhancing the scope beyond the categories commonly analysed within a well-to-wheel study - Primary Energy (PE) demand and greenhouse gas emissions which contribute to the Global Warming Potential (GWP100) (e.g. CO_2, CH_4, N_20) - is important in order to address additional goals of European policies beside the Kyoto commitments. These are, for example, an improved quality of air especially in urban areas and an enhanced security of supply of energy by decreasing the import dependency e.g. of the transport sector.

Consideration of the complete life cycle addresses the shifting of environmental burden between different life cycle phases. Widening of the scope of the environmental impact categories considered (e.g. summer smog forming potential (POCP[15]), Acidification Potential (AP)) also ensures that it is monitored if potential shifts between environmental impacts for the different bus systems arise.

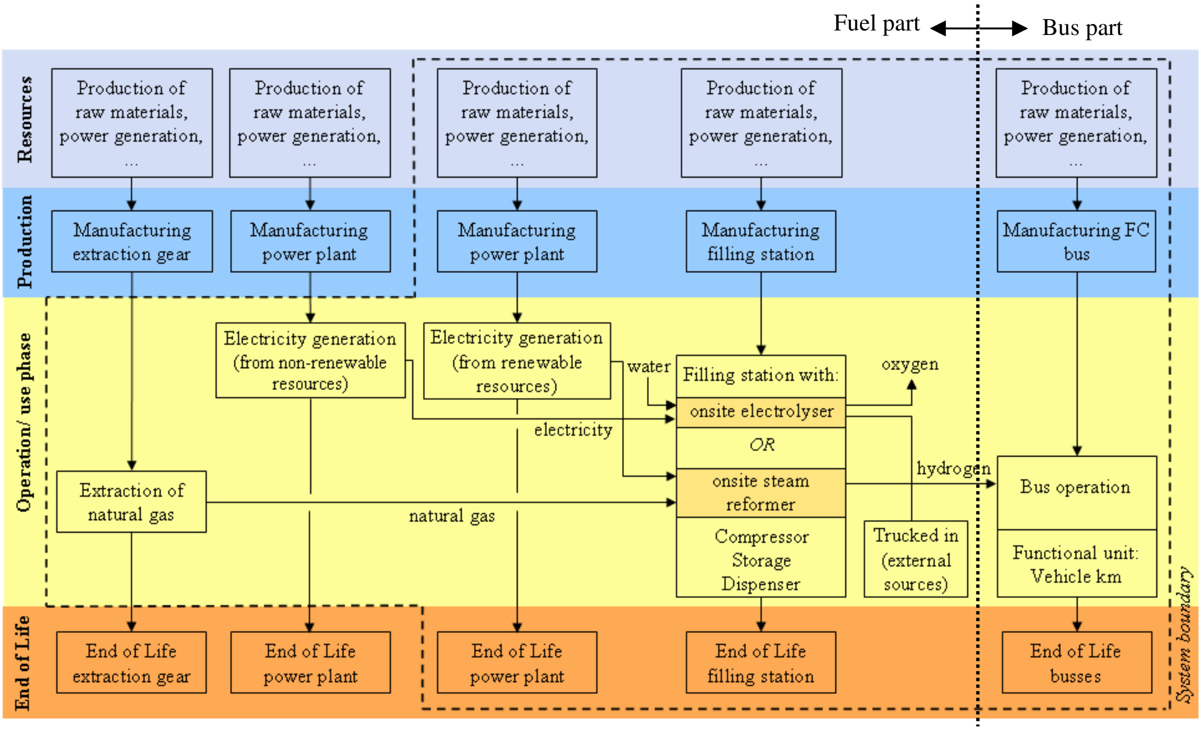

Figure 5-16: Life cycle of bus system

Using the methodology of Life Cycle Assessment a modular designed Life Cycle model for the manufacturing, operation (incl. fuel supply) and End-of-Life of different bus technologies was developed and used to quantify their environmental footprints.

5.6.2 Results

It is important to consider that the focus of the CUTE project was on the demonstration of the feasibility and reliability of the FC and H_2 technology, not on its efficiency when analysing and interpreting the LCA results. All results of the CUTE project were calculated and presented for technologies which are currently at a prototype stage (FC bus as well as H_2 infrastructure). The results are intended to serve as a baseline to measure the future improvements during the maturing process of the whole system consisting of the fuel supply and the vehicle

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[15] POCP: Photochemical oxidation potential

The main results of the LCA are presented in Figure 5-17 for the overall life cycle of the bus system and in Figure 5-18 for an example of the hydrogen production route.

In Figure 5-17 the FC Citaro[16] bus used in the project was compared with the NEBUS[17] (FC NEBUS), the predecessor prototype to the FC Citaro, a CNG Citaro (CNG EEV) which met the stringent European EEV emission limits and a Diesel Citaro which met the Euro 3 limits. The Diesel bus was set as a baseline against which the improvements and aggravations in terms of Primary Energy demand from non renewable resources (PE (n.ren.)) and three impact categories (GWP, POCP and AP) are given. European boundary conditions were assumed for the fuel supply, i.e. Diesel was produced in a European refinery using crude oil from the European crude oil supply mix, CNG was supplied using natural gas from the European grid compressing it using electricity taken from the European grid. For the FC buses the H_2 was produced via three different routes:

1. small scale on-site Steam reformer (H_2 st. ref.)
2. small scale on-site electrolyser using grid electricity (H_2 grid)
3. small scale on-site electrolyser using hydro power (H_2 hydro)

The results were calculated for a running distance of 720.000 km (12 a, 60.000 km/a) driven on the “Line 42” drive cycle representing a demanding drive cycle in Stuttgart with a max. gradient of 8% and an average speed of 16 km/h.

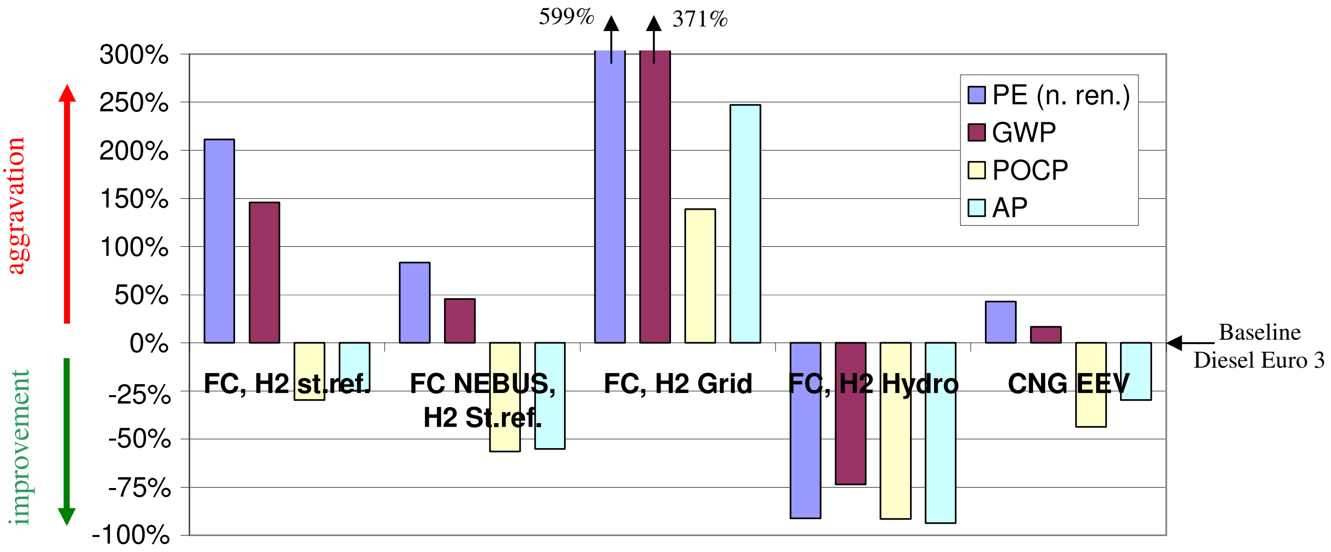

Figure 5-17: Comparison of FC, CNG with Diesel bus system on Line 42, EU15 boundary conditions

The production of hydrogen *via* a small scale on site steam reformer using natural gas and electricity from different regions (Europe (EU15), Germany (DE), Spain (ES)) is presented in Figure 5-18. The consumption figures are based on full load operation and are the same for all three routes. The route with the European boundary conditions is set to 100%. The results are given for 1 l of Diesel equivalent corresponding to 3.3 Nm³ of H_2 or 35,6 MJ energy content (net calorific value). Given are the Primary energy demand from non renewable resources (PE), the Global Warming Potential (GWP100), the summer smog formation potential (POCP) and the Acidification Potential (AP).

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[16] Citaro: Type of bus for public transport

[17] NEBUS: New electric bus, FC bus prototype developed by DaimlerChrysler

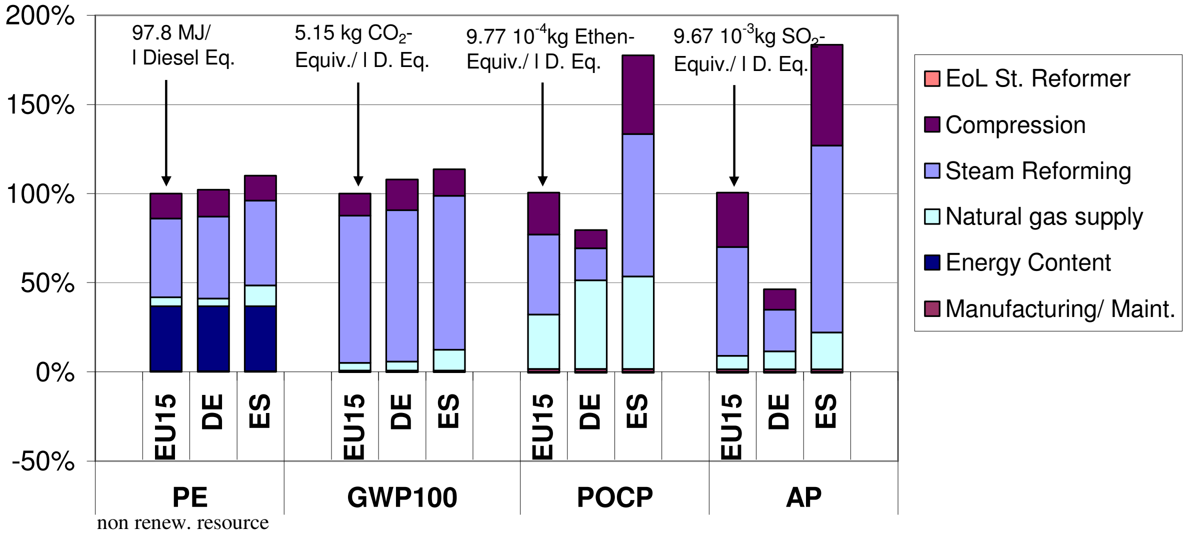

Figure 5-18: On-site H_2 production via steam reformer applying European, German and Spanish boundary conditions

Findings

The findings of the conducted LCA can be summarised as follows:

- the H_2/FC bus systems contributed to an improvement of the air quality in congested urban areas by featuring an emission free operation (for comparison a Diesel Euro 3 bus emits more than 80% of its harmful life cycle emissions[18] during the operation phase)
- the environmental profile of the H_2/FC bus system was highly dependant on the H_2 supply route chosen and on the overall efficiency of the whole fuel cell bus system (vehicle & fuel supply) particularly with regard to primary energy demand (from non renewable resources) and impact categories (see Figure 5-17)
- the usage of renewable energy carriers (e.g. hydro power) will address the Kyoto commitments and contribute to increased sustainability in the public transport sector by using domestic energy carriers such as hydro power (see Figure 5-17) or biomass.
- in terms of local environmental effects (e.g. summer smog caused by NO_x and HC emissions from traffic) the H_2/FC system showed its current advantages compared with conventional systems independent of the chosen H_2 supply route (see Figure 5-17)
- apart from the H_2 supply route which was chosen, the regional boundary conditions for the supply of energy carriers such as natural gas or electricity were decisive for the environmental profile of the bus system (see Figure 5-18)
- for the fuel cell bus analysed, the environmental burdens during manufacturing were approximately twice the burdens caused during the manufacturing of a state of the art diesel bus

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[18] With the exception of SO2 In accordance with the Auto Oil programme [European Commission: EU Fuel Quality Monitoring – 2002 Summary Report, <www.europa.eu.int/comm/environment/air/pdf>, 2004] the sulphur content is limited to 50 resp. 10 ppm, resulting in very little SO2 emissions during the diesel bus operation (< 2% of the life cycle SO_2 emissions)

5.6.3 Outlook

Based on the findings of the LCA study an outlook can be given on three thematic areas: diversity and security of energy supply, technology/energy efficiency and application of LCA methodology.

Security of Supply

- the H_2/FC system shows the potential to enable a significant increase in the diversity of energy resources as well as the share of renewable resources used in public transportation. It also can contribute to the EC policy goals of improved security of energy supplies through decreased import dependency on primary energy carriers. The left bar in Figure 5-19 shows the current status of the resource mix and import share for public transportation within Europe. The CUTE project demonstrated an increase of renewable resources (more than 40%[19]) and an increased diversity of energy resources used, while at the same time the import dependency for this sector is reduced by around 40 % (right bar).

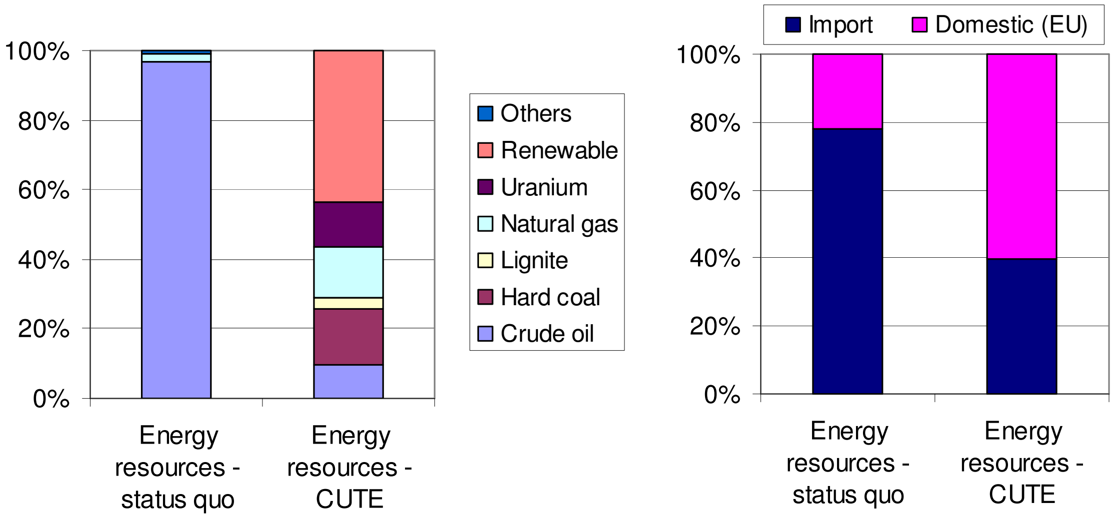

Figure 5-19: Mix of energy resources and share of energy imports used in public transportation in Europe (EU15) and in CUTE

Technology/ energy efficiency

- in comparison with diesel and CNG bus systems (based on internal combustion engines), the H_2/FC bus system showed different characteristics in its environmental profile. For internal combustion based bus systems, the CO_2 emissions are directly related to the fuel consumption while the other emissions (e.g. NO_x, particulate matter) are related to the engine setting. For the H_2/FC system there is a direct linear correlation between fuel consumption and emissions which are solely caused during the fuel production. Therefore the main goal from an environmental perspective is to improve the system efficiency (fuel production and vehicle).
- the FC bus system needs to be optimised for efficiency in order to be competitive with a diesel system. This becomes very apparent when energy carriers based on non renewable resources (e.g. natural gas, grid electricity based on mainly non renewable resources) are used for producing the hydrogen.
- the current prototypes used for on-site hydrogen production need to have greatly improved efficiency (see Figure 5-17) H_2 infrastructure suppliers state that they see a near term improvement potential of 10-15% for the system efficiency.

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[19] the 40% refer to the share of primary energy from renewable resources consumed to operate the FC buses at the nine locations considering the manufacturing of the FC buses, the H_2 fuel production via on site and external production routes as well as the end of life of the FC buses.

- the H_2 production plants, especially the steam reformers, consumed far less energy when they were operated at nominal production capacity. Thus an optimised utilisation of the H_2 production plant will be a first step towards a more efficient system

5.7 Training and Education – the human dimension of CUTE

5.7.1 Guiding questions

The human dimension in CUTE was addressed in Work Package 8 which dealt with training and education. The guiding questions for this field were:

- How was the training needs analysis (who needs to be trained for how long) performed?
- Who developed training materials and who performed the training sessions?
- How did the execution of the training take place?
- What were the experiences from the training?
- Were there educational material already available and where?

5.7.2 Introduction

Besides testing the fuel cell buses, filling stations and the hydrogen production in daily operation, one of the main objectives of the CUTE project was to reduce any public concerns about hydrogen and to raise awareness about sustainable mobility and energy supplies in the respective cities. Highly trained and communicative staff linking the people and technology (training), and the directing information to special target groups such as school student (education) were essential in order to reach this goal.

The objectives of the Training and Education Work Package were to analyse, compare, and assess how the CUTE partner cities trained their drivers and their staff of filling stations, and how Ballard Power Systems trained their site technicians.

The education activities used to spread the knowledge and the experiences gained with this future technology were also reviewed.

The results are mainly based on answers to a questionnaire that was sent to all CUTE partner cities. This questionnaire acted as a half-standardised interview with open questions. This qualitative survey allowed the recognition of the expert status of the interviewees by leaving adequate freedom to describe the unique experiences of the individual cities.

The "Human Part in CUTE" gives recommendations for future activities of training and education in connection with the introduction of a new technology. Governmental organisations introducing new technologies in the future can draw on the lessons learned in CUTE and transfer the experiences to their field of activity. The knowledge gained will be relevant not only for hydrogen or fuel-cell technology, but many more technologies, since they all need to be safely handled by well-trained staff, and they all will benefit from effective awareness raising education programmes.

5.7.3 Training

Training is defined as the execution of a systematic programme or a variety of scheduled exercises in order to develop and enhance skills, knowledge, capabilities and productive efficiency. Therefore, training – in contrast to “education” – mainly refers to the staff of the participating organisations that work with the fuel cell technology (drivers, filling station staff, and site technicians).

It is in the nature of a new technology, that there is no such thing as a perfect and an all-embracing preliminary version of training materials or procedures. Questions arose in connection with the use and practical application of the technology. Consequently, the preliminary training-manuals and handbooks need to be further developed and should be designed in a way that allows them to be amended and adapted, according to the experiences and in order to keep pace with ongoing technological innovations. Nevertheless, the starting point must be that the developer and manufacturer of new technologies systematically analyse the training needs of those who are supposed to use it, and incorporate the outcome of this investigation into training materials that are easy to understand and written in the mother language of the staff.

Tabletop emergency response drills should be made use of in the training: Experiences collected in London indicate that complex documents were rather ineffective training materials, simply because they were not read. The most effective training approach there turned out to be tabletop emergency response drills, which required the trained staff to transfer and apply their theoretical knowledge in order to solve a critical situation.

The presence of and the support by the Ballard site technicians in the participating cities – not only during training but also application – rendered additional training of the bus drivers obsolete. The site technicians diagnosed information demand wherever it arose and answered questions on the spot.

The most important aspects for the selection of the operation staff were, that they showed a lively interest in the new technology and volunteered to become part of this project. It seems desirable to recruit the staff on a voluntary basis as most CUTE partner cities did.

While safe handling of the new technology is essential, its presentation to the interested public is also important. The staff need to be able and willing to study new and complex contents and present and explain that to interested customers.

It would be worthwhile considering the development and introduction of a uniform European certificate for bus drivers and other staff handling fuel cell technology (e.g. operators of hydrogen filling stations, workshops, etc.). This could guarantee uniform safety standards and would acknowledge the responsible work of the staff.

General feedback from the staff regarding training needs and content should be harnessed regularly in a formalised way as has happened in Stockholm – preferably by way of written questionnaires to be filled in, in combination with regular (e.g. bi-annual) group-meetings. The feedback should be analysed and documented. Changes which have been prompted by the feedback should be communicated, so the staff clearly realise that their experiences and knowledge are highly valued and may cause changes.

5.7.4 Education

Education is the gradual process of acquiring knowledge, and – in the context of CUTE – mainly refers to activities focussing on pupils and students as the primary target group that will use the hydrogen and fuel cell technology in the near future. Their mobility patterns and awareness regarding environmental sustainability aspects are formed now, while they are young.

Most CUTE partner cities engaged strongly in educational activities (e.g. guided visitor tours to the bus depot). Hamburg and Stuttgart – as well as Perth, Western Australia (STEP) – have developed special education materials and concepts for teachers and pupils in the course of the fuel cell project. These were handed out free of charge. Some of the lessons learned from these activities are:

- ➔ The easier the materials can be integrated into the mandatory school-curriculum, the more likely it is that they are actually used. Therefore a close co-operation with all relevant stakeholders (school-authority, teacher, science, pupil-representatives, etc.) will be beneficial for the development of the education materials with regard to structure and teaching methodologies.
- ➔ Additional opportunities for schooling “outside the classroom”, such as at the bus depot, are generally well received by teachers and pupils/students.
- ➔ References should provide the teachers with an easy orientation, so they can make the most suitable choice (for additional materials and excursions) and do not get lost in the “jungle” of opportunities. The education materials should indicate other organisations and options for activities to create a whole net of education possibilities regarding hydrogen and fuel cell technology.

- ➔ A systematic and well structured collection of feedback from the teachers, facilitates the further-development of materials and (teaching-) concepts, in order to fully meet the (changing) needs of pupils and teachers.

5.8 Exploitation and dissemination of project results

5.8.1 Guiding questions

The Guiding questions for the task of exploiting and disseminating the results of the CUTE project were defined as follows:

- What were the means of communication of the project in the cities and how did they perform?
- What general means of communication were employed, and what were the reactions of the public, media, decision makers in industry and public policy?
- How did the exploitation and distribution marketing strategy work out?

5.8.2 Introduction

Dissemination of CUTE, the biggest commercial vehicle fleet on fuel cells ever operated, aimed at informing a widespread public on the project as well as its hydrogen and fuel cell technology, the project partners as well as the European Union as the co-funding institution.

5.8.3 Results

In the beginning of the project activities were designed to inform decision makers on the project and to convince them to support it, financially and organisationally. In the second step, when buses were delivered and running on the streets in the different cities, the strategy was to bring CUTE to as many people as possible and to promote hydrogen technology as a solution for future transportation challenges.
Most of the activities were the responsibility of the cities which applied their own strategies.

The success of CUTE dissemination can be seen by briefly mentioning some figures:

- More than 4 Mio. passengers were transported and directly experienced fuel cells. Assuming that nearly all of them knew they were on a fuel cell bus provided by transport companies this gives a lever of publicity which is far more than all other fuel cell projects currently running added together.

The feedback from the surveys undertaken show, that the activities with direct contact to the bus and its technology, events such as school days or open guided tours, were very successful. Also newspaper articles had a great influence on increasing the public’s knowledge about the CUTE project.

5.8.4 Lessons learned

For future projects on fuel cell and hydrogen the most effective means were those that reached people directly, as e.g. organized events, contacts with schools. It is more convincing to see and touch technology than to read about it in a newspaper.

On the project level there has to be more co-ordination and information exchange between the different cities to see what works out best / most efficiently.

The public support was evident for a small series of vehicles such as was the case in CUTE. However, for future activities people still require much more information, especially when talking about hydrogen infrastructure or large scale hydrogen fleet.

The challenge of all communication activities is…

- to arouse public interest
- to achieve the support for the development of the technology
- intuition and sensibility for environment friendliness of clean urban transport
- to dismantle prejudices against hydrogen

6 Conclusions

Prior to the CUTE project, the knowledge about fuel cell technology for public transportation and on-site hydrogen production was based on literature and theoretical values. This new technology had never been operated under real working conditions. There was an almost complete lack of information regarding

- the operation of fuel cell powered vehicles, especially buses, under normal working conditions;
- the efficiency and reliability of hydrogen infrastructure necessary to support these vehicles;
- certification of FC buses and hydrogen infrastructure; and
- public acceptance of this new technology.

The successful demonstration in CUTE of the reliability and effectiveness of hydrogen powered fuel cell buses for public transportation in daily operating conditions was an important first step towards closing the knowledge gap. During the duration of the CUTE project, the 27 buses have

- Operated for more than 62 000 hours,
- Travelled more than 850.000 km and
- Carried more than 4 Million passengers.

Besides the outstanding acceptance of the new technology by the public, the project provided a comprehensive data base of information and experiences, not only on the fuel cell powered buses but also for the hydrogen infrastructure.

In addition to the findings and experience related to the technologies, the CUTE project provided valuable experience in setting up, managing, coordinating and structuring a complex project with partners from multiple governments, across industries and research institutes, and on an international level. The CUTE project consisted of more than 25 formal Consortium partners, and numerous additional associated partners from all over Europe. The Project also shared information with its associated projects in Iceland (ECTOS) and Western Australia (STEP).

Specific results and findings are discussed in detail in Deliverables No 1 and 2.. These deliverables presents general findings and focuses on the experiences gained and how to improve future fuel cell and hydrogen projects.

The project demonstrated that the Assessment Framework and the accompanying methodologies that were developed did meet the demanding requirements imposed by a complex technology and project such as CUTE. The biggest hurdle that was successfully overcome was the handling of a huge amount of complex, diverse, technical information on new technologies being input from a widespread geographic spread by stakeholders with a very varied skill background. No substantial changes to the methodology were necessary and only minor modifications to the content were made.

The project also showed that the data collection procedure using Excel spreadsheets had its drawbacks. A web based data collection system was then developed and implemented.

The huge amount of data reported monthly meant that the effort to integrate, harmonize and especially conduct the plausibility checks on the data was enormous. Therefore to increase not only the efficiency but also the data quality, the implementation of a web based platform at the beginning of any future projects, with an integrated and automated plausibility check being carried out while entering the data, would be beneficial. For example, simple routines such as comparing the entered data with the last few data entered for similar periods would avoid flaws such as typing errors.

The data collection system should also have automated graph generation integrated and be constantly accessible through the internet to key personnel such as the Project Coordinator and Scientific Officer. This would ensure that the responsible actors are up to date at any time regarding the progress of the project.

One important experience from the project is that it is essential to have a clear structure within the project. The following discussion is therefore structured according to the CUTE Assessment Framework.

1. *Set up & operation of hydrogen production and refuelling facilities (WP1-3)*

   The project clearly identified the strengths and weaknesses of the hydrogen infrastructure systems and technology. The accompanying studies showed that there is an obvious potential for improving the performance, particularly the efficiencies, of the overall technology. The project also showed that problems with the refuelling stations were the largest contributor to the buses being forced out of operation. However in assessing the performance of the technology in the CUTE project, it must be understood that it is still at the developmental stage. Neither the refuelling technology nor the vehicle technology is nearing the stage where it could be put into mass production in the next two or three years.
   High pressure hydrogen compressor technology is not currently mature enough to fulfil high performance requirements such as continuous and reliable bus refuelling within acceptable time frames. While some aspects of dispensing technology seem to be nearing acceptable performance levels, legally accepted systems for measuring the hydrogen quantity at the max. pressure of 438 bars and beyond has not been achieved. While considerable improvement on nozzle technology was made during the CUTE project, there is a need for it to be developed further. The current situation where bus refuelling requires a large coupling then is used in cars also needs to questioned and carefully considered.

   The Life Cycle Assessment study also showed that the overall efficiency of the refuelling process itself must be considerably improved. The total amount of electricity consumed in the process is a major cost contributor and weakens the overall environmental profile of the H2-supply-chain.

   Lastly and most importantly, significant cost reductions must be achieved in order to bring hydrogen production and refuelling technology closer to market introduction.

   Based on the data and information made available by the infrastructure operators and suppliers, the accompanying studies provided them with new and interesting findings and results. The procedure of data collection and evaluation also showed potential for improvements concerning efficiency of the data collection procedure and the data quality.

   To increase the quality of the results obtained, the experiences during the project and the efficiency of the collection of consumption, production, maintenance and refuelling data it is essential to

   - define the collected data and measurement points and
   - to install an automated data collection system

   prior to the set up of the infrastructure.

   Prior to undertaking the certification of the hydrogen production and filling station systems for the CUTE project, there was no prior experience of a certification process for hydrogen infrastructure. A procedure was then developed by the project partners involved.
   The process of developing an international standard for the certification of hydrogen infrastructure has been initiated by the project consortium. This effort will have to be pushed by future projects and by all involved technical parties as a harmonized and efficient certification procedure is an important pre-condition for the acceptance of this new technology.
   CUTE has clearly shown that a fuel cell and hydrogen based transportation system is safe and reliable. However as there were only limited experiences with hydrogen refuelling stations prior to CUTE, very high safety standards and requirements were adopted for the design, maintenance and the operations. Hydrogen refuelling at a public station must become easier and less exceptional for the operators otherwise this technology will not succeed.

2. *Operation of the buses (WP 4, WP 5, WP 6)*

   The buses were designed with the focus on reliability not on energy efficiency. However their performance clearly exceeded all expectations. The reliability of the buses was comparable to diesel buses used in public transportation. The project therefore proved that the fuel cell technology is ready for daily use from a technical perspective.

   In general the fields in which vehicle improvements need to be made are:

   - Improvement of the overall efficiency of the fuel cell drive train as described in D2 (hybridisation, more efficient use of the fuel during idling, etc.)
   - Reduction of vehicle weight
   - Improvement of comfort aspects by using a pure electric drive train
   - Reduction of costs especially with regard to fuel cells, electric drive train, hydrogen storage technology
   - Increasing the lifetime of the fuel cells to meet commercial vehicle requirements

   The accompanying studies of the bus operation provided valuable information and results with regard to the influence of topographical and climatic conditions on the performance of the buses. To increase the quality and value of the information within a similar project, it is necessary to

   - install weight sensors, GPS, passenger counters to support the data collection and
   - redefine testing procedures.

   As the CUTE buses were the first fuel cell powered buses for public transportation produced under near series conditions, no certification process was in place prior. A certification procedure was developed by DaimlerChrysler and Ballard Power Systems. The process to develop an international standard for the certification of fuel cell powered buses has been initiated and must be pursued further as an efficient certification procedure is another important element of the acceptance of this new technology.

3. *Quality and Safety for H_2 filling stations (WP 7)*

   The project clearly showed that it is essential to implement an incident reporting scheme from the beginning. As the hydrogen filling stations were either prototype plants or customized solutions, it is important to share all experience to improve the technology. This goal can only be achieved if quality and safety related incidents are shared by the parties involved. To reach the next level regarding quality and reliability of the infrastructure components it also necessary to share the experience at the component and material level, not just at the overall system level.

   The experience showed that

   - the initiation of the Task Force on Safety and Security,
   - sharing the operating experiences, particularly with regard to incidents, with the partners in project meetings and
   - the implementation of an emergency response plan

   increased the confidence within the project partners. Accordingly, those three issues should be an essential part of any future (hydrogen) projects.

4. *Experiences regarding training and education (WP 8)*

   Numerous training and education events were carried out within the CUTE project. They have been a tremendous success. The experience showed that there is a huge demand by the public, including decision makers, bus and hydrogen infrastructure technical staff, community members, researchers and engineers, for information on the new technology. This demand extends to both the fuel cell powered buses and hydrogen production. Even though many people were reached, future projects should address the following events as an integrative part to further increase the knowledge:

- education of the generation of the future (between 10 and 20 years),
- education of decision makers,
- education of the "money generation" (older than 50 years)
- training methods of technical staff

To increase the effectiveness and efficiency of the efforts of all participating partners, all dissemination activities at the different sites should be coordinated. Therefore in future comparable projects, one person should be assigned to this task.

5. *Environmental and economic evaluation and future potentials (WP 9)*

The environmental and economic studies showed that fuel cell technology offers its greatest potential benefit to sustainable public transportation when it uses energy for hydrogen production from renewable resources such as hydro power, wind and solar power. Although the current version of the fuel cell bus, due to its focus on reliability, hasn't been as efficient as possible, studies have shown that fuel cell technology can achieve considerable fuel savings compared with diesel technology.

The study also showed that the boundary conditions assumed for the hydrogen infrastructure, e.g. number, size and location of plants, has a significant influence on the economics, while the regional boundary conditions of electricity generation and natural gas provision are crucial for the environmental evaluation.

Various studies have been conducted on hydrogen production to determine the future hydrogen cost. One conclusion of the CUTE study was that the boundary conditions have a significant influence on the economic and ecological performance of the hydrogen production. This means that it is essential to have detailed documentation of the specific boundary conditions of each individual situation in order to avoid drawing the wrong conclusions. This issue is important for future studies. Nevertheless further cost reductions through technology improvements are very necessary as all studies have shown that the current technology of hydrogen production is too expensive even in larger scale applications.

An integral part of the environmental study was the benchmarking of fuel cell powered public transportation with diesel and CNG powered systems. While there were good data available for diesel systems, there was a lack of emission data from operation of CNG vehicles. Therefore emission measurement trials (tail pipe emissions) especially for CNG and H_2-ICE systems should be an integral part of future projects on hydrogen powered transportation systems.

6. *Review of dissemination activities (WP 10)*

Throughout the project, the participating cities/ partners worked to increase the visibility of the project. Each partner developed its own ideas and ways to achieve this. Even though the visibility of the project was outstanding throughout the whole project duration, there is still potential for improvement. To increase the efficiency of the activities in future (hydrogen) projects, it is essential

- to coordinate the activities at different sites/ partners and
- to follow a common communication guideline.

Also it is important to focus more on getting general information on the project to reach many more people than only those interested in technical matters.

7. *Project coordination*

The project management arrangements proved to be suitable to coordinate a project such as CUTE. The biannual meetings held at the bus operation sites proved to be a very good "monitoring tool" on the project progress for the Project Coordinator, all partners and the Scientific Officer from the European Commission. Moreover those meetings generated a better understanding by each site of the situation at other sites, as well as strengthened the collaboration between the sites.

Due to the fact that the project was using a new technology and there was no existing knowledge about what factors would influence performance, the technical coordination required more time than expected and more time than was planned to be committed by the relevant stakeholders. This placed great reliance on the Work Package leaders and the partners responsible for each task.

To increase the efficiency and the quality of the outcome of future (hydrogen) projects facing similar challenges, the following issues should be considered from the beginning of the project:

- timely implementation of an Assessment Framework to better incorporate data needs into the work flow (equipment and organisation),
- coordinated and structured data acquisition, definition of necessary data and assignment of responsible persons,
- clarifying that communication between the project partners is the responsibility of each partners and not the responsibility of the project coordinator,
- use available tools for communication, e.g. web meetings
- set up internal networks and make sure that the experiences made on different sites/ partners are shared with the project consortium. For example the establishment of the Task Force on Safety and Security combined the knowledge and experience of infrastructure sites and did speed up the handling/ prevent of safety incidents
- share experience with other European funded project without violating confidentiality issues, and.

ANNEXES

ANNEX 0	List of Deliverables
ANNEX A	Project Calendar
ANNEX B	CUTE Assessment Framework
ANNEX C	Phase 1 Evaluators' report
ANNEX D	Restructuring Deliverables List after Phase 1
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ANNEX G	Monthly Site Summaries
ANNEX H	Hydrogen Infrastructure Technology description

ANNEX 0: List of Deliverables

Deliverable No[20]	**Deliverable title**	**Delivery date**[21]	**Dissemination level**[22]
D 1	Hydrogen Infrastructure -Operation Results of the Various Hydrogen Production & Supply Routes and Filling Stations	50	RE
D 2	Operation of FC busses - Experiences & results of operation under different climatic, topographic and traffic conditions	50	RE
D3	Quality & Safety Methodology	54	PU
D9	Report on admission of system components	54	RE
D4	Training & Education – the human part of CUTE	50	PU
D5	LCA of the different bus technologies	50	RE
D6	Economic analysis of hydrogen infrastructure	50	PU
D7	Dissemination a) Final conference b) Brochure on experiences made c) Web page d) Report on dissemination activities conducted	 52 51 Ongoing 54	PU
D8	Final report - Report - -Executive summary	54	 PU PU

[1] Please indicate the dissemination level using one of the following codes:
PU = Public
RE = Restricted to a group specified by the consortium (including the Commission Services).
CO = Confidential, only for members of the consortium (including the Commission Services).

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[20] Deliverable numbers in order of delivery dates: D1 – Dn

[21] Month in which the deliverable will be available. Month 0 marking the start of the project, and all delivery dates being relative to this start date.

[22] Please indicate the dissemination level using one of the following codes:
PU = Public
RE = Restricted to a group specified by the consortium (including the Commission Services).
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ANNEXES A-H

Annexes A-H are restricted – see separate folder for annexes:

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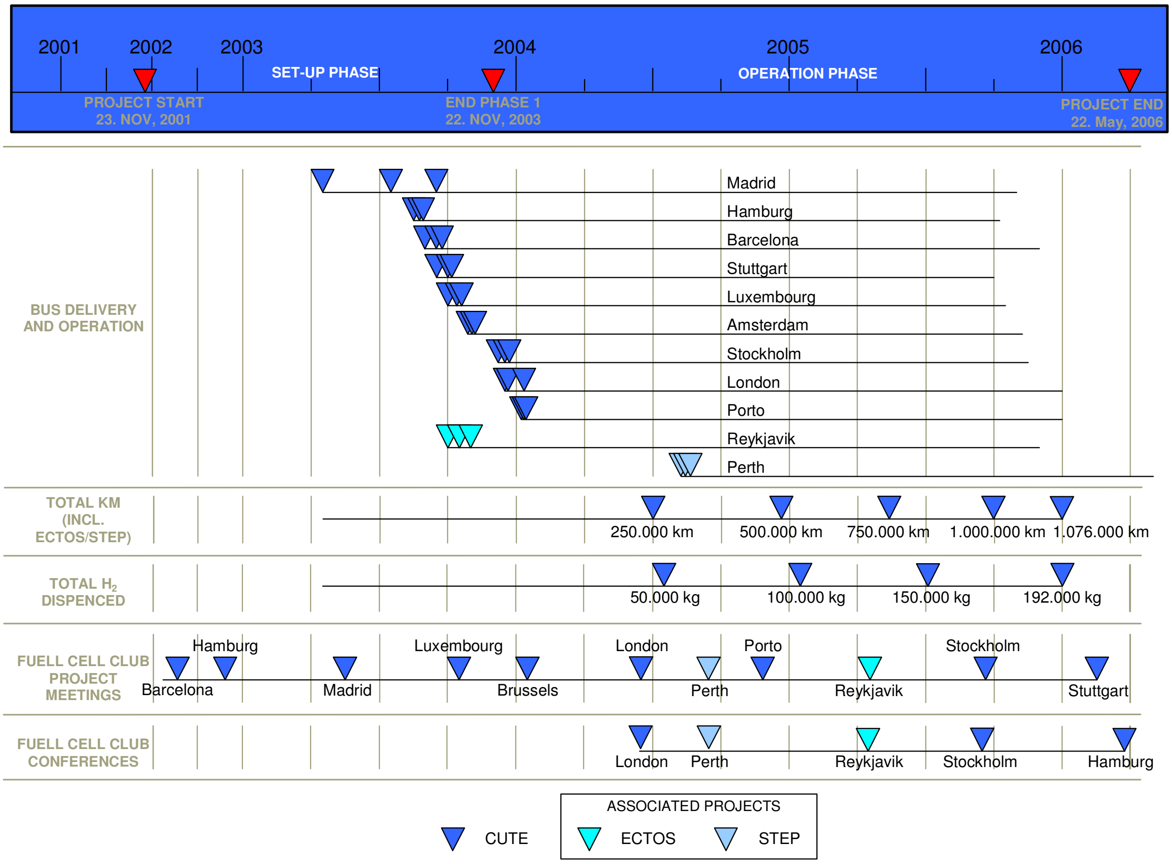
A Project Calendar



B The CUTE Assessment framework

Version A
Version B

C Phase 1 Evaluators report

D Restructuring Deliverables list after Phase 1

Deliverable No	Deliverable title OLD	Deliverable No	Deliverable title NEW	Delivery date	Dissemination level*)
D 1	Handbook for installing a complete H_2 supply chain via electrolysis	D1	Hydrogen Infrastructure - Operation Results of the Various Hydrogen Production & Supply Routes and Filling Stations	50	RE
D 2	Handbook for the operation of a H_2 production route via electrolysis				
D 3	Revised maintenance plan for the complete production facility				
.....	......				
D 13	Maintenance plan of the filling station and the garage				
D 15	Catalogue of improvements of the filling station and the garage				
D 14	Delivery of one fuel cell driven bus	D2	Operation of FC buses – Experiences & results of operation under different climatic, topographic and traffic conditions	50	RE
D 16	Results of operational use of FC buses as a function of the climate				
D 17	Compilation of experiences from drivers of FC buses in warm and cold regions of Europe.				
.....	....				
D 27	Guidelines for replacement of wearing parts as a function of the different traffic conditions.				
D 29	Analysis of existing regulations for the admission and certification	D3	Quality & Safety Methodology	54	PU
D 28	Report on admission of system components	D9	Report on Admission of system components	54	RE
D 30	Handbooks for the description of the applied components				
D 31	Detailed description of working procedures and working conditions for the operating and maintenance staff	D4	Training & Education – the human part of CUTE	50	PU
......	......				
D 34	Requirement catalogues for industrial education/training and academic research programs				

D 35	Compilation of necessary educational contents				
D 36	Report on the methodology development of the different surveys	D5	LCA of the different bus technologies	50	RE
D 37	Report of the environmental analysis of the fuel cell bus systems including the different production routes, the use phase and the recycling phase				
D 38	Comparison of the new propulsion technology with conventionally powered bus systems considering the primary energy, the emissions and the used resources				
D 39	Technical and economical reports	D6	Economic analysis of hydrogen infrastructure	50	PU
D 40	Exploitation and implementation plans	D7	Dissemination e) Final Conference f) Brochure g) Web page h) Report on dissemination activities conducted	 52 51 Ongoing 54	PU
D 41	Web site presentation of the project				
D 42	Presentation material on different media for the project, conferences and workshop proceedings				
D 43	Consortium agreement	D8	Final report - Report - Exec. Summary	54	 CO PU
D 44	Reports (6 monthly or annual and mid-term)				
D 45	Final project report				

*) level of dissemination will be finally defined until month 50.

E EC Reporting

F Project meetings

G Monthly site summaries

H Hydrogen infrastructure Technology description

Hydrogen can be produced by different technologies using different energy sources. In addition, there are 2 major philosophical differences as the hydrogen can be either produced on-site at the filling station or externally by centralised plants.

One unique fact of the CUTE project has been that numerous different hydrogen infrastructure solutions have been an integral part of the project. As illustrated in Figure G.1 both external supply and on-site production along with different compression and storage solutions have been realised in the CUTE hydrogen filling stations[23].

As besides the demonstration of the technical feasibility of different infrastructure concepts the ecological and economic analysis is an important part of the project, different energy supply routes for the different technologies have been used to quantify the ecological footprint of the hydrogen production concepts. For on-site electrolysis (Amsterdam, Barcelona, Hamburg, Stockholm and Reykjavik (ECTOS)) electricity from the national grid mix (non renewable resource) and electricity generated by

- Wind power
- Solar energy
- Hydro power
- Biomass combustion and
- Geothermal energy

has been used as the energy source. Natural gas is used as the energy source for the on-site steam reformer in Madrid and Stuttgart. The hydrogen produced at centralised plants for the external supply has been produced either via electrolyser (Porto) or as a by-product of a chemical plant (Luxembourg) or a refinery (Perth (STEP)).

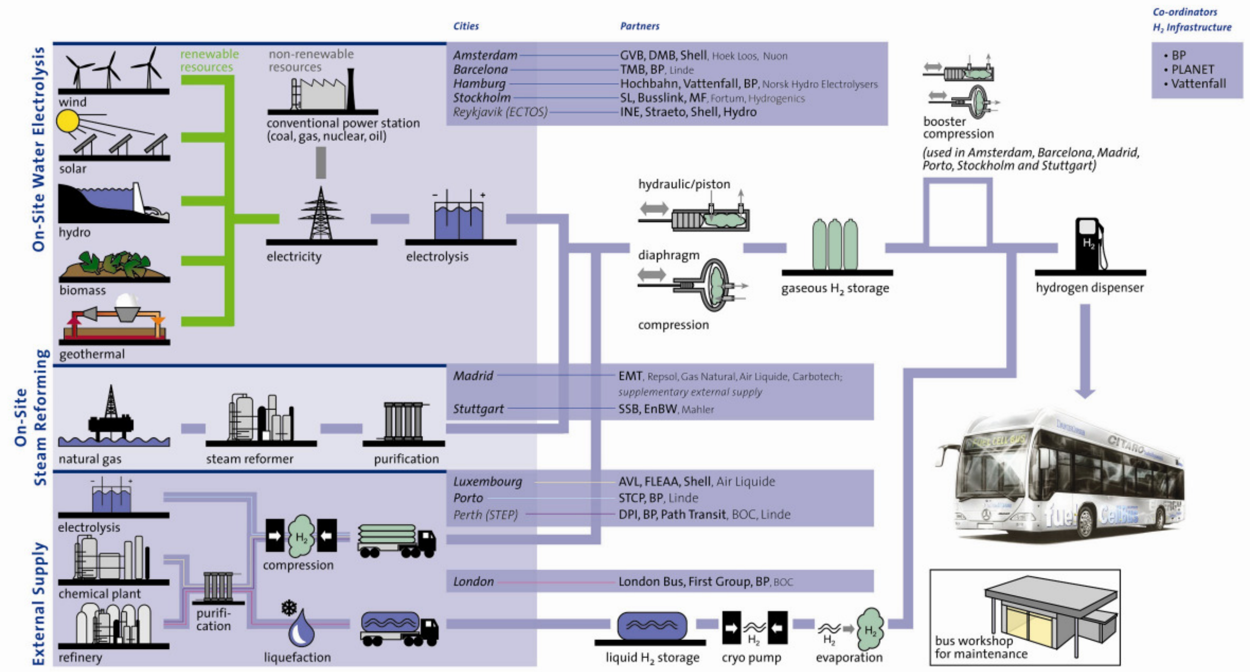


Figure G.1 Structure of hydrogen supply within CUTE

Besides the different production routes various storage concepts, compression technologies and filling procedures have been implemented.

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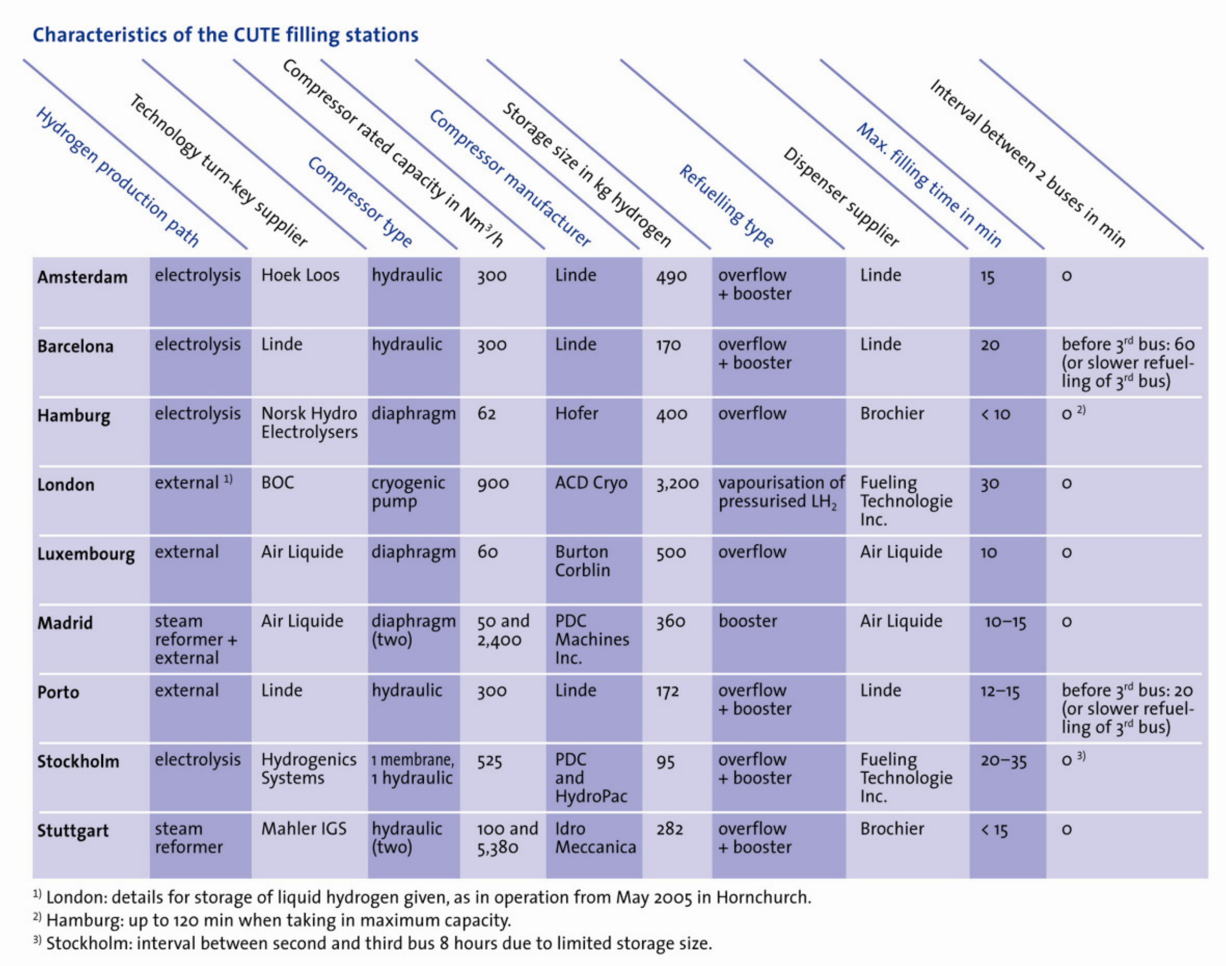
[23] For detailed description of the different technologies used within the CUTE project, please see Schuckert et al, “Hydrogen Supply Infrastructure and Fuel Cell Bus Technology”, Ulm 2004

The compressed hydrogen has been stored either in on-site storage banks (Amsterdam, Barcelona, Hamburg, Stockholm, Reykjavik (ECTOS), Madrid and Stuttgart) or in case of external supply the compressed hydrogen has been stored in the trailers delivered by the respective company, while in London the delivered liquefied hydrogen has been stored in liquid H_2 storage tanks. The different installed compressor technologies and refuelling procedures are displayed in Table G.1.



Characteristics of the CUTE filling stations

	Hydrogen production path	Technology turn-key supplier	Compressor type	Compressor rated capacity in Nm^3/h	Compressor manufacturer	Storage size in kg hydrogen	Refuelling type	Dispenser supplier	Max. filling time in min	Interval between 2 buses in min
Amsterdam	electrolysis	Hoek Loos	hydraulic	300	Linde	490	overflow + booster	Linde	15	0
Barcelona	electrolysis	Linde	hydraulic	300	Linde	170	overflow + booster	Linde	20	before 3rd bus: 60 (or slower refuelling of 3rd bus)
Hamburg	electrolysis	Norsk Hydro Electrolysers	diaphragm	62	Hofer	400	overflow	Brochier	< 10	0 [2]
London	external [1]	BOC	cryogenic pump	900	ACD Cryo	3,200	vapourisation of pressurised LH_2	Fueling Technologie Inc.	30	0
Luxembourg	external	Air Liquide	diaphragm	60	Burton Corblin	500	overflow	Air Liquide	10	0
Madrid	steam reformer + external	Air Liquide	diaphragm (two)	50 and 2,400	PDC Machines Inc.	360	booster	Air Liquide	10–15	0
Porto	external	Linde	hydraulic	300	Linde	172	overflow + booster	Linde	12–15	before 3rd bus: 20 (or slower refuelling of 3rd bus)
Stockholm	electrolysis	Hydrogenics Systems	1 membrane, 1 hydraulic	525	PDC and HydroPac	95	overflow + booster	Fueling Technologie Inc.	20–35	0 [3]
Stuttgart	steam reformer	Mahler IGS	hydraulic (two)	100 and 5,380	Idro Meccanica	282	overflow + booster	Brochier	< 15	0

[1] London: details for storage of liquid hydrogen given, as in operation from May 2005 in Hornchurch.
[2] Hamburg: up to 120 min when taking in maximum capacity.
[3] Stockholm: interval between second and third bus 8 hours due to limited storage size.

Table G.1 Technical characteristics of the CUTE filing stations