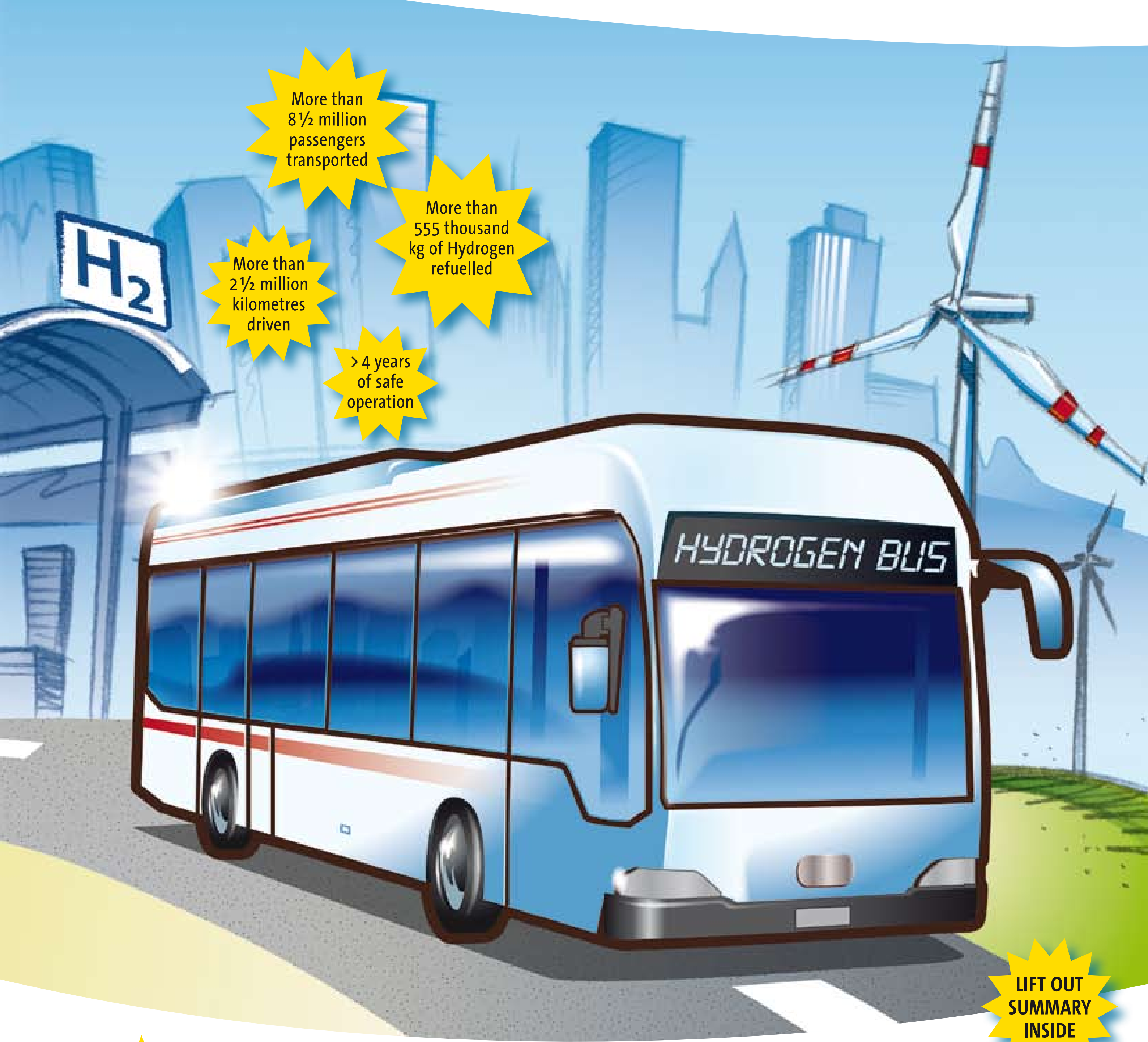
HyFLEET:CUTE

HYDROGEN TRANSPORTS

Bus Technology & Fuel for TODAY and for a Sustainable Future.



LIFT OUT SUMMARY INSIDE

The HyFLEET:CUTE Project is co-financed by the European Union

A Report on the Achievements and Learnings from

The HyFLEET:CUTE Project 2006 – 2009

The HyFLEET:CUTE Project Partners: Uniting for Progress

Government Partners

Automotive Companies

Transport Companies

Energy Companies and Infrastructure Suppliers

Academic and Consulting

Clean Public Transport is Here and Now

When the European Union embarked on supporting the development of hydrogen powered buses as one route towards clean public transport, there was no certainty of the outcomes. The remarkable results detailed in this Report are testament to the energy and commitment of all involved and to the foresight of the policy makers and planners.

Mitigating climate change, securing energy supply and assuring air quality are major global challenges. The European Union has invested much effort and resources into developing and implementing policies and initiatives to enable a clean, secure and de-carbonised energy future for our communities, especially for our transport systems. Promoting alternative clean fuels and efficient, innovative propulsion are key elements of European Union policy and will be essential to the continued competitiveness of the European vehicle and equipment industries.

The Policy Frameworks for achieving these energy goals are linked and we need to exploit synergies between the different actions. The promotion of innovation and creation of jobs in the Lisbon Strategy is linked to policies and programmes to meet the energy and environmental targets outlined in the so-called "20-20-20 by 2020" Energy Package. The Green Paper on Urban Mobility promotes the use of clean public transport and concepts such as co-modal transport, thereby reducing impacts of car usage. It also underlines the importance of investing in new technologies and the need for policy incentives, such as green procurement, to stimulate market introduction of clean technologies.

More information on these initiatives can be accessed at:

- http://ec.europa.eu/commission_barroso/president/pdf/COM2008_030_en.pdf
- http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/misc/107136.pdf
- http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0781:FIN:EN:PDF

TOTAL DEUTSCHLAND

One of 14 H_2ICE Buses at TOTAL Station, Berlin

ICELANDIC NEW ENERGY (INE)

H_2FC Bus with plume of water vapour, Shell Refueller, Iceland

PE INTERNATIONAL

Proud drivers of H_2FC Bus, Beijing

hySOLUTIONS

Hamburg H_2FC bus fleet

Through all of these initiatives, hydrogen can play a central role as a potential alternative and clean transport energy carrier producing zero CO_2 emissions at the exhaust. The outstanding results of the HyFLEET:CUTE project, following hard on the heels of the success of the previous CUTE Project, show that Europe is in sight of commercialization of this leading edge technology. The challenge now is to capitalise on these successes, capture the learning and build it into clean, efficient transport systems for Europe, thereby creating employment opportunities.

To achieve these ambitions we will need to work on many fronts – working with the European institutions, national and regional authorities and industry associations. HyFLEET:CUTE has given impetus to these discussions and collaborations, as well as establishing goals and milestones. It is important that these are built upon.

HyFLEET:CUTE has shown unequivocally that

- Hydrogen can be a low or even emission-free transport fuel;
- Fuel cells are a practical propulsion system for transport;
- Today's technology – internal combustion engines – can run efficiently and very cleanly on hydrogen;
- Hydrogen can be produced efficiently and with virtually zero atmospheric pollutant and carbon emissions when renewable primary energy sources or nuclear energy are utilised;
- Infrastructure to produce, supply and distribute hydrogen for transport can be implemented efficiently and with no fundamental obstacles; and, most importantly
- A hydrogen based transport system can be implemented and can operate safely, delivering substantial long term public benefits.

Barcelona H_2FC bus at BP station

Prince Willem-Alexander after riding on the Amsterdam H_2FC Bus

There is no doubt that Europe and the world are facing a paradigm change in the future as we move from our present fossil fuel based energy systems to a new energy and fuel mix which will include hydrogen. Transition has to be planned to avoid disruption. How we plan for it, how we prepare our community and our industry for it and adjust to the new challenges will be the key to how successfully we move through the change into a prosperous and new future.

I now urge all stakeholders to come together and work collaboratively to build towards this future. The recently formed public-private-partnership, the European Fuel Cell and Hydrogen Joint Undertaking, provides stakeholders with a focal point for European collaboration and for aligning efforts at national and regional levels. I encourage the HyFLEET:CUTE partners to participate fully in this initiative and to contribute their knowledge and vast experience in taking forward new initiatives for hydrogen buses.

I congratulate all the HyFLEET:CUTE partners for their highly successful and ground breaking work.

Matthias Ruete
Director-General
Energy and Transport
European Commission

Contents

TOTAL DEUTSCHLAND

Introduction to the HyFLEET:CUTE Project

Project Overview

The HyFLEET:CUTE project has involved the operation of 47 hydrogen powered buses in regular public transport service in 10 cities on three continents (see back cover). The Project started in 2006 and concludes at the end of 2009. Its aim was to diversify and reduce energy consumption in the transport system by developing new, fuel efficient hydrogen powered bus technology, plus clean, efficient and safe production and distribution of hydrogen as a transport fuel.

HyFLEET:CUTE was co-funded by the European Commission and 31 Industry partners through the Commission's 6th Framework Programme.

In particular, the HyFLEET:CUTE Project demonstrated these major developments:

1. The further development of Hydrogen Powered Bus Technology

Fuel Cell (FC) Power Train

- Thirty three hydrogen powered FC buses continued operations for at least one year in Amsterdam, Barcelona, Beijing (China), Hamburg, London, Luxembourg, Madrid, Perth (Australia) and Reykjavik.
- A prototype next generation FC/battery hybrid bus with greater fuel efficiency was developed, tested and demonstrated.

Internal Combustion Engines (ICEs)

- Different types of ICE buses were developed and operated. The first four buses were powered by naturally aspirated engines. An additional ten buses were provided with a turbo-charged engine and direct fuel injection in order to gain a higher power output. The fifteenth bus was developed with additional auxiliary power provided by a fuel cell system.

LONDON BUS SERVICES LTD

H_2FC Bus at Refueller, Hornchurch, London

2. The further development of Hydrogen Infrastructure

Existing hydrogen infrastructure was put through intensified operation and was further optimized in order to gain on efficiency and to lower station downtimes and operating costs. Additionally a hydrogen refuelling infrastructure was designed, built and demonstrated in Germany (Berlin).

In order to evaluate the different production methods and technologies, hydrogen was produced on-site at the refuelling station or supplied to the refuelling station from an off-site hydrogen production plant. The Project demonstrated the following on-site H_2 production methods:

- Steam reforming of natural gas and Liquefied Petroleum Gas (LPG)
- Water electrolysis – with renewable energy sources (e.g. wind based electricity) playing a major role in the production and distribution of clean hydrogen.

The project also included the operation of stationary fuel cells to provide power and heat to a service station (see page 39).

A wide range of accompanying studies and dissemination activities were also carried out (see pages 36–45).

About Hydrogen

Hydrogen is the most abundant element on the earth although it is not found in nature in its energy rich molecular state – H_2. It is an energy carrier[1] that can be derived from a wide range of energy sources, both fossil and renewable.

Table Intro 1: Comparison of hydrogen and diesel energy densities

SOURCE:
BASED ON WWW.DWV-INFO.DE

The energy content of [2]	is equivalent to
1 Nm^3 of gaseous hydrogen	0,30 litres of diesel
1 litre of liquid hydrogen	0,24 litres of diesel
1 kg of hydrogen	2,79 kg / 3,33 litres of diesel

Production Quantity, Properties and Application

Hydrogen has been used as an industrial gas for more than 100 years. The world hydrogen production is not monitored but was estimated in the year 2000 at around 45 billion kg. The European Union (EU-15) produced about 5,5 billion kg. At present, 49 % of hydrogen is produced by reforming natural gas and 29 % comes from coal gasification. Further methods of production include partial oxidation, cracking and other petrochemical processes. Electrolysis – splitting water using electric energy – potentially is the 'greenest' mode of H_2 production but had, and still has, a minimal production share.

Most of today's quantities are 'captive'; produced in bulk amounts for immediate on-site consumption and mainly used in chemical and petrochemical plants (e.g. for fertiliser synthesis). However, hydrogen supply by road transport to customers is also an everyday business with proven Industry Codes of Practice.

Due to its low volumetric energy density, hydrogen is stored and transported as a compressed gas (CGH_2 or GH_2) or in liquefied state (LH_2) at about - 253 °C. Hydrogen's low boiling point makes liquefaction very energy intensive but decreases transportation costs.

When H_2 is produced from water via electrolysis, it is highly desirable that the hydrogen for use in transportation is derived from renewable primary energy. In this way, H_2 provides a considerable overall environmental benefit along the supply chain (from 'well-to-wheel') in terms of pollutants and greenhouse gas emissions compared to conventional energy supply (see pages 36 – 39). In future, renewable electricity is likely to be generated on a large scale, e.g. off shore wind farms and solar power plants.

The direct use of hydrogen for energy purposes is mainly for power and heat generation. Today this sector only plays a minor role. This is likely to change over the coming decades when hydrogen may become an energy carrier as important as electricity and may even be used to buffer store intermittent, renewable energy.

1] An energy carrier is a substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes (ISO 13600).en.wikipedia.org/wiki/Energy_carrier

2] Based on LHV (lower heating value)

Structure of this Brochure

The HyFLEET:CUTE Project was a very broadly based, international Private-Public partnership. As such it had great complexities and interlinking of activities. In order to present the project's achievements and learnings in a coherent and easily understood format, it is structured as follows:

1. The brochure is arranged in **SECTIONS**.
2. Each section focuses on a **THEME**.
3. Each theme is addressed as follows:

- The **FACTS** are presented: What was achieved?
- **QUESTIONS** are answered: What have we learnt?
- Comments are made on the **FUTURE**: Where should we go next to best use our learning?

The HyFLEET:CUTE Project at a Glance

Project Context	
Duration of the Project	January 2006 – December 2009
Number of European Cities / Countries	8 Cities / 6 Countries
Number of Cities outside Europe	2 Cities / 2 Countries
Numbers of Project Partners	31
Project Investment: Total	43 million Euro
Project Investment: Industry & Other Organisations	24 million Euro
Project Investment: European Commission	19 million Euro
Hydrogen Bus Operations	
Number of H_2 Powered Buses Demonstrated	33 Hydrogen Fuel Cell Buses 14 Hydrogen Internal Combustion Engine Buses
Kilometres Travelled • H_2 Fuel Cell Buses[1] • H_2 Internal Combustion Engine Buses	 > 2,1 million km > 415 thousand km
Hours of Bus Operation • H_2 Fuel Cell Buses[1] • H_2 Internal Combustion Engine Buses	 > 140 thousand hours > 29 thousand hours
Bus Availability • H_2 Fuel Cell Buses[1] • H_2 Internal Combustion Engine Buses[2]	 > 92 % 89 %
Number of Passengers Transported[1]	> 8,5 million
Hydrogen Infrastructure	
Hydrogen Station Units demonstrated	10
Availability of Hydrogen Station Units	89,8 %
Hydrogen Refuelled[1]	> 555 thousand kg
Hydrogen production and supply paths demonstrated: • On-site water electrolysis • On-site LPG/CNG steam reforming • External supply	 4 2 6
Quality & Safety and Environmental Impact	
Accidents (Injury to Humans or the Environment)	Nil
Diesel Replaced[1]	> 1 million litres
Share of renewable energy used for on-site H_2 generation	79 %
Dissemination & Communication	
• Reach • Workshops/Forums • Web-Site hits • HyFLEET:CUTE Video Viewings	Global 3 on 3 Continents > 67 thousand unique visitors from 92 different countries > 2.000 web viewings; > 500 hard copies distributed

1] Figures are inclusive of CUTE; ECTOS; STEP; FCBB & HyFLEET:CUTE (Jan. 2006 – July 2009) projects
2] Figure is for Naturally Aspirated H_2 ICE Buses only

Water vapour, the H_2FC Bus's only emission, escapes from the exhaust

Glossary of Abbreviations

DAIMLER

H_2FC Buses on display at the Australian F1 Grand Prix, 2006

Abbreviation	Explanation
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CUTE Project	Clean Urban Transport for Europe Project, 2001–2006
ECTOS	A partner of the CUTE Project in Reykjavik, Iceland
EU	European Union
FC	Fuel Cell(s)
FCBB	Fuel Cell Bus Project Beijing, China
GHBP	Global Hydrogen Bus Platform
GH_2	Gaseous Hydrogen
GHG	Greenhouse Gases (mainly Carbon Dioxide & Methane)
GWP 100	Global Warming Potential considering a 100 year time horizon
H_2	Hydrogen – energy rich molecular state
H_2FC	Hydrogen Fuel Cell
HV	High Voltage
ICE	Internal Combustion Engine
ILCD	International Reference Life Cycle Data System
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LH_2	Liquefied Hydrogen
LPG	Liquefied Petroleum Gas
MEA	Membrane Electrode Assembly
Nm^3	Normal Cubic Metres (defined at 0°C and 1,013 bar)
NA	Naturally Aspirated
PEM	Proton Exchange Membrane (also known as Polymer Electrolyte Membrane)
TC	Turbo-Charged
SEE	Sustainable Energy Europe Campaign (http://www.sustenergy.org/)
STEP	A partner of the CUTE Project in Perth, Western Australia
TÜV	A German Certifying Body
WtW	Well-to-Wheel (Life Cycle parameter)

Hydrogen Infrastructure in HyFLEET:CUTE

The Facts

Parameter	Infrastructure Data
Total Hydrogen dispensed	555.951 kg[1]
Hydrogen dispensed	326.468 kg
Number of Refuellings	13.149
H_2 dispensed to vehicles outside HyFLEET:CUTE or fed to stationary fuel cells	18.832 kg
H_2 produced on-site	158.455 kg
H_2 delivered to site from external sources	232.322 kg
Average availability of the Stations Units[2]	89,8 %

1] This figure includes data from the CUTE, ECTOS, STEP, FCBB & HyFEET:CUTE (Jan. 2006 – July 2009) projects
2] Ratio of time that the unit was operational (i.e. operating or on stand-by) to total time. Periods when the unit was not operational ("downtime") were recorded in hours (see following pages for details)

Questions Answered

Question 1: What are the important descriptions and definitions for understanding Infrastructure Data Results

Hydrogen supply paths

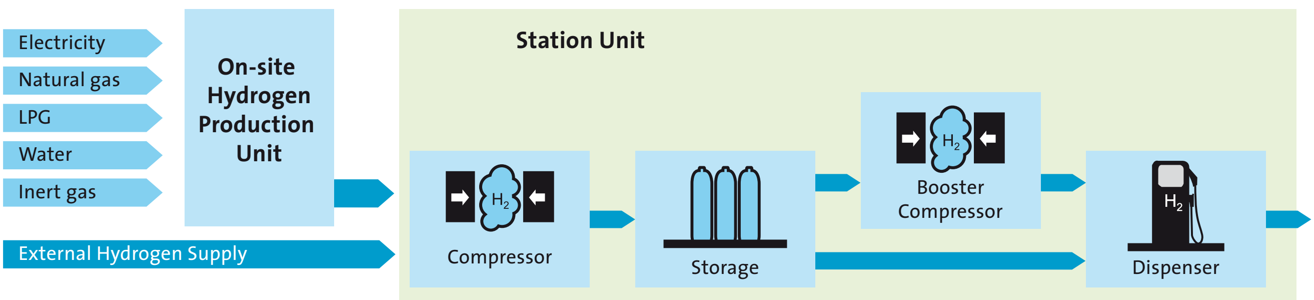
The hydrogen supply paths used in HyFLEET:CUTE were mostly those implemented in previous hydrogen bus projects. Only the Berlin plant was specifically developed and constructed for HyFLEET:CUTE.

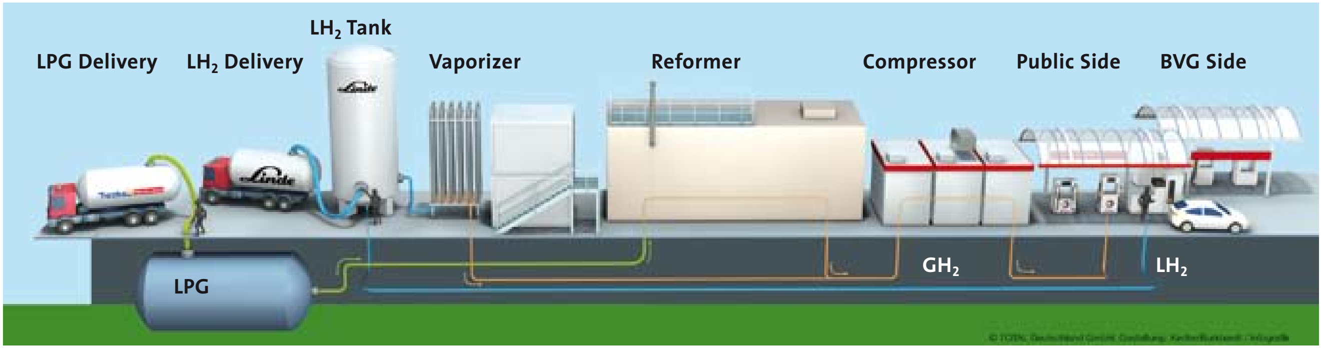
The simplest facility consisted of just a **Station Unit** for compressing, storing and dispensing hydrogen regularly delivered by truck from sources external to the station (see IS – Figure 1). However, the majority of the facilities also included an on-site **Production Unit**. IS – Table 1 outlines the supply pathways. Some sites included an option of using external backup in case of delivery problems with the normal supply path.

London and Berlin had liquid hydrogen delivery to the site. The Berlin site was the most complex with a mix of on-site hydrogen generation from LPG and external LH_2 delivery (see IS – Figure 2). Both LH_2 and GH_2 were stored on the site. As well as refuelling the project buses with GH_2 at 350 bar (labelled as the "BVG side" in IS – Figure 2), other vehicles could be refuelled on the "public side" of the station. This included LH_2 dispensing and 700 bar refuelling of cars. An ionic compressor was added in parallel to the piston compressor during the operating phase.

Two stationary fuel cells were also installed at the Berlin site to utilise the boil-off from the LH_2. The power produced was largely utilised by the conventional refuelling station itself. Excess was fed into the city grid. The heat from a water-cooled fuel cell was used for hot water generation and for heating the station shop in winter. The air-cooled unit provided power only. A showroom was built to display the units to visitors. An evaluation of the stationary fuel cells can be found on page 39.

IS – Figure 1: Generalised schematic of the HyFLEET:CUTE hydrogen infrastructures





IS – Figure 2: Overview of the hydrogen infrastructure facility in Berlin. The storage for GH_2 and the stationary fuel cells are not included

Performance of the Infrastructure

Question 2: What was the availability of the hydrogen infrastructure and what were the causes for downtime?

The average availability of the **Stations Units** was 89,8 %.

Five factors dominated Station Unit downtime (IS – Figure 3): the Production Units, hydrogen compressors (including a cryogenic pump for LH_2 in London), maintenance, safety concerns and the dispensing equipment. Overall, key issues that were evident in the CUTE Project continued to occur in HyFLEET:CUTE. They need to be remedied now.

A substantial part of downtime was caused by **external** problems which were not the result of difficulties with the Station Units themselves. Namely, these were failures in the Production Unit or the external supply. The average availability of the Station Units themselves was 93,8 % with each unit achieving 89 % or better.

The main **internal** factor that reduced the availability of the Station Units was the hydrogen compressors, the heart of the unit. It is the only category in IS – Figure 3 with contributions from all 10 project sites.

Production Unit availability varied significantly across the sites.

Electrolysis: There were no issues with the stacks, i.e. the core of the electrolyser units at any of the sites. Technical issues which did arise, such as material failures, were analysed in detail and solutions developed and implemented.

Reformers: Both reformer sites faced severe issues with the heart of the unit, i.e. the reformer tubes. These technical issues were addressed and overcome. However it seems that downscaling of reformer technology for decentralised production currently is accompanied by a decrease in system stability.

The trial has shown that contingency arrangements for backup supplies by trailer delivery are vital for sites with on-site hydrogen Production Units.

IS – Table 1: Outline of the supply pathways

Site	Amsterdam	Barcelona	Beijing	Berlin	Hamburg	London	Luxembourg	Madrid	Perth	Reykjavik
Regular external hydrogen supply			X	X		X	X	X	X	
On-site water electrolysis	X	X			X					X
On-site natural gas reforming								X		
On-site LPG reforming				X						
Backup external hydrogen supply		X		X	X				X	
Integration into public fuelling station				X						X

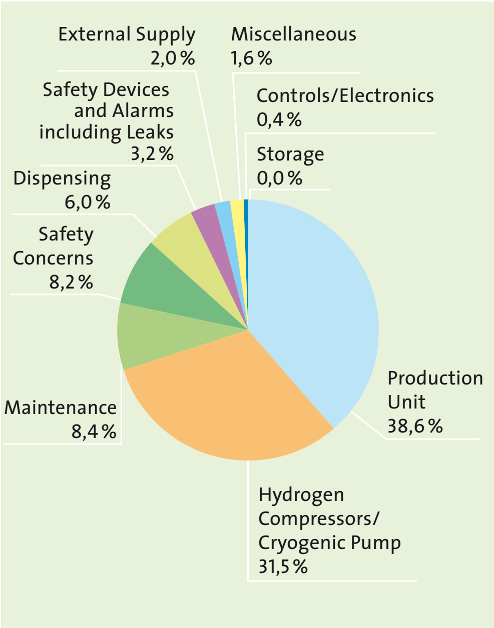
Question 3: Why wasn't all the hydrogen supplied to the Station Units actually utilised?

The hydrogen available at the refuelling stations was utilised by both the project buses and the stationary fuel cells, as well as by vehicles not operating within the HyFLEET:CUTE project. Data in the "Facts" Table on page 11 suggest that more than 10 % of the hydrogen supply was not utilised by either the vehicles or the stationary cells.

Two factors need to be considered when assessing this (apparent) loss of hydrogen:

- Several standard infrastructure management activities lead to release of hydrogen. These include purging of installations when they are shut down or started, regeneration of the hydrogen purification units in the reformers and the electrolysers, and boil-off losses from liquid hydrogen storages. The losses caused by individual factors vary from site to site and it is difficult to segregate individual contributions.
  All equipment manufacturers are developing and implementing measures to minimise these losses.
- Loss investigation was impeded by uncertainty surrounding the accuracy of hydrogen meters. In one extreme case, the error in a dispenser meter was up to 50 % in some readings. The meter was replaced and the data were corrected. At other sites, faulty readings were suspected but the issue was unsolved. These problems are being addressed by meter manufacturers, regulators and companies involved in the supply of infrastructure equipment.

Finally, it should also be noted that over half of the H_2 losses were at one site where there were particular difficulties.



IS – Figure 3: Normalised distribution of downtime hours of the Station Units with respect to cause.
Note: Downtime hours at each site have been normalised to one year for the sake of comparison between sites. "Maintenance" stands for scheduled maintenance; "Safety Concerns" for periods when the station was technically operational but removed from service due to system safety concerns. Downtime caused under "Production Unit" and "External Supply" result from issues upstream of the Station Unit in the hydrogen supply chain. All other categories indicate failure and repair of the stated Station Unit components

Question 4: What was learnt from intensified infrastructure operation?

During the HyFLEET:CUTE project between 20 % and 46 % more hydrogen per day was dispensed when compared with the same sites in the predecessor projects CUTE and ECTOS. In Hamburg, with its fleet enlarged from 3 to 9 buses, the increase was 160 %. The capacity of some infrastructure components had to be reinforced to cater for this.

Tests showed that the design parameters for some stations did not allow sufficient operating flexibility to increase the utilisation of the plant. An example of this was the constraint imposed by the size of the on-site storage that serves as a buffer between hydrogen generation and consumption. Increasing the utilisation further would also require having larger service teams for both vehicles and infrastructure.

Question 5: What was the energy demand for supplying hydrogen to the buses? Was the intensified operation beneficial in this respect?

The power consumption of the Station Units per kilogram hydrogen dispensed varied appreciably from site to site. This resulted as much from the engineering design characteristics of the individual refuellers as from the way the hydrogen was supplied to the Station Unit. For example, variations in the start and end pressures of the trailers for external supply, of the compressors and of buses can cause large power consumption differences.

Station Units
All former CUTE Station Units had lower specific power consumption under HyFLEET:CUTE. This was partly because the operation was more intense in HyFLEET:CUTE and therefore the power demand per unit of hydrogen dispensed for constantly operating safety devices and controls was smaller.

Production Units – Electrolysis
The power consumption per kilogram of hydrogen produced shows an increase from CUTE to HyFLEET:CUTE. Running the units near their design limits (under intensified operation) and ageing of the stacks seem to be the most relevant factors here.

Production Units – Reformers
For the reformers, extensive energy data are not available. The reason is that reformers operate at high temperature, so – unlike electrolysers – they cannot easily be started and stopped within a short period of time. Once station storage was full, the units usually continued operation at the lowest production level possible. Part-load operation affects process efficiency negatively, so the overall figures are not representative.

Entire hydrogen infrastructure facility
As an example, the hydrogen supply chains for on-site generation from water electrolysis, purification, compression, storage and dispensing displayed an efficiency of up to 52 %. There is room for improvement.

Question 6: What are the cost implications of hydrogen purity?

A model was developed to assess the impact that hydrogen purity requirements and quality monitoring have on Hydrogen costs.

When applying the “standard” specifications (those required for the operation of the buses in HyFLEET:CUTE) for current 60 Nm^3/h production capacity systems, the costs for ensuring hydrogen purity for steam reforming amount to about 27 % of the total costs and about 17 % for water electrolysis.

Applying “tight” specifications – as given in a technical paper of the Society of Automotive Engineers – increases total costs. What is more, the purity-related share rises to 36 % (reforming) and 25 %, (electrolysis).

When studying future larger systems, the total costs per kg of hydrogen decrease, whereas the share of expenses related to hydrogen purity increases to similar levels as occurs with the tight specifications for current, small scale plants.

TOTAL DEUTSCHLAND

TOTAL Refueller Berlin

EMPRESA MUNICIPAL DE TRANSPORTES DE MADRID (EMT)

Repsol Refueller Madrid

The Future

Question 7: What improvements in the system are recommended for the future?

Given the prototype character of the current hydrogen refuelling facilities, their overall level of performance has been satisfactory. However, infrastructure currently seems to be the element in the entire hydrogen bus operational chain which requires the greatest level of performance improvement in order to facilitate commercial implementation. Infrastructure suppliers have recommended a dedicated Task Force to develop this aspect, perhaps through the Fuel Cell and Hydrogen Joint Technology Initiative.

The results of the HyFLEET:CUTE Project and similar activities, and the lessons articulated in various reports should be assimilated into these activities and built upon. The key issues – such as hydrogen metering and hydrogen losses, reliability of on-site hydrogen generation, hydrogen compressors, the dispensing equipment (i.e. the user interface), and energy consumption – have been outlined above.

There is also a need for modular system design that enables simple scaling up with growing fleets and increasing intensity of operation. Modularisation must come hand-in-hand with simplification and a basic level of standardisation to help reduce investment cost and increase efficiency. Variable load patterns, intermittent operation and part-load conditions will also be important for the fuelling station of the future.

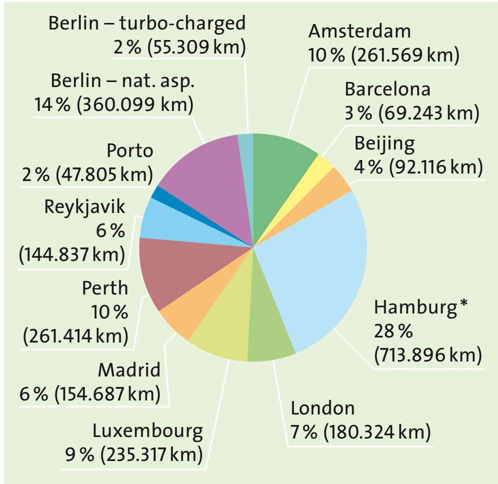
Note: Further aspects of infrastructure performance are discussed in the section on quality, safety and training on pages 32–35

H_2 Bus Operations in HyFLEET:CUTE

The Facts in Overview

AVL, LUXEMBOURG

H_2FC (left) & H_2ICE Buses at Bus Depot Luxembourg

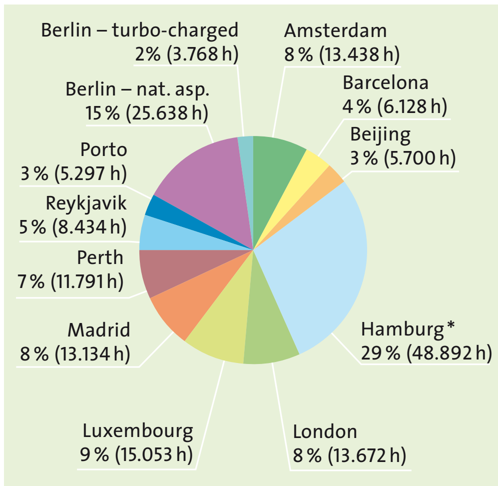


BusOp – Figure 1: Total kilometres driven within HyFLEET:CUTE (Jan. 2006 – July 2009), CUTE, ECTOS, STEP and FCBB and the relative percentages by city site

The kilometres driven and hours of operation are evidence of the outstanding success of the technology.

Parameter	Bus Data
Number of H_2 Powered Buses Demonstrated	33 Hydrogen Fuel Cell Buses 14 Hydrogen Internal Combustion Engine Buses
Kilometres Travelled H_2 Fuel Cell Buses [1]	2.161.208 km (1.081.485 km in HyFLEET:CUTE)
H_2 Internal Combustion Engine Buses	415.408 km
Hours of Bus Operation H_2 Fuel Cell Buses [1]	141.541 h (66.038 in HyFLEET:CUTE)
H_2 Internal Combustion Engine Buses	29.406 h
Bus Availability H_2 Fuel Cell Buses [1]	> 92 %
H_2 Internal Combustion Engine Buses [2]	89 %
Number of Passengers Transported [1]	> 8,5 million

1] Figures are inclusive of CUTE; ECTOS; STEP, FCBB & HyFLEET:CUTE (Jan. 2006 – July 2009) projects
2] Figure is for Naturally Aspirated H_2 ICE (NA ICE) Buses only



BusOp – Figure 2: Total hours of operation within HyFLEET:CUTE (Jan. 2006 – July 2009), CUTE, ECTOS, STEP and FCBB and the relative percentages by city site

* Data inclusive of the CUTE project sites Stockholm and Stuttgart because during HyFLEET:CUTE these buses were operated in Hamburg

The performance of the FC and ICE buses within the HyFLEET:CUTE project **alone** is summarised separately in the following pages.

H_2 Fuel Cell Buses

The Facts

Within the HyFLEET:CUTE project, the FC bus fleet of 33 buses achieved the results shown in H_2FC – Table 1.

The key technical data for the Fuel Cell buses is provided in H_2FC – Table 2. This table includes the data for the FuelCELL-Hybrid Bus developed and demonstrated during the HyFLEET:CUTE project.

Parameter	Fuel Cell Buses (HyFLEET:CUTE)
Kilometres driven	1.081.485 km
Hours of operation	66.038 h
Average speed	16,4 km/h
Average fuel consumption	21,9 kg/100 km (72,9 l/100 km Diesel Equivalent)
Bus availability[1]	92,6 %

H_2FC – Table 1: Results for H_2FC Buses within the HyFLEET:CUTE Project: Jan. 2006 – July 2009

Vehicle	Fuel Cell Bus Fleet	FuelCELL-Hybrid
Label	Mercedes-Benz	Mercedes-Benz
Model	Citaro	Citaro
Length	12 m	12 m
Height	3,67 m	3,40 m
Max. Weight	19 t	18 t
Net Weight	14,2 t	13,2 t
Transport Capacity	70 passengers	76 passengers
Driving Range	ca. 200 km	> 250 km
Power Fuel Cell System	250 kW	120 kW
HV-Battery	–	26,9 kWh, max 180 kW
Drive power	205 kW for 15 – 20 secs	220 kW for 15 – 20 secs
Fuel Cell Tanks	9 cylinders, > 40 kg, 350 bar	7 cylinders, 35 kg, 350 bar

H_2FC – Table 2: Key technical data of fuel cell bus fleet and FuelCELL-Hybrid

1] Bus availability was defined as the ratio of time buses were not in maintenance to the total timeframe of the project operation expressed as a percentage

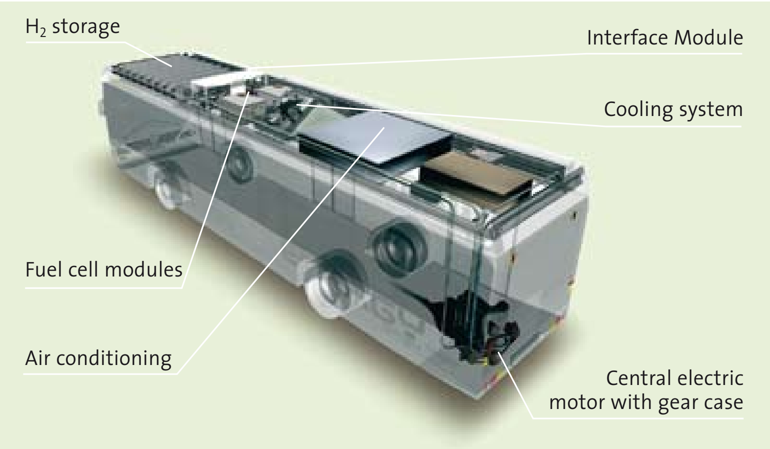
Hamburg H_2FC Bus fleet ready for action

Questions Answered

Question 1: What were the performance parameters of the buses?

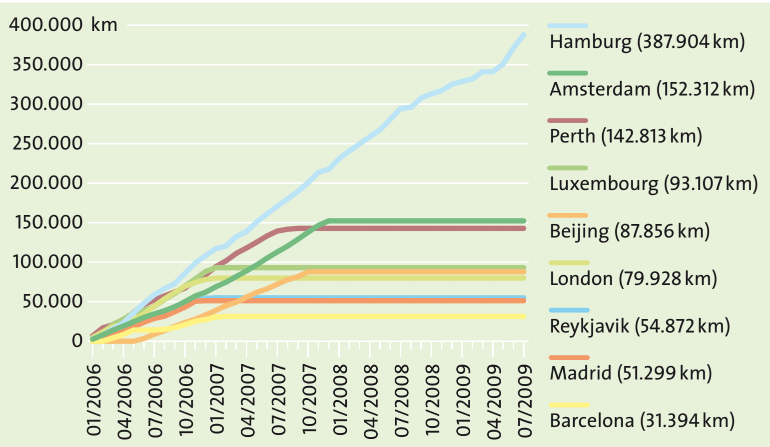
The operation of the 33 fuel cell buses within HyFLEET:CUTE was a very successful continuation of the CUTE, ECTOS, STEP and FCB Beijing projects.

Context of the Operations



H_2FC – Figure 1: Technical design of the fuel cell buses

Kilometres of Operation



H_2FC – Figure 2: Cumulative distance driven per FC bus site within HyFLEET:CUTE (km driven), Jan. 2006 – July 2009

The buses performed very well in an extremely wide range of climatic conditions; from hot and dry in Madrid to cold and humid in Reykjavik; from flat in Hamburg to hilly in Luxembourg; from congested in London to full speed in Perth. The ambient air temperatures ranged from -5 °C to 36 °C.

There were no major breakdowns or problems caused by the fuel cell technology and their components or of the buses themselves.

Kilometres of Operation

Within the HyFLEET:CUTE project, the H_2FC buses in Hamburg covered the largest distance of 341.046 km. This was due to its operation of 9 buses over an extended period (see H_2FC – Figure 2).

The buses operating in Barcelona covered the least distance due to problems with the hydrogen infrastructure.

Operating hours

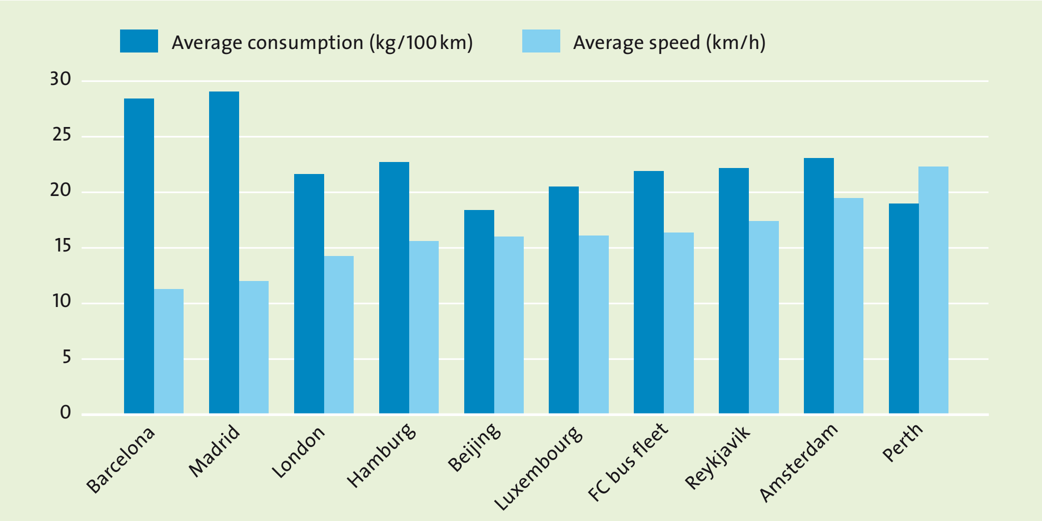
The average daily operation was approximately 7 hours; ranging from approximately 9 hours in London down to Beijing with 5,5 hours per day.

Average speed and fuel consumption

The average speed was approximately 16,4 km/h but differed substantially between the cities. Perth buses averaged more than 22 km/h, while the Barcelona buses achieved 11 km/h, as shown in H_2FC – Figure 3. Key influencing factors were the traffic conditions, topography and number of stops per km.

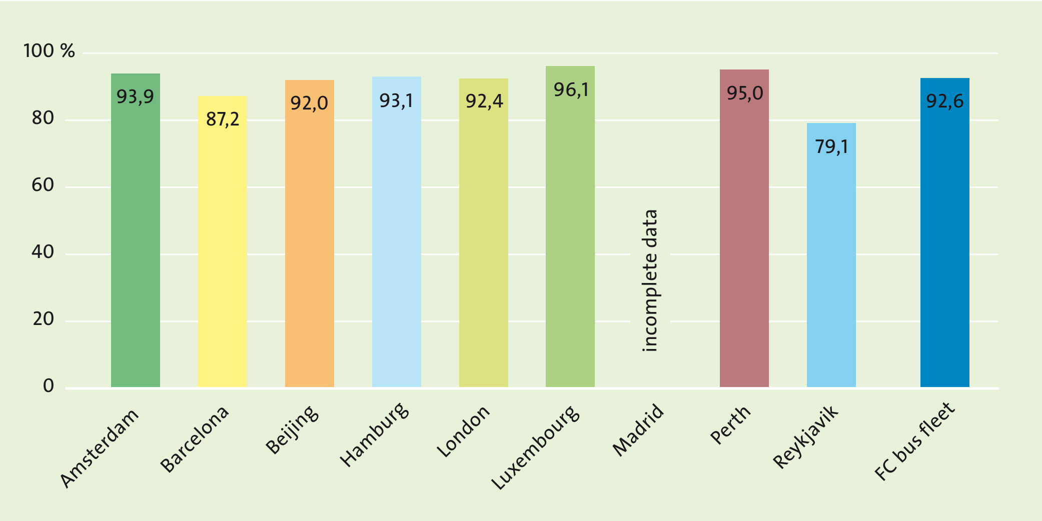
The average fuel consumption was 21,9 kg of hydrogen per 100 kilometres driven (H_2FC – Figure 3). It ranged from 29,1 kg/100 km in Madrid, to 19,0 kg/100 km in Perth. These data are even more impressive given that the buses were designed for high reliability

Average speed and fuel consumption



H_2FC – Figure 3: Average speed per FC bus site vs. average fuel consumption within HyFLEET:CUTE (km/h)

Bus availability



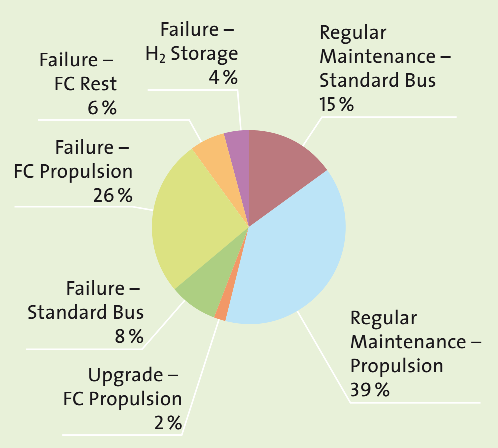
H_2FC – Figure 4: Average bus availability per site in HyFLEET:CUTE (%)

to ensure high availability for the bus operators and not optimised for fuel efficiency. These results were also achieved in regular daily operation and not from specific fuel consumption measurement test drives.

As outlined below, the development of the next generation FuelCELL-Hybrid bus has focussed on fuel efficiency.

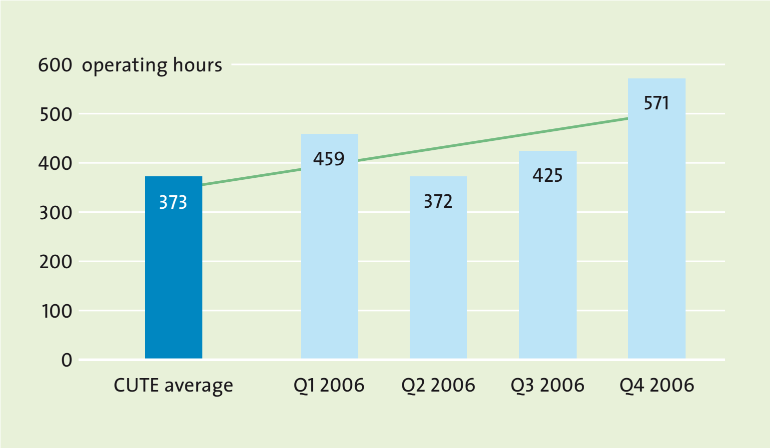
Bus availability

The performance of the fuel cell buses was better than expected with a high average availability in HyFLEET:CUTE of 92,6 % (H_2FC – Figure 4). This was in part the result of the commitment of two technicians per site servicing the buses.



H_2FC – Figure 5: Percentage of Downtime Caused by Different Components within the Buses

Quarterly operating hours per bus



H_2FC – Figure 6: Quarterly operating hours in Luxembourg during CUTE and HyFLEET:CUTE

Question 2: What were the main technical problems during the operation of the fuel cell buses?

Less than 8 % of the overall downtime of the buses was directly related to failure of the standard bus (H_2FC – Figure 5). Most of the downtime related to work with standard mechanical components or electrical components such as the main inverter and the monitoring boards of the fuel cells.

Components such as the inverters and gas regulators were improved and upgraded over the life of the project and are now showing greatly increased lifetimes ranging from 3 times up to 16 times longer than at the commencement.

The regular maintenance of the FC system and related components also reduced failures in the FC propulsion system.

As anticipated, the FC system itself showed some performance degradation over time. FC stack lifetime was reduced as some materials degraded and catalyst was deactived. Increased levels of pollutants (e.g. carbon monoxide and carbon dioxide) in the hydrogen fuel degraded the performance at some sites. Air quality contaminants in Beijing also caused problems with the performance of some stacks and the particulate filters had to be modified and the air filters changed more frequently.

The lessons learned have led to improvements in MEA designs in the next generation FC stack, and to an improved understanding of the effects of operating conditions on stack performance and reliability.

Question 3: Were there safety related problems in operation?

There were no major safety related incidents in the operation of the 33 FC buses. This good result validates both the vehicle design and the maintenance concept used.

Question 4: What was the availability & reliability of the FC bus system with intensified operation?

The continued and intensified operation of the fuel cell buses was a goal in HyFLEET:CUTE. This was achieved.

As an example, H_2FC – Figure 6 shows the mean, quarterly operating hours for the three Luxembourg buses. When averaged for the year, the buses achieved a 22 % increase during the HyFLEET:CUTE project period.

Importantly, the availability improved across all sites from 81,6 % to 92,6 %.

The increased reliability of the FC buses can also be seen in the more than 85 % reduction of 'red light alarms' for major system failures, and more than 90 % decrease in road calls (H_2FC – Figure 7).

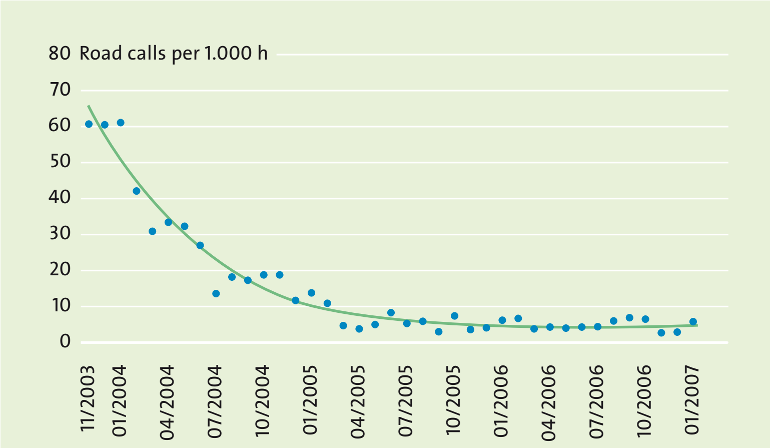
Due to the prolonged operation of the FC buses in cities such as Hamburg and Amsterdam it was possible to double the operating hours for the fuel cell drivetrain when compared to CUTE. More than 6.000 hours of operation were achieved on individual buses during the HyFLEET:CUTE project.

Question 5: Were there any new learnings about the factors influencing fuel consumption by FC buses (e.g. topography, climate, traffic)?

A range of tests were conducted to analyse the external factors influencing fuel consumption. These included driving behaviour, climate and local topography. Key findings included:

- Driving behaviour or topographic characteristics of the route can influence fuel consumption by up to 25 %.
- Climate influences fuel efficiency and consumption by affecting the power demand of the auxiliary systems such as the cabin heating and the air conditioning, especially when the temperature is below 0° or above 20°C.
- The age of the fuel cell stack, i.e. how many operating hours the stack has run, greatly impacts on fuel consumption and fuel efficiency.
- Previous measurements by the drive train supplier showing a difference in fuel consumption of about 15 % between the gearbox shift modes 1 (economy) and 5 (power) were validated under operational driving conditions. Results suggested mode 4 of the transmission provided the optimum balance between power and consumption.

Road calls

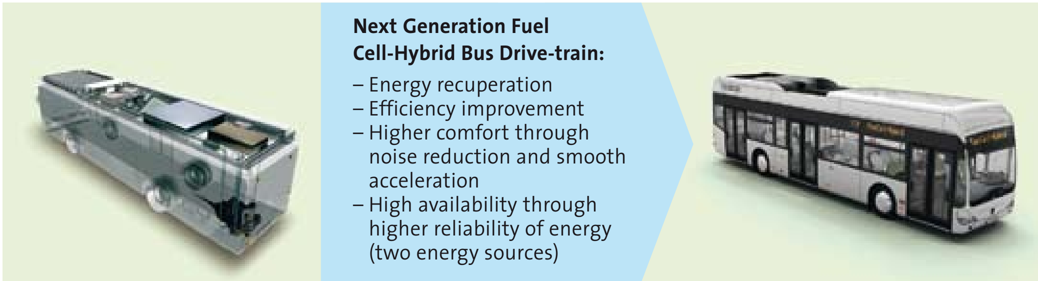


H_2FC – Figure 7: Road calls

Question 6: The next generation FC bus: What lessons from the operation of the FC buses in CUTE and HyFLEET:CUTE have been integrated?

The key challenge to overcome has been to reduce fuel consumption by up to 50 % through improvement in energy efficiency while maintaining or, if possible, increasing the overall vehicle reliability. Lifetime and cost have also been key drivers in the development.

The main developments included in the next Generation FC hybrid bus prototype are summarised in H_2FC – Figure 8.



H_2FC – Figure 8: Development improvements from the existing fuel cell buses to the FuelCELL – Hybrid Bus

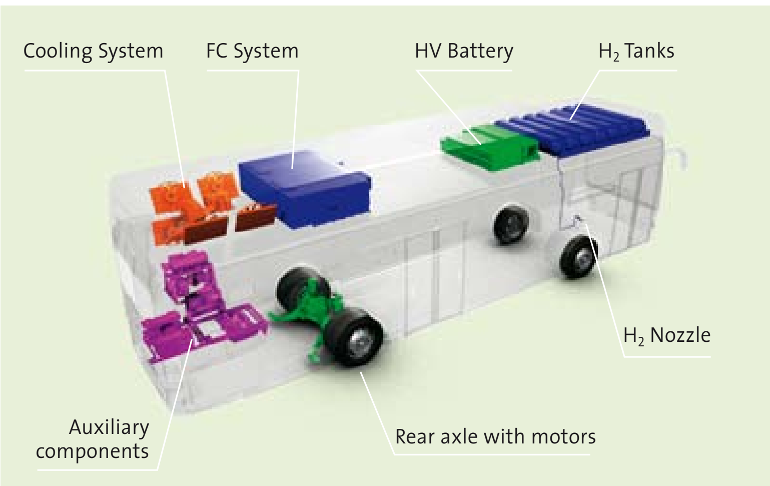
Citaro Fuel Cell (CUTE) Specifications	
Power FC-System	250 kW
Drive power	205 kW, for > 15 – 20 sec
Range	180 – 220 km
HV-Battery	–
Efficiency FC-System	43 – 38 %
H_2-Consumption	20 – 24 kg/100 km
Expected warranty	2 years, 2.000 h

Citaro FuelCELL-Hybrid Specifications	
Power FC-System	120 kW
Drive power	240 kW, for < 15 – 20 sec
Range	> 250 km
HV-Battery	180 kW power max, 26,9 kWh
Efficiency FC-System	58 – 51 %
H_2-Consumption	10 – 14 kg/100 km
Expected warranty	6 years, 12.000 h

The fuel consumption reduction goal of 50 % was reached. The warranty is expected to increase from a minimum of 2.000 hours to 12.000 hours.

The design of the FuelCELL-Hybrid is shown in detail in H_2FC – Figure 9. All key components are described in detail below.

H_2FC – Figure 9: Key components of the Citaro FuelCELL – Hybrid prototype bus



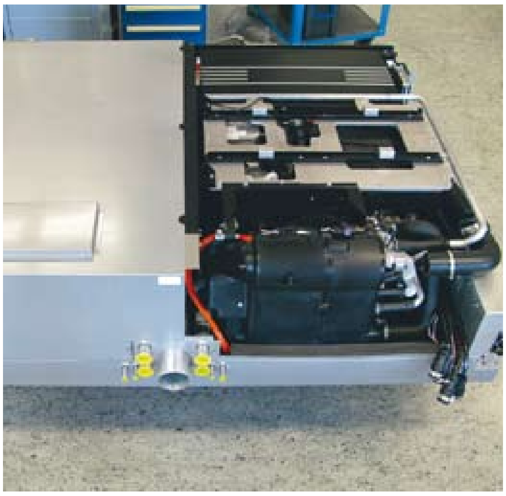
Fuel Cell System

The new fuel cell system uses a slightly adapted design of the passenger car system to facilitate synergies with the development costs and testing. Two passenger car systems with a joint net power output of 120 kW are being used.

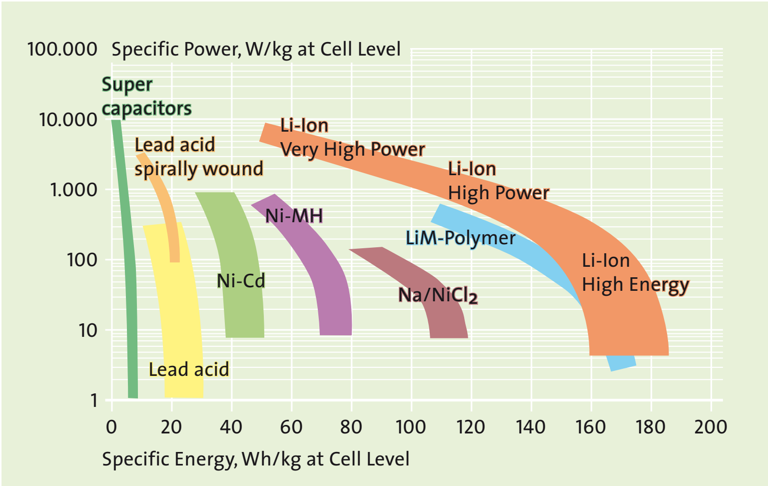
Battery energy storage

Lithium-ion battery technology was selected following an extensive evaluation of energy storage technology. The advantages are:

- High energy capacity
- Predictable performance
  – State of charge
  – Battery status
- Closed battery,
  – Maintenance-free
- Low self-discharge (< 5 % per month)


DAIMLER

H_2FC – Figure 10: Fuel cell system module of the Citaro FuelCELL – Hybrid



EVOBUS 2009

H_2FC – Figure 11: Battery technologies – power vs energy storage

Hydrogen storage system
The hydrogen storage system of the FuelCELL hybrid has been downsized as a result of the improved efficiency of the drive train. This has led to the reduction in the overall weight of the bus. The 350 bar system incorporating proven components from the HyFLEET:CUTE buses has been maintained in the new bus. The reliability and maturity of the system has also been enhanced through improved gas piping.

Wheel hub drive
The rear axle has 2 wheel hub motors (see H_2FC – Figure 12) and has been specifically developed to match the required speeds, load capabilities and energy efficiency. It also serves as a generator for energy regeneration during braking.

Cooling system
The size of the cooling system of the FuelCELL hybrid has been substantially

DAIMLER

H_2FC – Figure 12: Wheel hub motor

reduced, with significant noise and weight reductions resulting from utilisation of standard automotive components. The reduction in size has had no influence on the performance.

Auxiliaries
The auxiliary components in the FuelCELL Hybrid are driven electrically. This means that they operate only on demand and are not driven continuously as with the belt driven systems on the fuel cell buses. This will result in higher efficiency and lower maintenance of the components.

Question 6: What has been learnt from the operation of the FC hybrid prototype with regard to efficiency, availability, emissions etc.?

The operating strategy of the overall system of the FuelCELL-Hybrid prototype has been further improved through road testing over several months. These tests have also demonstrated:

- A doubling of the fuel efficiency compared with the HyFLEET:CUTE fuel cell bus
- Very low noise
- Zero emissions operating the FuelCELL-Hybrid
- Simplified maintenance and service concept
- Costs over lifetime have been reduced
- Reduced operating costs.

The Future

What are the next steps to improve the system regarding availability, safety, energy efficiency and cost beyond HyFLEET:CUTE?

The prototype will be tested and progressively enhanced in order to improve the overall system. It is planned to develop a small fleet and operate the FC buses in various cities in Europe and to use the learning from this work to bring the FC technology to commercialisation.

AVL, LUXEMBOURG

One of Luxembourg's H_2FC buses passes five thousand operating hours

H_2 Internal Combustion Engine Buses

MAN NUTZFAHRZEUGE

The fleet of 14 hydrogen buses in the depot of BVG in Spandau/Berlin

The Facts

MAN Nutzfahrzeuge AG (MAN) developed a fleet of fourteen buses powered by two different hydrogen Internal Combustion Engine (ICE) technologies for operation in regular public transport service. The buses were operated throughout the HyFLEET:CUTE Project by the Berlin Bus Company (BVG – Berliner Verkehrsbetriebe).

All the buses were based on the standard low floor MAN City Bus Lion's City model.

1. The first four buses had naturally aspirated ICE (NA ICE) technology with 150 kW of power. This technology has been progressively developed and improved over the last decade.

2. MAN also developed ten buses for the HyFLEET:CUTE Project with turbo-charged ICE (TC ICE) technology with 200 kW of power.

3. A fifteenth prototype bus was based on the turbo-charged bus technology and incorporated a fuel cell to provide auxiliary power for the bus systems. This bus was constructed in order to demonstrate the possibilities of this technology and was not operated in regular public transport service.

Parameters	ICE buses HyFLEET:CUTE [1]
Kilometres driven	360.099 km
Hours of operation	25.638 h
Average speed	13,1 km/h
Average fuel consumption	21,6 kg/100 km (71,9 l/100 km Diesel Equivalent)
Bus availability [2]	89,0 %

H_2ICE – Table 1: Results for H_2-ICE Buses within the HyFLEET:CUTE Project (Jan. 2006 – July 2009)

1] Naturally aspirated buses only
2] Bus availability was defined by the ratio of time buses were not in maintenance to the total timeframe of the project operation expressed as a percentage.

		Buses 1–4 naturally aspirated	Buses 5–14 turbo-charged
Vehicle	Label	MAN low floor bus	
	Model	Lion's City	
	Length total	12 m	
	Height; Width	app. 3,4 m; 2,5 m	
	Max. Weight	18,0 t	
	Net. Weight	12 t	12,9 t
	Transp. Capacity	80 Persons	77 Persons
	Driving Range	> 200 km	> 250 km
Engine	Model	MAN Aspirated-Engine (H 2876 UH01)	MAN Turbo-Engine (H 2876 LUH01)
	Engine Output	150 kW at 2.200 RPM	200 kW at 2.000 RPM
	Torque	760 Nm at 1.000 – 1.400 RPM	1100 Nm at 1.400 – 1.600 RPM
Storage Unit	Model	Hydrogen-high-pressure Light-weight construction	
	System, Capacity	10 vessels, type III, Dynetek 10 x 205 l = 2.050 l (app. 50 kg H_2)	
	Compression	max. 350 bar (@ normal conditions)	
Basics	Air Conditioning	Driver's cab only	Passenger compartment

H_2ICE – Table 2: Summary of Key Vehicle Data for MAN ICE buses

Questions Answered

Question 1: What new technology was involved?

Hydrogen buses with naturally aspirated ICE technology

The first four buses delivered to BVG had naturally aspirated ICE technology (see H_2ICE – Figure 1 below) which developed 150 kW of power and was adequate for normal city bus operations.

This technology proved very reliable during the operation in Berlin, with no major breakdowns. Apart from normal service work, very few repairs were necessary.

Initial problems were solved by changes within the engine software and/or by improved components. The buses and the technology performed well when measured by distance driven, hours of operation and availability.

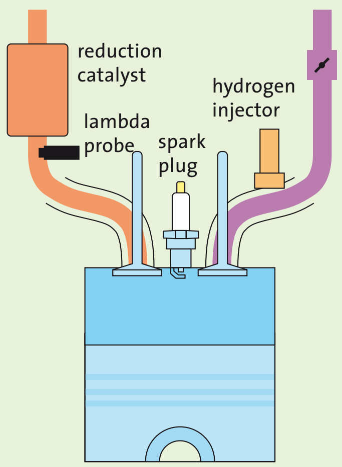
Hydrogen buses with turbo-charged ICE Technology

The turbo-charged ICE technology (see H_2ICE – Figure 3) was developed to provide increased power. This enabled the entire bus to be air conditioned, as well as giving improved acceleration away from bus stops and smoother integration of the vehicle into traffic flows.

A second development goal was to improve the fuel economy to give a greater operating range for the buses. This enabled the easier integration of the buses into regular day to day fleet operation, avoiding returning to the base for refuelling during the day.

To achieve these two main goals the engine concept had to be changed to a turbo-charged engine with internal mixture formation. This required direct fuel injection and therefore the design of a completely different type of injector.

While the engine itself showed no problems, the fuel injectors caused considerable downtime of the turbo-charged buses. Most of the injectors showed premature wear that caused an insufficient leak proofing of the valve seat. This, in turn, led to an additional uncontrolled amount of fuel in the cylinder and resulted in irregular engine operation.



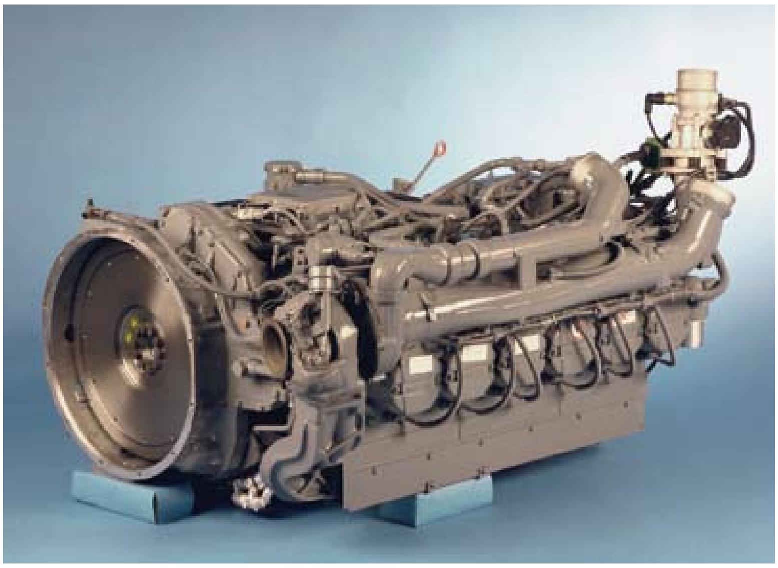
Characteristics:
- Lambda = 1 – naturally aspirated engine
- closed loop lambda control with lambda probe
- external mixture formation with hydrogen injectors
- low injection pressure
- low requirements on fuel conditioning
- spark ignition
- power control with butterfly valve
- exhaust gas treatment with reduction catalyst
- conventional technology, low costs
- low compression ratio (~8)
- low specific power
- relative low efficiency

H_2ICE – Figure 1: Design of the naturally aspirated hydrogen engine

Question 2: What were the performance parameters of the buses during operation?

The performance of the turbo-charged ICE technology reflected its development status with a number of issues being highlighted and overcome as the programme progressed.

The major issue to be addressed was the performance of the fuel injectors which caused the engines to under-perform and a consequent series of issues and failures with the buses. The end result was that the anticipated improved fuel economy was not observed, overall bus performance was not in line with design criteria and the availability was comparatively low.



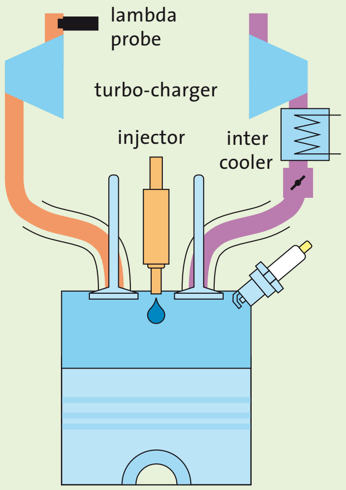
MAN NUTZFAHRZEUGE

H_2ICE – Figure 2: Picture of prototype turbo-charged hydrogen engine MAN H 2876 LUH01

Turbo-charged Hydrogen prototype bus with auxiliary power unit (APU) and energy management

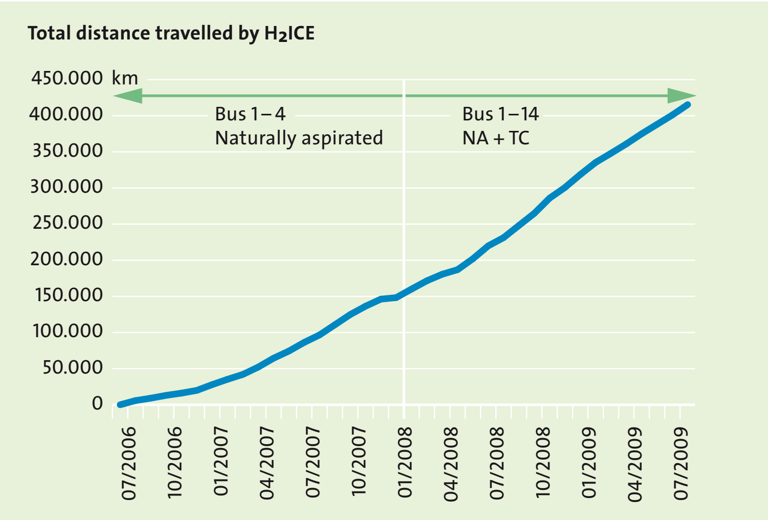
The main purpose for developing this additional research and development vehicle was to improve the fuel economy through improved energy management while maintaining the benefits of the turbo-charged ICE technology.

The incorporation of the fuel cell providing electrical power meant that this could be used to power key auxiliaries such as the air conditioning, which have a high power demand. The fuel cell was able to supply a 24 Volt on-board electrical supply independent of the operation of the ICE engine (see H_2ICE – Figure 7).

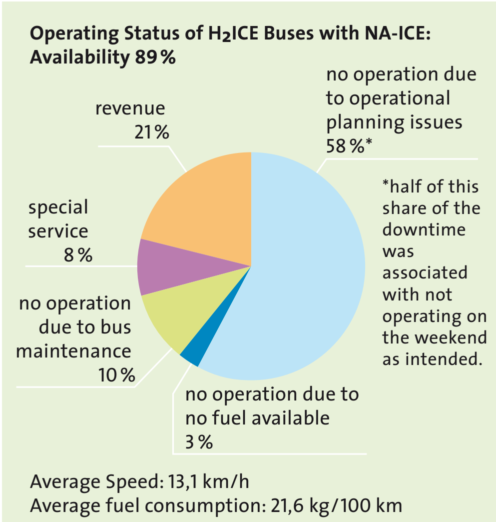


Engine concept:
- Lean operation with inter cooled turbo-charger
- interior mixture formation with solenoid injectors
- low injection pressure (variable from 3–10 bar)
- early start of injection
- spark ignited
- power regulation via throttle valve and variable air/fuel ratio (Lambda >2)
- no exhaust gas after treatment
- low injection pressure, no expensive fuel conditioning system needed
- no backfiring
- medium compression ratio of 11:1
- higher specific power
- improved efficiency

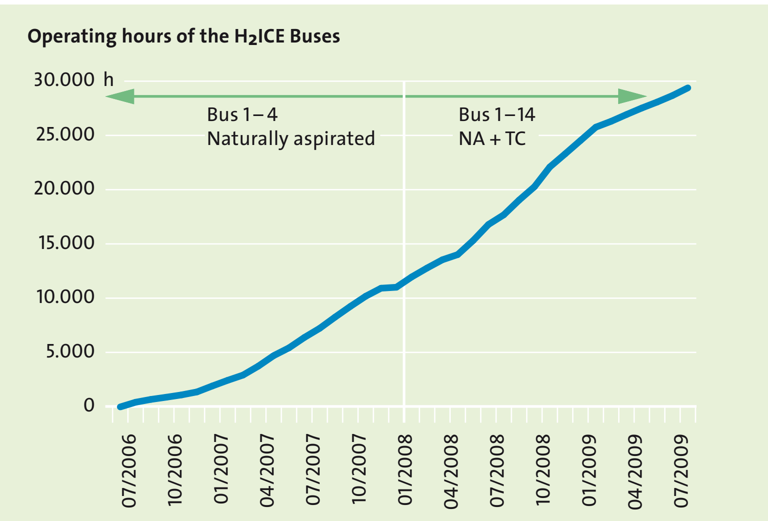
H_2ICE – Figure 3: Design of the turbo-charged hydrogen engine MAN H 2876 LUH01



H_2ICE – Figure 4: Total distance travelled by the Berlin hydrogen bus fleet



H_2ICE – Figure 6: Performance of the naturally aspirated H_2 ICE Bus



H_2ICE – Figure 5: Total operation hours of the buses of the Berlin hydrogen bus fleet

This system has not been tested in public transport operations. However, initial results from dynamometer testing are promising. They suggest an improved fuel economy over the turbo-charged ICE of approximately 4 % (see H_2ICE – Figure 8).

Question 3: What were the main technical problems during the operation of the buses?

The naturally aspirated engines performed well throughout the programme. Neither the drive train nor the engines themselves displayed any major problems. Initial issues were readily resolved through changes in engine software and, in some cases, improved components.

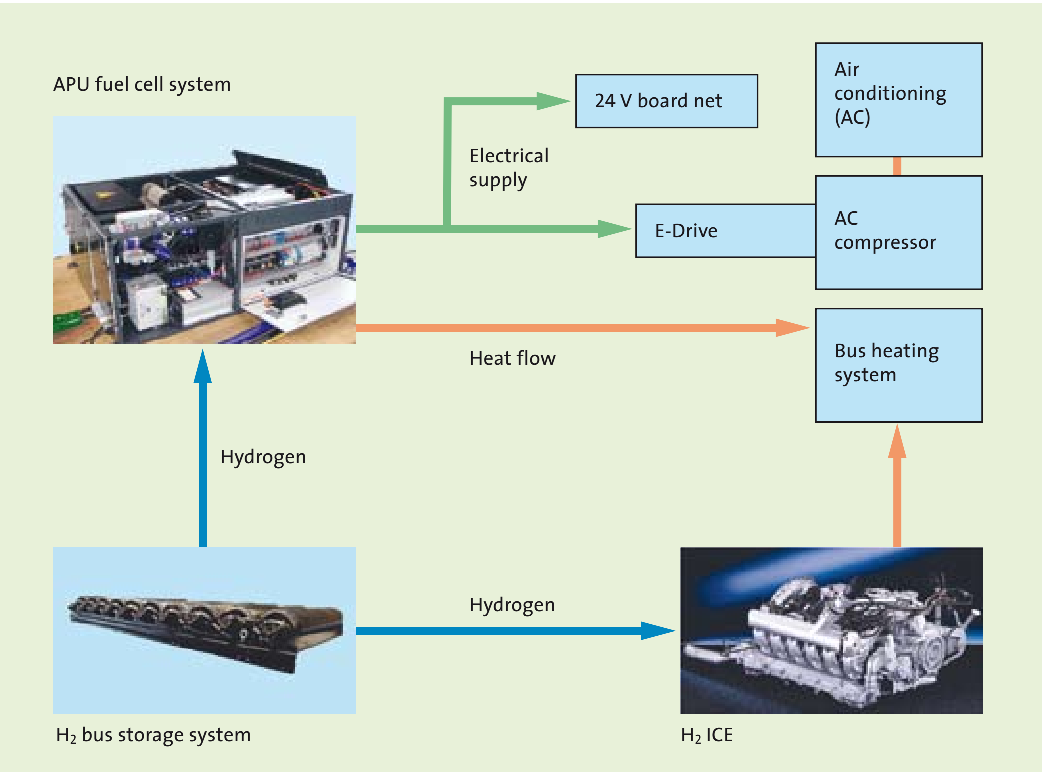
The results demonstrate that this technology would be ready for commercialisation.

The turbo-charged technology has some fundamental differences from the naturally aspirated engines, mainly with respect to the fuel injection system. The breakdowns of the fuel injector systems has meant that MAN and its suppliers have gained valuable knowledge about the causes of the failure and possible remedies, including new materials.

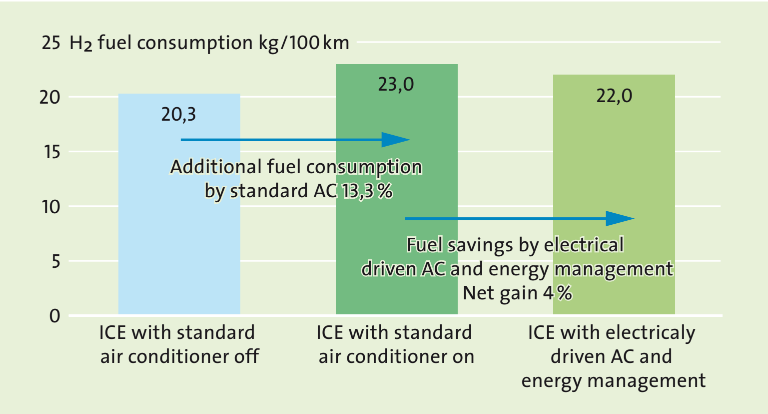
This learning is proving valuable in the further development of the technology for fuel injected hydrogen vehicles, as well as other possible applications.

MAN NUTZFAHRZEUGE

MAN-prototype bus with turbo-charged engine, fuel cell auxiliary power unit and energy management



H_2ICE – Figure 7: Diagram of APU energy management system



H_2ICE – Figure 8: Fuel savings by energy management. These results show the fuel consumption as recorded from dynamometer testing for the turbo-charged ICE (left and centre bars), and the Prototype turbo-charged bus with FC APU and energy management. (Dynamometer speed profile: heavy service/4,5 stops/km/ bus half loaded)

Question 4: Were there any safety related problems in operation?

One unexpected release of hydrogen occurred when a check valve within the tank nozzle failed. The component was replaced and the problem did not re-occur.

Question 5: Were there any new insights about the factors influencing fuel consumption of H_2ICE (e.g. topography, climate, traffic)?

As was expected, traffic conditions and passenger load were the most important factors influencing the fuel consumption. These factors caused variations of up to +/- 20 % in fuel economy.

Surprisingly, climate conditions showed little impact on fuel economy.

Question 6: What lessons from the operation of the 150 kW ICE H_2 buses were integrated into the development of the turbo-charged H_2 ICE buses?

A number of improvements were incorporated into the turbo-charged buses which were derived from the performance of the naturally aspirated buses.

These improvements included:

- The installation of the specially coded TN1 refuelling nozzle allowing hydrogen buses to be refuelled at car filling stations. This smaller nozzle can be used without increasing refuelling times and is now the standard refuelling interface for MAN and future Mercedes-Benz CITARO fuel cell buses.
- A lighter hood covering the hydrogen storage system.
- Improved piping of the safety system monitoring the pressure by incorporating tank valves which are closed when the engine is switched off.
- Installation of a digital fuel indicator to provide the driver with a more accurate indication of the remaining fuel enabling better use of the full tank capacity.

Question 7: What were the lessons from the operation of the 200 kW H_2 ICE (incl. APU prototype) with regard to efficiency, availability, emissions etc.?

The fuel injector issues on the turbo-charged engines resulted in limited data collection and practical experience from full in-service operations.

However, comparative tests on the roller dynamometer showed that the more powerful turbo-charged engine consumes about 25 % less hydrogen than the naturally aspirated engine under similar operating conditions. Additionally, the NOx-emissions of the turbo-charged engine without catalyst nearly equals the level of the naturally aspirated engine with a catalyst. This has important potential implications for the environmental impacts of the turbo-charged technology through requiring less specialised precious metals.

MAN NUTZFAHRZEUGE

H_2ICE Bus, Olympic Stadium, Berlin

The Future

Question 8: What should be the next steps to improve the system regarding availability, energy efficiency and cost in the future?

The technology of hydrogen city buses with naturally aspirated ICE proved their operational readiness. The turbo-charged hydrogen ICE showed improvements in fuel consumption and performance but still needs development and optimization work, especially focusing on the fuel injection system.

While reliable and economical bus operation is approaching reality, there is still a need to improve the technology. Cost reduction and efficiency improvement along the entire well-to-wheel chain is essential in order to meet the expectations of the market.

Quality, Safety and Training in HyFLEET:CUTE

The Facts

Incidents affecting Quality and Safety
Quality and safety monitoring in HyFLEET:CUTE was done with two reporting tools; one incident reporting scheme for monitoring and discussion (called the Task Force) and one web-based system. A distinction was made between incidents and accidents (see page 33 for definitions).

From January 2006 through to June 2007, a total of 279 independent performance incidents were reported through the web-based system. The table below shows the top five performance incidents by indicator and % frequency.

About 1/3 of the records relating to indicator # 5 were computer errors at one of the stations. These errors did not affect safety at the station but they affected the quality of the operation.

1] All recorded single incidents associated with more than one indicator have been included in each indicator as a separate item

Q. & S. indicator no.	Description	% of Records[1]
5	Interrupted operation of hydrogen station	50,56
6	Emergency shut-down	8,61
7	Gas or liquid leakages	7,78
3,3	Vehicle failure affecting vehicle operation	7,22
3,1	Technical failure in dispenser or filling equipment affecting vehicle operation	6,11

Q. S. & T. – Table 1: Top 5 Incidents reported through web-based (SoFi) system

City	Activity needed	Activity
Amsterdam	No activity needed	
Barcelona	Meeting	Meeting with local authorities
Hamburg	Certification activities	CE certification of components and systems, plant inspection
London	Meeting	Meeting with local authorities and community
Luxembourg	No activity needed	
Madrid	Meeting	Calibration of instruments, test of safety instruments
Reykjavik	No activity needed	

Q. S. & T. – Table 2: Re-certification of the Hydrogen Stations

After June 2007, the cities continuing to run buses reported incidents solely through the Task Force. From July 2007 to July 2009 only two incidents were reported. It is important to note that during the HyFLEET:CUTE project there were no accidents that resulted in injury to humans or the environment.

Regulatory approval of infrastructure and vehicles
Re-certification of the former hydrogen infrastructure and certification of the new hydrogen refuelling station in Berlin were significantly less resource demanding and time consuming than for previous projects. Q. S. & T. – Table 2 shows activities undertaken in 7 of the stations.

The TOTAL hydrogen refuelling station was certified in four months. Re-certification of the Mercedes-Benz Citaro Fuel Cell Buses was done as a common task for all cities, undertaken by EvoBus/Daimler and Ballard Power Systems. This was completed within 6 months.

Certification of the MAN hydrogen ICE buses was undertaken by NEOMAN, in close cooperation with TÜV. An agreement with authorities regarding the overall approval procedure was accomplished and no particular problems arose.

Training of technicians/drivers
Bus technicians and bus drivers were recruited on a voluntary basis. The majority of this group were trained under a previous project. Additional training was carried out in HyFLEET:CUTE as needed.

The number of bus drivers trained varied substantially from one city to another. While about 10 people were trained as part of the London project, more than 200 people were trained as part of the Madrid project. All together some 600 people were trained. The duration of the training program varied from one hour to 2 days.

Questions Answered

Question 1: What was the methodology used to collect data?

The quality and safety reporting systems previously established under the CUTE project were further developed and improved during HyFLEET:CUTE with one web based system (SoFi), and a system for reporting and follow-ups by the Task Force on Safety and Security. Both systems covered all types of irregularities in the hydrogen infrastructures – both accidents and incidents.

These 'irregularities' were considered at two levels:

Minor or Near Miss Incidents: A sudden unintended event with no consequences, but that affected the quality of the operations or had the potential to become an accident.

Accidents: An undesired and unplanned event that has caused harm to people, assets or environment.

The quality and safety data were categorized according to ten Q. & S. indicators (see Q. S. & T. – Table 3). The data presented in Q. S. & T. – Table 1 should be read in conjunction with this list.

Question 2: Were there any permitting/ approval problems?

No problems were reported relating to the certification, re-certification and obtaining of permissions for the HyFLEET:CUTE infrastructure and buses. The lack of proven regulations, codes and standards for hydrogen technology in community environments re-inforced the importance of close communication with the approval authorities and in the provision of relevant and comprehensive technical and safety related information to regulatory officials.

1	Number of kilometres driven
2	Hydrogen filled on the bus
3	Number of unexpected vehicle stops
4	Number of corrections due to hydrogen gas quality
5	Number of interruptions of operation
6	Number of emergency shut downs
7	Number of leakages (all kind: gas or liquid)
8	Number of accidents causing injury to people, damage to property and environment
9	Number of deviations of safety systems discovered
10	Number of quality, safety or security deviations and/or near-misses not covered by the indicators 3 – 9

Q. S. & T. – Table 3: Indicators used for interpreting Q. & S. data

Question 3: In terms of quality, safety and training, what lessons were learned by using the refuelling technology on a daily basis?

1. Maturity of the technology

Technical components important to the smooth operation of the hydrogen refuelling stations have still not reached a mature level. Nonetheless, the technology and systems are constantly improving.

2. Collecting and Reporting Quality and Safety Data is integral to optimisation of the technology

Communicating quality and safety matters has its challenges. The key within the HyFLEET:CUTE project has been to regard any irregularity as a starting point for further improvement instead of a 'failure' of the particular station.

Whether an irregularity is safety or quality related is not always easy to conclude when each irregularity is considered separately. However, repeated quality irregularities might eventually have a safety impact.

EMT, MADRID

H_2FC Bus, Repsol Refuelling Station, Madrid

Trucked-in H_2, Beijing, China

3. The importance of the 'human factor' in Quality and Safety

Training is a key word when it comes to safety. Having skilled personnel knowing the technology and the systems was crucial. Team responsibilities and coordination of actions across organizational boundaries, including suppliers, was important in establishing common "best operational practices" respected by all parties involved.

It is notable that the quality and safety records in HyFLEET:CUTE relate mainly to technical irregularities and incidents. Industrial experience suggests more than 80 % of all incidents are related to human errors. The reason why the experiences in HyFLEET:CUTE (<1%) were different from this would benefit from further evaluation.

4. Safety is an on-going issue

An important lesson learnt in this project is that the basic safety philosophy needs to be addressed continuously.

Question 4: What safety systems and procedures were in place at the sites for the H_2 infrastructure and bus maintenance workshops?

The variety of hydrogen refuelling stations and bus combinations led to a variety of technologies, layouts and modes of operation and the technical safety systems varied accordingly. Administrative safety systems were more or less the same for all stations, but details differed from one station to another.

Safety aspects were integrated into procedures for operation and maintenance and were readily available at the refuelling station and the bus garage.

PE INTERNATIONAL

MAN NUTZFAHRZEUGE

Refuelling the H_2ICE Bus, Berlin

The Future

Question 5: What has been done so far and what more needs to be done?

Lessons for the future from HYFLEET:CUTE in relation to quality, safety and training can be summarized as follows:

- Quality, safety and training were a continuous focus in the project. The emphasis put on the reporting of incidents as a **tool for further improvement** was a key driver in the partners continuing to report.
- Facilitating the involvement of suppliers in resolving issues where relevant proved successful.
- Footprint, equipment, refuelling time and logistics need further improvement. Design of the station needs to be simple, and any future extension/upgrades must be easy to incorporate. Equipment, e.g. compressors, reformers, electrolysers, need to be improved on in terms of their reliability and availability. The components and systems needs to be further developed to be fit for use in the transport sector.
- The HyApproval handbook provides a useful tool for approval authorities to help them understand the hydrogen refuelling system.
- A special focus should be put on the user interface, both in the layout and refuelling hose arrangements. Components like hoses and metering devices need improvement to optimise safety and ensure accuracy in dispensing. Operators should be involved in further development of the interface between the buses and the dispenser/station.
- Training of operators, technicians and bus drivers should be a continuous process. A case book of real and possible incidents needs to be developed for training purposes.

http://www.hyapproval.org/

Environmental Impact

As part of the European Commission's effort to inform policy development and for better implementation of a pan-European strategy for sustainable development, the HyFLEET:CUTE project undertook a number of impact assessment studies. These studies considered the environmental, social and economic impacts of hydrogen powered buses on ordinary citizens and their potential contribution to achieving EU targets for emissions reduction and diversity of energy supply. The environmental and social studies are reported in brief in the following two sections. The economic study on the requirements for hydrogen purity appears in the section looking at Hydrogen Infrastructure (see page 14).

Questions Answered

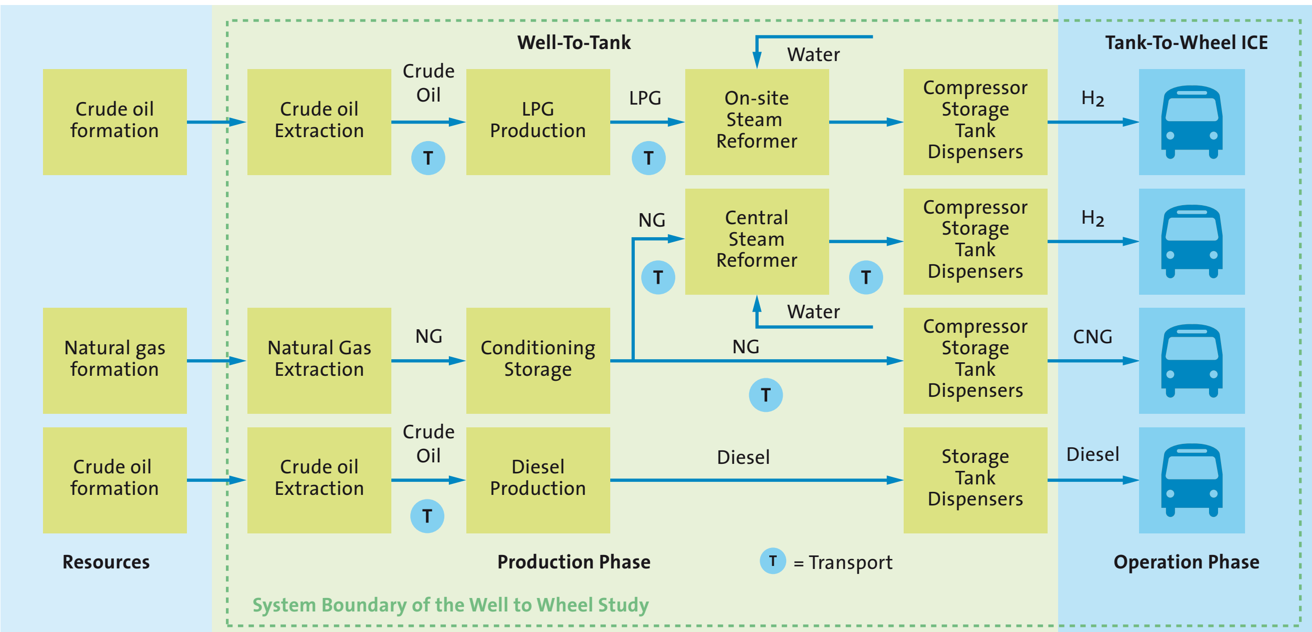
Question 1: What is the overall environmental effect of the H_2 ICE bus system compared to conventional buses (primary energy demand, GHG emissions)?

A Well-to-Wheel (WtW) analysis of primary energy demand and greenhouse gas emissions was carried out for three internal combustion based (ICE) technologies: Diesel, CNG and Hydrogen. Env – Figure 1 displays the boundaries of the system under consideration for hydrogen, diesel and CNG production and consumption pathways. Two H_2ICE bus technologies were used in the course of the project; a conventional naturally aspirated (NA) bus and an improved, turbo-charged (TC) bus. These technologies were studied separately.

The fuel consumption data used were representative of the technologies based on test data, certification cycles and published information.

Although not used in the HyFLEET:CUTE project, an important addition to the possible energy pathways shown in Env – Figure 1 is the supply of hydrogen via on-site water electrolysis using hydro-power. This was also included in the analysis, the results of which are shown in Env – Figure 2. This leads, as expected, to a vastly improved environmental performance.

Env – Figure 1: System Boundary and production/consumption pathways of hydrogen (as used in HyFLEET:CUTE), diesel and CNG systems, from production of raw materials (in this case crude oil and natural gas formation) to final use in an ICE bus



In summary, the WtW analysis found that:

- With current production pathways, CNG and diesel are comparable and show the lowest GHG emissions of the pathways analysed using non renewable resources.
- Substantial reduction in GHG emissions from hydrogen production can be achieved through fuel supply routes using renewable energy sources (almost 80 % in the case of the TC bus)
- Improvements in energy consumption in the H_2ICE buses can compensate for the less favourable outcomes when using H_2 pathways based on fossil fuels. Theoretically, a reduction of 50 % in fuel consumption by the turbo-charged H_2ICE bus would achieve comparable GHG emissions to diesel and CNG ICE bus pathways.

In the context of these results, it is relevant to note that using hydrogen in powering transport would significantly contribute to the diversification of energy resources (especially the share of renewable resources) and it can play an important role in improving the security of energy supply. Furthermore, it also contributes to an improvement of air quality in urban areas by featuring an almost emission free operation.

Env – Figure 2: WtW GHG emissions (calculated as GWP100) of H_2 ICE and CNG buses relative to diesel buses considering fuel supply and fuel use with European boundary conditions

MAN NUTZFAHRZEUGE

H_2ICE Buses leave BVG Spandau Depot for regular service in Berlin

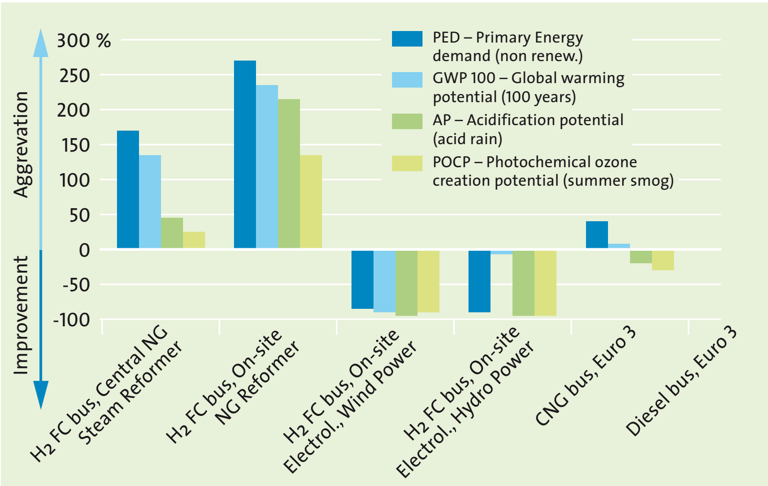
Question 2: What is the environmental profile of operating H_2 FC buses in China?

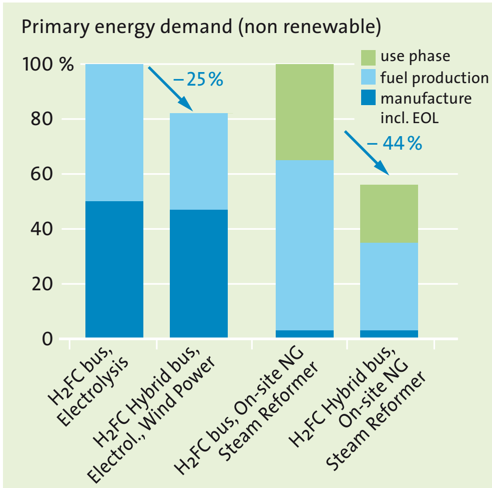
A LCA of the hydrogen infrastructure and the total life cycle of bus systems was done for the Beijing site.

The fuel supply data for the LCA were based on Chinese boundary conditions. For fuel consumption, data from the three bus types (H_2, CNG, diesel) measured on a specific route (Line 42) in Stuttgart during the CUTE project was used.

The LCA results (see Env – Figure 3) show the relative changes for the H_2 FC bus system and CNG bus system compared to a Diesel Euro 3 system. Euro 3 was selected as it is the current emission standard for China (2008).

The H_2 FC system with hydrogen supply from electrolysers and electricity from renewable resources is the best performing system in all impact categories. The GWP of the H_2 FC system with electrolyser and hydro power supply achieves only limited advantages compared to the diesel system.





Env – Figure 3: Life Cycle Impact Assessment of H_2 FC, CNG and diesel buses with Chinese boundary conditions

Env – Figure 4: Projected reduction in energy demand from non-renewable sources: FuelCELL-Hybrid Bus

This is because the emission factors for Chinese hydro power (CO_2 and CH_4) indicated in relevant literature are 4 – 5 times higher compared to average European values.

The fuel supply routes that employ fossil-fuel based electricity for compression and / or for fuel production show higher impacts than diesel due to the emissions of the mainly coal-based Chinese grid electricity.

Question 3: What improvements in environmental impact are likely to be achieved by the FuelCELL-Hybrid Prototype?

The manufacturing of the FuelCELL-Hybrid bus prototype will deliver roughly 10 % less GWP (GHG emissions) than the manufacturing of the previous Fuel Cell Bus. This is mainly due to an improved design which delivers weight reduction.

The total life cycle has also been modelled, including the bus production, average bus operation for 720.000 km (including H_2 fuel supply) and the end of life of the bus.

Data from certified tests were not available at the time of printing; however, the following results were calculated assuming an expected 45 % reduction of fuel consumption (based on simulation) for the FuelCELL-Hybrid [1] compared to the Fuel Cell Bus.

The projected reduction in energy demand from non-renewable resources over the complete life cycle of the FuelCELL-Hybrid prototype bus is shown in Env – Figure 4.

Question 4: How do previously conducted studies on energy efficiency and GHG emissions compare to the studies conducted in the HyFLEET:CUTE project?

Projects related to the LCA of hydrogen and bio-fuels production for transport purposes within Europe were identified. It was found that there is a need for a consistent data format that defines modelling approaches, boundary conditions and assumptions in a precise and uniform way.

To make robust Life Cycle Inventory (LCI) data available it is highly recommended that all future EU projects use as a basis the International Reference Life Cycle Data System ILCD) handbook and the ILCD data format (see http://lct.jrc.ec.europa.eu/).

As part of this study within HyFLEET:CUTE, life cycle inventory data sets on hydrogen production were published in the ILCD format. These data sets are available at <http://www.global-hydrogen-bus-platform.com> under Information Centre, downloads.

1] FuelCELL-Hybrid Bus Prototype' STATUS REVIEW, Berlin May, 2009

PE INTERNATIONAL

H_2FC Bus in Beijing alongside H_2 storage trailer

TOTAL DEUTSCHLAND

Stationary Fuel Cells, TOTAL Station, Berlin

LCA Studies: A Summary

Based on the findings of the Life Cycle based environmental studies, it is clear that:

1. The life cycle based approach is an appropriate way to determine the full environmental profile of the different bus systems. It is essential to keep this LCA updated over time in order to capture the effect of technological advances;
2. Regional boundary conditions (energy carrier supply, driving cycle etc.) are crucial for an accurate assessment of the environmental impact of the hydrogen production and power system.

Question 5: What was learnt from the operation of the 2 stationary fuel cell systems in Berlin?

At the Berlin refuelling station liquid H_2 is stored at - 253 °C. Due to the gradual warming that normally and constantly occurs, gaseous hydrogen is produced. This process – called ‘boil-off’ – was capitalised on by supplying the boil-off gas to two stationary fuel cells that were installed at the station. The air-cooled PEM (Proton Exchange Membrane) fuel cell from AXANE generates electricity. The water-cooled PEM fuel cell from EPS generates both heat and electricity. Each system has a maximum output of 5 kW of electricity. This arrangement has increased the total efficiency of the filling station, with surplus energy being fed into the city’s electricity grid.

A scientific analysis showed net electrical efficiencies of the fuel cell systems between 32 % and 47 %. The net thermal efficiencies recorded showed a wider range (25 % to 50 %). This is due to the fact that the heat usage from a fuel cell system can be varied and does not always have to be at the maximum of the heat production level of the system. The maximum overall efficiency for the CHP, water-cooled PEM fuel cell system was close to 87 %. Due to problems with peripheral elements and breakdowns that were, in most cases, not related to the fuel cell itself, the availability of the fuel cell systems ranged from 61 % to 70 %.

Social Impact

Questions Answered

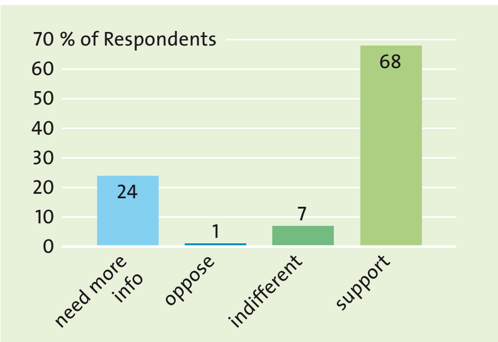
Question 1: What is the level of acceptance in the Community of the H_2 technologies?

Acceptance will have an important influence on the use of H_2 as a fuel and the broad marketing of hydrogen technologies. Failure to consider public attitudes may lead to serious obstacles to the establishment of a mass market infrastructure. A study on customer acceptance assessed the level of acceptance of hydrogen technologies among the general public. In particular, it looked at the level of 'uncertainty' as an area of potential future influence.

2.833 people were personally interviewed in eight cities (Amsterdam, Barcelona, Berlin, Hamburg, London, Luxembourg, Madrid and Reykjavik) between September and October 2006. In addition, 519 people participated in online interviews between August and September 2006.

The main results from the Acceptance Study were as follows:

- Associations with the word hydrogen were positive or neutral in 92 % of the cases.
- 78 % of the interviewees were aware that hydrogen can be used as a fuel and 72 % of participants agreed that there is a need to find alternative fuels for vehicles.
- The substitution of conventional buses by hydrogen buses in the cities was supported by a large majority of respondents and opposed by only 1 %. The remainder stated that they were indifferent or needed more information to come to a decision (see Soc – Figure 1).
- Assuming that people have the choice between a conventional bus and a hydrogen bus under the same conditions (route and ticket price), 76 % would choose the hydrogen bus and 1 % the conventional one. 21 % would have no preference (2 % did not respond).
- Asked "Would raised (ticket) prices for hydrogen buses be justifiable?" overall 44 % responded 'yes' and 57 % 'no'. However, some cities showed a greater than 50 % willingness to accept higher prices.



Soc – Figure 1: Survey Responses to the question: Do you support the Introduction of hydrogen buses into Public Transport?

In relation to further information campaigns, it would be most effective to target the proportion of the community in the 'unsure' groupings [the 31 % on the question 'substitution of conventional buses by hydrogen buses' (see Soc – Figure 1) and the 21 % from the question on 'bus choice'] to further increase the balance of acceptance. This would require some further research into the reasons why people were unsure or concerned about Hydrogen powered buses and to focus a campaign on these issues.

Question 2: What are Society's views of H_2 as a transport fuel?

The University of Iceland and Icelandic New Energy collaborated to undertake a range of research projects to give more insight into consumers' choices concerning transport fuel. This research was undertaken in the context of the demonstration of the H_2FC buses in normal operation and the current discussion on the need for cleaner and leaner transport technology.

Three communication approaches were used to engage target groups in dialogues: focus group discussions, workshops and semi-structured interviews. Participants had the freedom to introduce their own ideas concerning clean transport. Hydrogen was introduced as one of a range of possible fuels with the intention of acquiring a deeper understanding of the public's preferences and correlations between perceptions of environmental quality and future fuel options. The participants were selected so as to have a mix of energy experts, decision makers of the future and those who currently held strategic positions within Icelandic society.

Results from the research included:

- The level of knowledge about alternative fuel options was generally low and the groups were more concerned with the external effects of the use of renewable energy (lost land from hydropower dams) rather than emissions.
- The 'visibility' of the technology was thought to be the most effective way of raising understanding about the options available. The high 'visibility' of the H_2FC Buses had contributed to the raised awareness of H_2 as a local fuel option.
- In the context of Iceland, the prevalence of 'clean' energy for the production of electricity generally lessened the environmental argument for Hydrogen powered buses and increased the importance of the economics/affordability.
- Local media was found to be influential in modifying views but not very accurate in conveying information.
- No consensus was found regarding the option of charging for GHG emissions.

INE, ICELAND

In depth interviews and focus group discussions are recommended as tools to study the dimensions of social acceptance.

Surveys showed that women and young people, in particular, asked for more information on hydrogen solutions

Question 3: What lessons were learnt about Community Engagement when implementing a H_2 powered bus programme?

The HyFLEET:CUTE partners collaborated to produce 'Guidelines for Local Community Engagement' to be used by anyone wishing to commence H_2 powered bus operations. The project partners found that new technology and new fuels require a broad education and awareness-raising programme due to both natural and official concerns and curiosities. These programmes range from working with the Community in which refuelling infrastructure will be located through to the passengers riding on the buses and the regulatory officials ensuring that safety and other standards are met. The Guidelines provide practical information on the 'how' and 'when' of communication and share some case studies from the project.

Extracts from the HyFLEET:CUTE publication on Community Engagement (see http://www.global-hydrogen-bus-platform.com under Information Centre, Downloads)

Dissemination and Communications in HyFLEET:CUTE

The Facts

HyFLEET:CUTE was the 2009 Sustainable Energy Europe (SEE) Award Winner in the Demonstration and Dissemination Category

Communication and dissemination activities were undertaken at both a Project and a Partner Level.

Project Level Activities

Communication Mode	Main Features
Project Website www.global-hydrogen-bus-platform.com	800 Subscribers to News Service world-wide 67.240 Unique visitors from 95 different countries Most popular pages were: • Hydrogen Infrastructure • Hydrogen Bus Technology
HyFLEET:CUTE Regular E-News Service	93 News Items posted on website and emailed to subscribers of News Service
Publications (sample)	• Seven, 4 page E-Newsletters sent to subscribers and placed on web site. • Articles in “The (EU) Parliament” magazine and EC “Research Review” magazine (2008) • Chapter in the Encyclopaedia of Electrochemical Power Sources (in Press), 2009 • “People, Transport and Hydrogen Fuel”, Guidelines for Local Community Engagement when Implementing Hydrogen Powered Transport
HyFLEET:CUTE Project Video: Hard Copy & On Line	547 hard copies distributed by project partners from June 2007; Video available to view on Project Website from mid-2008 – July 2009; > 2.000 viewings
Events (sample)	Melbourne F1 Grand Prix – Bus Demonstration (2006) FIFA World Cup – Bus Demonstration (2006)
Forums/Workshops	Training for interested parties outside the project partnership occured in: Melbourne (2006); Beijing (2007); Berlin (2008)
Participation/Presentations at International Conferences and Workshops	Approximately 20 invited presentations, including U.S.A., Australia, Romania, Italy, Brussels, Japan, China, Iceland, Sweden, Canada, Slovenia

Partner Level Activities

Communication Mode	Main Features (approximations)
Distribution of brochures, Leaflets and other printed material	> 100.000 to Passengers; > 25.000 to Others
Multimedia Presentations	100.000 viewers
Workshops and Events[1]	170 Events 60 scientific presentations 140 community presentations
Surveys	10.000 people surveyed
Press Activities & Decision Making	50 TV Reports 200 News Articles 100 Presentations to Decision makers
Schools	2.000 pupils 4 Curriculums developed (German & English)
Information Sharing	8 face to face 2 day Partner Meetings held

Note: Data in Table are for the period Jan. 2006 – July 2009

1] Some of the events included:
- Opening of the LPG reformer/stationary fuel cells in Berlin with Transport Ministers from Germany and France present
- Open days at all bus depots
- Awards: Land der Ideen (worldwide TV radio & print coverage)

Partners receiving Sustainable Energy Europe Award 2009

Questions Answered

Question 1: What were the goals of the Global Hydrogen Bus Platform and were they reached?

The Global Hydrogen Bus Platform (GHBP) was the banner under which the Project level dissemination activities for HyFLEET:CUTE were conducted. In practice the Platform was a multi-media, multi-level, and multi-dimensional suite of dissemination activities.

The purpose of the GHBP was to achieve raised awareness of what the project was about and informing the work of the European Commission and other key decision makers in governments, industry and the community in developing a sustainable energy future.

The platform achieved its dissemination and communication goals which was in a large part attributable to the very pro-active approach taken in disseminating information. Every opportunity was taken to 'push' information out to the relevant stakeholders and the broader community by means of a range of tools.

The Project Website
Considerable information was made available publicly which was regularly accessed demonstrating the very high level of international visibility.

Personal contacts
Written information has been strongly supplemented by personal contacts with large numbers of community members through open days, workshops and many other types of public events.

Informing on Safety
The GHBP has played a key role in dispelling some commonly held hydrogen myths and in disseminating objective data about the safety performance of the project bus and refuelling technology and systems.

Policy and Political Engagement
The activities and outcomes from HyFLEET:CUTE are directly linked to the European Union Energy Policy objectives. The GHBP activities have helped to bring these policies to life through informing the community that the policies have practical outcomes that touch the everyday lives of

PE INTERNATIONAL

PE INTERNATIONAL

Project Co-ordinator welcomes delegates to Beijing Workshop 2007

Right: Participants at HyFLEET:CUTE workshop for New Member States, Berlin 2008

people. Throughout the project the GHBP has had contact with numerous individual decision makers; including Ministers of Governments, CEOs of major companies and senior public officials. These contacts have been productive and fruitful. Efforts to engage them as groups and facilitate discussions have been less successful.

International Collaboration

Participation in Conferences and other activities in Europe, Australia, North America and Asia were an effective way of increasing both general and detailed knowledge of the project's activities and achievements. Participation in the activities of the International Fuel Cell Bus Workshop has provided an effective avenue to increase the depth of understanding among key technical stakeholders outside HyFLEET:CUTE. These small scale, personal discussions have also been extremely useful for exchanging information and understanding between projects internationally.

Community Stories I:

- Bus Drivers in Perth, Western Australia reported that a group of pedestrians stopped and applauded the bus as it passed on its first operational run;
- A cleaning lady in the Reykjavik project office asked if the Fuel Cell Buses had recently commenced operation in her neighbourhood. When confirmed, she exclaimed: "Ah that explains it! Now I need to get a new alarm clock because I don't wake up any more from the noise of the first morning bus!"

Question 2: What were the reactions of the public, media and decision makers in industry and public policy?

Public reactions

Wherever members of the public have been exposed to hydrogen powered transport, its reality and its potential, they have strongly supported the project and its expansion into fully commercial and widespread activities. This is confirmed through the surveys conducted within HyFLEET:CUTE (see pages 40–41) and in other projects such as AcceptH_2, and in other forums (e.g. STEP in Australia).

Media reactions

Media reactions have ranged from strongly supportive to sensationalising. Media with interests in scientific, environmental, energy, technical and policy areas have been supportive. Media reports have generally given balanced information showing both the results and the future possibilities. The large volume of information readily available to the media was often utilised as background and supporting information to the reporting. Notes of caution have been expressed about the technology costs and the timeline to commercialisation.

Some sensationalising media reactions continue but certainly with less frequency than might have been expected. In general, this type of reporting seems to have been associated with specific incidents or local issues.

Reactions of Decision Makers

Reactions from decision makers in both industry and public policy have also generally been very supportive but overlaid with concern for issues such as practicality, timing, cost and impact on climate change.

One of the key objectives of the GHBP was to move the discussion out from the commonly heard group of "hydrogen believers" and into the broader community. This was to have been achieved by bringing together decision makers from different arenas to share their views and understandings and to reach common ground. This has proved challenging but remains a key future task if accelerated development and commercial introduction of hydrogen public transport systems is to be achieved in the near future.

Separately, a number of bus operators have formed the Hydrogen Bus Alliance to push and prepare for the commercialisation of hydrogen buses.

A recurring feature throughout many jurisdictions is the emergence of a relatively small number of highly energetic and effective political champions for hydrogen technology within Parliaments. One of the challenges remains to move this level of support into the broader parliamentary constituencies.

Community Stories II:

- Passengers in several cities including Beijing were reported to be waiting for the "Hydrogen" bus rather than taking the first bus that came along.
- Following the loose connection of a cooling hose on a bus in Reykjavik which caused a visible steam cloud, a television reporter was interviewing a bus passenger: Q: "How does it feel to know that there might be a hydrogen bomb going off on the roof of the bus?" R (in a very calm voice): "Come on! This is only electricity generation with a fuel cell. It has absolutely nothing to do with nuclear radioactivity". The cameras were shut down.

The Future

There is no doubt that a paradigm change is coming in the future with respect to transport fuels. It is not a question of "if" the change will occur but rather **"how disruptive will it be, in what way and when?"** The question which follows immediately is: **"how, and how effectively, do we plan for this new and different future?"** What actions will we take – as individuals, as communities, as Governments and as industry?

Against this picture, the future for successful and imminent commercialisation of hydrogen powered public transport lies in a more concerted and committed 'buy-in' from industry and the political stakeholders, in both recognising and accepting the coming paradigm shift and planning for it. As has been outlined, the general public already possesses a strong buy-in, well in advance of other stakeholders and is impatient for industry and government leaders to catch up.

A Message from the Participating Cities in the HyFLEET:CUTE Project

"We are committed to providing our cities with an efficient and reliable public transport service, based on clean, renewable energy.
Our successful participation in the HyFLEET:CUTE Project has helped us work towards realising this commitment.

We support a vision of the future where hydrogen produced locally through renewable resources plays a major role in our transport energy system. We strongly encourage Industry and Governments to continue to work with us to realise this vision within a decade."

CITY OF AMSTERDAM

Job Cohen
Mayor of Amsterdam

CITY OF BARCELONA

Jordi Hereu
Mayor of Barcelona

TSINGHUA UNIVERSITY, BEIJING

Professor Lun Jingguang
Tsinghua University, Beijing and the national coordinator of the GEF-UNDP-China fuel cell bus co-operation project.

CITY OF BERLIN

Harald Wolf
Senator for Economics, Technology and Women's Issues and Mayor of Berlin

A Message from the Participating Cities in the HyFLEET:CUTE Project


CITY OF HAMBURG

Ole von Beust
First Mayor, City of Hamburg


CITY OF LONDON

Boris Johnson
Mayor of London


CITY OF LUXEMBOURG

Paul Helminger
Mayor of Luxembourg


CITY OF MADRID

Alberto Ruiz-Gallardón
Mayor, City of Madrid


GOVERNMENT OF WESTERN AUSTRALIA

Hon. Simon O'Brien MLC
Minister for Transport,
Government of Western Australia


CITY OF REYKJAVIK

Hanna Birna Kristjansdottir
Mayor of Reykjavik

The HyFLEET:CUTE Project – What can we conclude?

By any measure, the HyFLEET:CUTE Project has been an outstanding success. The more than 2,5 million kilometres travelled, the 170.947 hours of bus operation and the 555 tonnes of hydrogen dispensed – all accomplished safely – are clear testament in themselves.

PE INTERNATIONAL

First of 3, H_2FC Buses unloading at the Fremantle port in Western Australia

INE

Refuelling Station, Reykjavik

It is equally clear that the future of energy for transport is, at best, uncertain. The questions about our current systems; the pressures on existing fossil fuel reserves from both the supply and demand side; the concerns about the impacts on climate and the broader environment, as well as human health, and the economic pressures on the vehicle industry itself – all suggest a future that is very different from the past and the present. The future may well involve disruptive changes within our communities.

Added to this is the strong evidence of wide-spread and strong public support for governments to implement, or to require the implementation of, clean public transport.

In this context, the fact that the hydrogen public transport vehicle and refuelling technology works and can be commercialised holds significant promise.

However, there are a number of challenges that need to be overcome.

- The bus technology must be able to be operated with minimal special support in a standard public transport bus fleet;
- The purchase price of the buses must be significantly reduced to coincide with commercialisation;
- Procurement decisions should not be based only on first cost, but lifetime operational costs including external costs associated with carbon fuels and pollutants;
- Hydrogen must be able to be produced cheaply and through renewable means;
- Hydrogen infrastructure, especially the electrolyser and steam reformer units which are the key components of on-site H_2 production and also the hydrogen compressors and dispensing equipment, must be able to operate as reliably as the buses.

BVG, BERLIN

H_2ICE bus visits the streets of Luxembourg

PIERRE ADENIS

A quiet moment at the TOTAL H_2 Refuelling Station in Berlin

Political support for hydrogen bus public transport is seeking increased certainty of outcomes. The frequent, early claims that commercialisation of hydrogen powered transport is “nearly there” has certainly not been helpful. It is also clear that an understanding of the results from the H_2 bus projects and the obvious potential of hydrogen powered transport is not strong. Key decision-makers throughout our community are not engaged in discussion with each other nor understanding each others’ constraints and opportunities.

HyFLEET:CUTE has demonstrated a way forward. Not only has the successful technology demonstration achieved engagement with the general public but constructive discussion between the project partners has been a positive feature that has advanced the cause of hydrogen powered transport.

In parallel, the various recent initiatives by the European Commission, Governments, industry and the public show considerable promise in facilitating development paths.

Undoubtedly, the future for successful and imminent commercialisation of hydrogen powered public transport lies in more vigorous and broadly based ‘buy-in’ from industry and the political stakeholders in both recognising the coming disruption and planning for it. As has been outlined above, the general public already has indicated a buy-in; well in advance of these other stakeholders, and is expecting them to catch up sooner rather than later.

Hydrogen transport projects need to move quickly from development and demonstration, to large scale projects involving large fleets of buses. These fleets must be fuelled with hydrogen which is generated through renewable means, and the buses fully integrated into normal commercial public transport bus operations. At this point we will finally have achieved a truly sustainable transport initiative.

Our final message

AVL, LUXEMBOURG

H_2FC and H_2ICE Buses on the roads of Luxembourg – reflecting a successful partnership

VATTENFALL

Hamburg H_2 Refueller – using H_2 from renewable sources and servicing a fleet of H_2FC buses

DAIMLER

A Glimpse of the Future: H_2 Citaro FuelCELL-Hybrid bus from Daimler/Evobus being put through its paces around Mannheim.

HyFLEET:CUTE has shown that Hydrogen does transport – **cleanly and safely!**

Hydrogen powered buses are **here** and they are **now!**

Ensuring they are here to stay is our next challenge!

The HyFLEET:CUTE Project Team

TOTAL DEUTSCHLAND

Project Partners at Berlin Partner Meeting, June 2006

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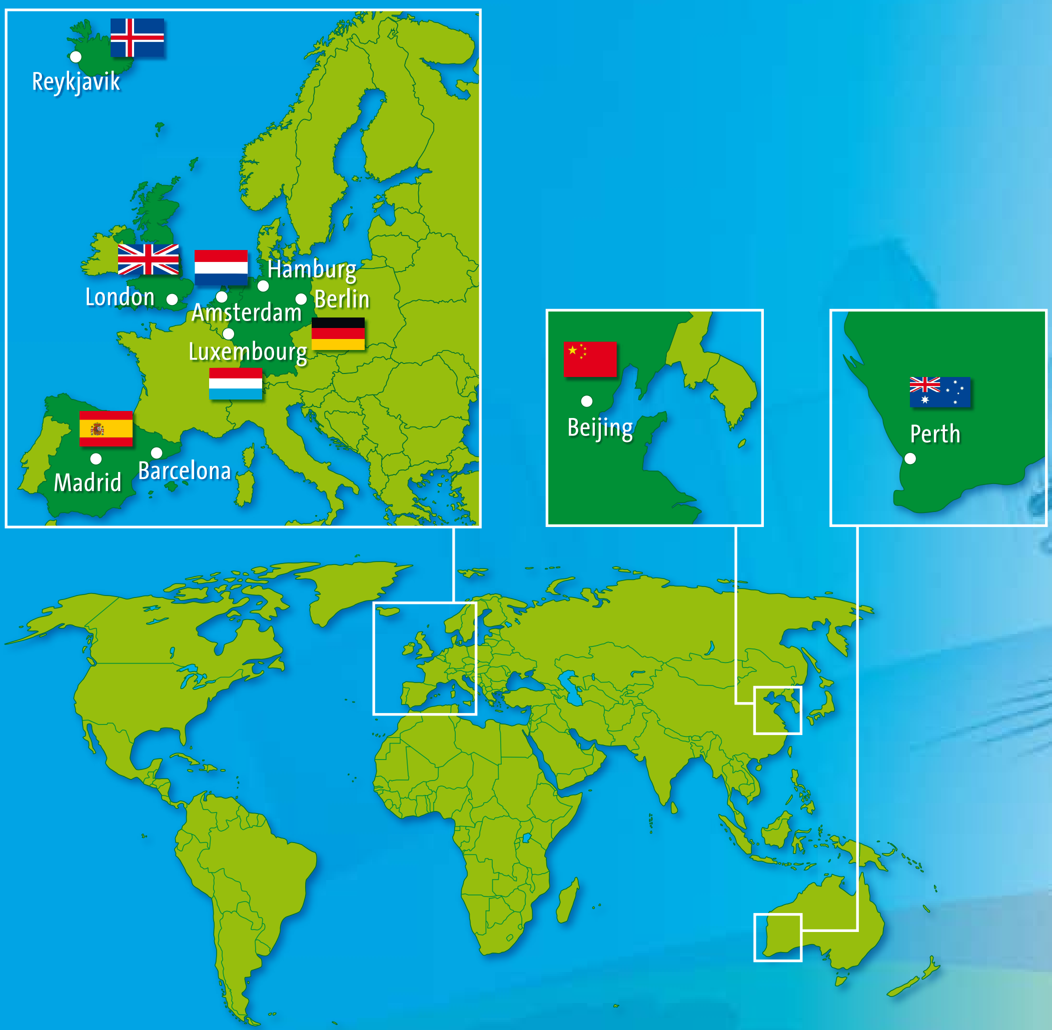
THE HyFLEET:CUTE PROJECT

- Operation of 33 hydrogen fuel cell powered buses & design, construction and testing of the next generation hydrogen fuel cell bus
- Design, construction and operation of 14 hydrogen-powered internal combustion engine buses in Berlin
- Development and testing of a new hydrogen refuelling infrastructure in Berlin
- Continued operation, optimization and testing of existing hydrogen infrastructure
- Assessment of the environmental, social and economic impacts of the H_2 powered buses



HyFLEET:CUTE

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