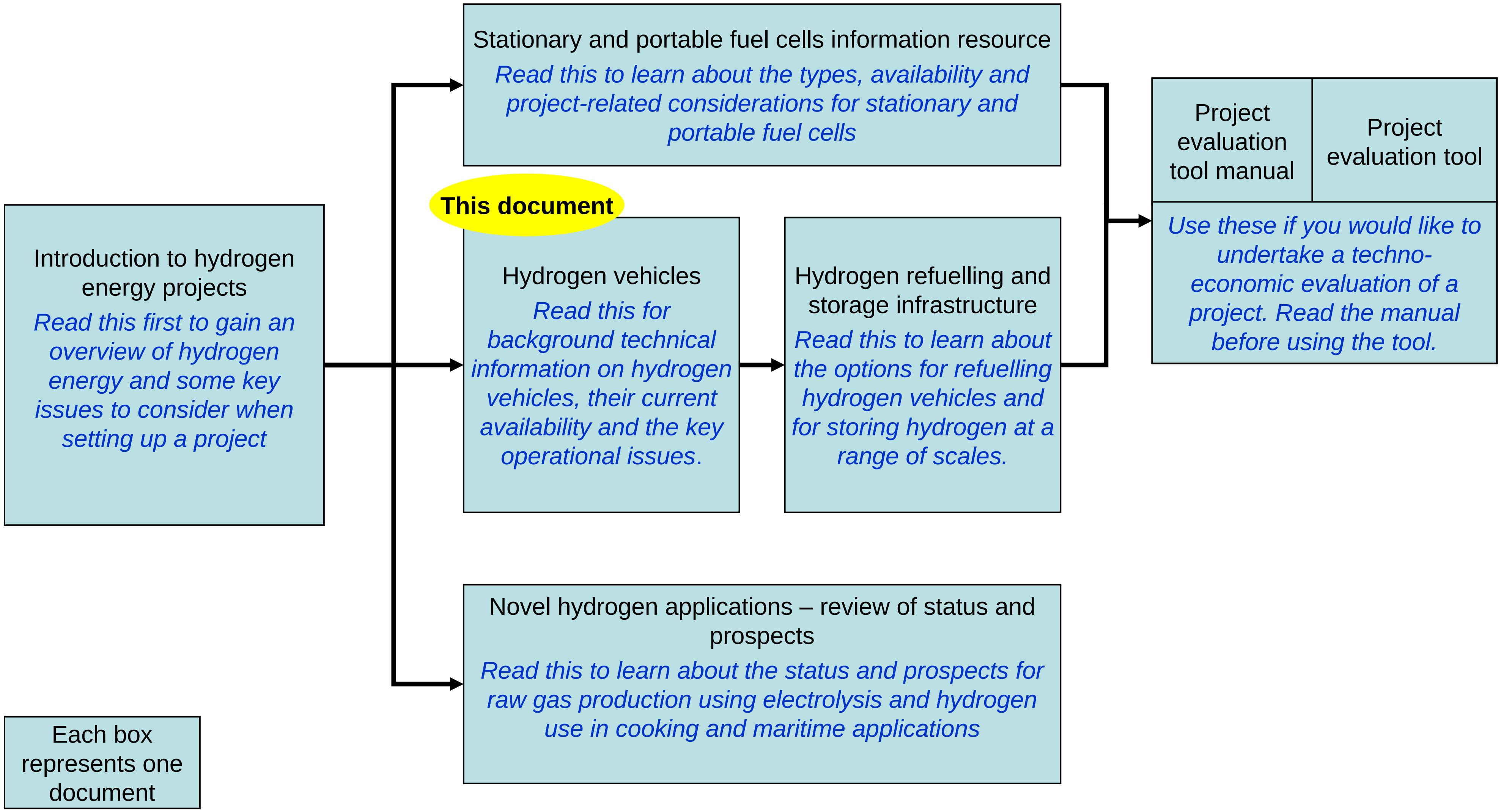
Hydrogen Vehicles

Information Resource for Highlands & Islands Enterprise

About this document

- In 2006 the HIE Renewable Energy team commissioned a consulting team to assist with the identification and assessment of hydrogen energy opportunities across the region. As part of this work the project team conducted a workshop in each LEC area to introduce the hydrogen energy opportunity and identify potential project ideas. Over 80 individual ideas surfaced, at varying levels of ambition, detail and feasibility.
- The project team worked with HIE to identify several recurrent themes among the ideas:
    - What are all the issues that need to be considered when setting up a hydrogen project?
    - What different stationary and portable hydrogen applications are there?
    - How can hydrogen be used in road vehicles?
    - How can hydrogen be stored and what refuelling facilities would be required for hydrogen vehicles?
    - What are the prospects for hydrogen use in maritime applications or cooking? Could bottled hydrogen and oxygen be produced and sold?
    - How can developers undertake technical and economic evaluation of their ideas?
- HIE judged that the best way to provide value to the LECs would be through a suite of information resources and tools based on these themes, to enable ideas to be developed and assessed further. These tools fit together as shown overleaf.

Document Map



About the authors

Element Energy

- **Element Energy is an engineering consultancy specialising in the low carbon energy sector. It formed in 2003 as a spin off from larger engineering practice Whitbybird.**
- **Services:**
  - Engineering services for low carbon energy projects
  - Innovation in new energy technologies and storage solutions
  - Strategic advice and consultancy
  - Project management and funding assistance
  - Specialist knowledge in hydrogen and fuel cell projects

E4tech

- **E4tech is a sustainable energy business consultancy, based in the UK and in Switzerland (established 1997)**
- **Services:**
  - Business strategy
  - Organisational support and interim management
  - Technology and market review to assist financing
  - Policy input for local and national government
  - Support to technology startups
  - Focus on hydrogen energy, bioenergy and sustainable buildings

PURE Energy Centre

- **The Pure Energy Centre has one aim: to give you access to the most effective energy storage techniques in the world to grow your business/community and increase your energy independence**
- **Services/products:**
  - Renewable hydrogen training courses
  - Consultancy for energy and storage technologies
  - Sales of hydrogen production units
  - R&D contract work for third parties

Commonly used acronyms

AFC Alkaline Fuel Cell

C H2 Compressed Hydrogen

CHP Combined Heat and Power

CNG Compressed Natural Gas

CRES Centre for Renewable Energy Studies (Greece)

DoE United States Department of Energy

EC CUTE European Commission Clean Urban Transport for Europe

EC HyCom EC Hydrogen Communities

FC Fuel Cell

FP6&7 Framework Programmes 6&7 (EU instrument for funding research)

H&I Highlands and Islands

H2ICE Hydrogen Internal Combustion Engine

HAZOP Hazard and Safety Operational Studies

HHV High Heating Value

HIE Highlands and Islands Enterprise

HSE Health and Safety Executive

ICE Internal Combustion Engine

LCIP Low Carbon Innovation Programme (Carbon Trust)

LEC Local Enterprise Company

LHV Low Heating Value

LNG Liquid Natural Gas

LPG Liquid Petroleum Gas

MCFC Molten Carbonate Fuel Cell

MCPs Manifold Cylinder Packs

MEA Membrane Electrode Assembly

NOx Nitrous oxides (pollutants)

O&M Operation and Maintenance

OEM Original Equipment Manufacturer

PAFC Phosphoric Acid Fuel Cell

PE Primary Energy

PEM Primary Exchange Membrane/Polymer ion Exchange Membrane

PSA Pressure Swing Absorption

R&D Research and Development

ROCs Renewable Obligation Certificates (see Defra website)

SME Small to Medium Enterprises

SOFC Solid Oxide Fuel Cell

UPS Uninterruptible Power Supply

VSA Vacuum Swing Absorption

ZEMSHIPS Zero Emission Ships

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Introduction – motivations for use of hydrogen as a transport fuel

Of all the potential applications for hydrogen it is perhaps its potential for use as a transport fuel that has provoked the greatest interest around the world. There are a number of social and political motivations for a transition to hydrogen as a transport fuel, from decarbonising the transport sector to reducing dependency on imported oil. The key motivations are summarised below:

- **Security of energy supply** – due to the wide diversity of primary energy sources from which hydrogen can be generated
- **Reduced CO_2 emissions** - due to the potential to derive hydrogen from low carbon energy sources, especially renewables
- **Improved energy efficiency** – due to efficiency benefits offered by hydrogen fuelled vehicles, especially fuel cells
- **Reduced air pollution** – as the use of hydrogen in a fuel cell engine emits only water and very few pollutants are emitted when used in a combustion engine
- **Reduced noise** – fuel cell vehicles generate significantly less noise than the incumbent ICE based vehicles.
- **Better vehicles** – the ability to spread weight over the car and to shift to electric drive systems leads many to postulate that the fuel cell will ultimately lead to a superior driving experience than incumbent ICE based vehicles.

The details of drivers for hydrogen vehicles worldwide have been explored in numerous publications, some of which are referenced below.

www.eere.energy.gov/hydrogenandfuelcells/ pdfs/national_h2_roadmap.pdf – DoE hydrogen roadmap
https://www.hfpeurope.org/uploads/678/688/hydrogen-vision-report_HLG_2003_en.pdf - European high level hydrogen vision

Introduction to hydrogen vehicles

In order for a transition to hydrogen as a fuel for road transport to take place, significant developments in vehicle technology are needed. There are three main options for hydrogen vehicles, presenting differing degrees of technical challenge. These options are as follows:

Hythane vehicles – Hythane is a mixture of hydrogen and natural gas (up to a 20% hydrogen concentration). Vehicles adapted to run on compressed natural gas (CNG) can run on hythane, hence the technology required for hythane vehicles is already relatively mature.

Hydrogen internal combustion vehicles (H2ICE) – The gasoline powered internal combustion engine can be adapted to run on hydrogen fuel. This is less technologically challenging than development of fuel cell vehicles and is seen by some as a bridging technology.

Fuel cell vehicles – A fuel cell is an electrochemical device that generates electricity from the combination of hydrogen and oxygen (which can be taken from the air). Development of fuel cell vehicles represents the greatest technological challenges, requiring not only development of the fuel cell itself but also of electric drivetrains for vehicles.

Further details on each of these vehicle options is given on the following pages.

Introduction to hydrogen vehicles – Fuel cell vehicles

All multinational vehicle developers (known as OEMs) are investing significant funds in the development of hydrogen fuelled vehicles. Most of these are investing in fuel cell technology, perceiving fuel cells to be the ultimate solution to the environmental problems of fossil fuelled ICE's.

The projections for the date of commercial availability of fuel cell vehicles vary. There has been a tendency to over-hype the immediate prospect of fuel cell engines. Technological work is still required on fuel cells in particular to improve lifetime, sensitivity to climate and fuel storage as well as to reduce unit costs. However many large vehicle manufacturers (e.g. Daimler Chrysler) see 2012 as a point at which fuel cell vehicles will emerge as truly commercially available products.

Whilst 2012 is a date used by many OEM's as the earliest date for commercial availability of mainstream product, there will be opportunities for fuel cell vehicle operation before then. These come from providing real life operational experience of prototype fuel cell vehicles in the field and from providing a marketplace for fuel cell vehicles for niche applications, often provided by small, more flexible developers (for example fuel cell powered fork lift trucks).

Fuel cell vehicles powered by hydrogen emit only water and have very low noise emissions. Fuel cell vehicles tend to require a very high purity hydrogen supply.

Daimler Chrysler Citaro fuel cell bus, operated in London as part of the EC funded CUTE project.

Honda's prototype fuel cell Civic. Commercial availability is still 5 to 8 years away.

Introduction to hydrogen vehicles – Internal combustion engines (ICE)

A number of large OEM's and a wide range of smaller SME developers are preparing hydrogen fuelled ICEs (H2ICE) as a bridging technology until fuel cell vehicles become widely available. The logic of H2ICE development is that the technology can be developed faster and more reliably than fuel cells, as it requires only modifications to an existing well developed technology (the gasoline powered ICE).

H2ICE's currently offer the lowest cost option for hydrogen fuelled vehicles and can be supported in the field by credible automotive players. At present they represent the most 'commercial' option for hydrogen vehicle deployment, though vehicles are typically more than twice the cost of the fossil fuelled equivalent. The long term relevance of H2ICE's beyond acting as a bridging technology to fuel cells is likely to be defined by the speed with which fuel cell vehicles meet their cost and performance targets.

H2ICE's emit negligible level of particulates and sulphurous oxides. However, there is the potential for significant NOx emissions due to high cylinder temperatures. Engines must be carefully calibrated to keep NOx emissions within the statutory minima. H2ICE engines tend to be able to run on a lower purity hydrogen supply than fuel cell engines (standard industrial grade purity hydrogen is adequate for ICE engines).

Ford E450 shuttle bus with hydrogen ICE

Source: *(www.greencarcongress.com)*

BMWs hydrogen powered 7 series incorporates hydrogen ICE technology and liquid hydrogen storage

Source: (www.bmwworld.com)

Introduction to hydrogen vehicles – Hydrogen natural gas mixtures (hythane)

Mixing hydrogen with natural gas (up to 20% concentrations) creates a blend, known as hythane, which can be used in existing CNG (compressed natural gas) vehicles. The introduction of hydrogen into the blend has a disproportionate effect on emissions and overall engine efficiency.

Hydrogen CNG blends used in CNG vehicles offer the least technologically arduous means to introduce hydrogen into the transport fuel mix. However, the relevance of the technology is limited to the local acceptance of CNG vehicle technology. In Germany, for example, there are over 500 CNG filling stations, by contrast in the UK, there are only 24 stations, with 3 in Scotland [1].

A Sunline Transit Agency SunBus refuelling with a 20% H_2 80%CNG mix (2004)

Source: Sunline Transit Agency

[1] www.ngva.co.uk

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Timescales for availability of hydrogen vehicles

A wide variety of types of hydrogen vehicles, from buses to motorbikes and including off-road vehicles such as fork-lifts, are being trialled at various locations around the world. These vehicles include fuel cell, hydrogen ICE and hythane fuelled technologies.

All of these hydrogen vehicles are currently pre-commercial or demonstration vehicles and as such are only available at significantly higher prices (particularly in the case of fuel cell vehicles) and do not offer the same levels of reliability or range as conventional alternatives.

It is difficult to predict with any certainty the rate of progress of hydrogen vehicle development and the date at which hydrogen vehicles will be available as a commercial product. There is particular uncertainty over the rate of commercialisation of hydrogen fuel cell vehicles, although many experts agree that their roll-out will occur between 2012 and 2020. The timing of commercialisation is likely to vary for different types of vehicle, with larger, fleet-based vehicles such as buses approaching commercialisation before smaller passenger cars.

The table on the following page provides an indication of the anticipated timings for commercialisation of hydrogen vehicles, based on targets set in the European Hydrogen Platform deployment strategy[1].

[1]Based on the European Hydrogen Platform deployment strategy
https://www.hfpeurope.org/uploads/677/687/HFP_DS_Report__second_draft_v8_061204.pdf

Timescales for availability of hydrogen vehicles

	2006	2012+ (early commercial availability)	2030 (widespread uptake)
Fuel cell	Very limited availability of vehicles. Most OEM's focus on specific deployment centres. Some SME activity to produce viable niche vehicles. R&D ongoing into lifetime and cost.	Premium product already used in niche sectors. Bus and small vehicle sector (e.g. bikes) develop first. Passenger vehicles from 2015(?)	Better vehicles based on fuel cells available for all vehicle types
Hydrogen ICE	Acceptable reliability. Available from some SME's and major OEM suppliers. Cost 2-3 times base vehicle cost. Both bus and passenger vehicle options exist. Performance improved with hybridization. R&D into NOx emission reduction. Potential for cost reduction through high volume purchase.	Costs reduced by increased volume, cost premium remains (20-50%). Available for passenger car and bus. Available in hybrid configuration . Fuel consumption higher than FC's. NOx emission issue resolved.	Limited relevance once FC vehicles are developed.
Hythane	Concept proven. Requires broader demonstration.	Accepted technology – relevant to regions where CNG is taken up.	

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OEM car companies are developing hydrogen vehicles, but availability is very limited

OEMs stands for Original Equipment Manufacturers and, in the context of the automotive industry, refers to the large, multinational car companies such as General Motors, Ford, Toyota etc. All OEM car companies are developing hydrogen fuelled vehicles. Most of the companies are developing fuel cell vehicles often in hybrid configuration.

These vehicles tend to be clustered near OEM R&D centres, or in large public private demonstration programs such as, for example, in California and Tokyo.

Due to the historic lack of investment and lack of political support for hydrogen, OEM's have tended to steer away from deployment in the U.K.

There is, in general, a lack of interest from OEMs in small-scale demonstration projects, as it is seen as a diversion from the main goal of technology development. Only if a trial offers some particularly useful operational data or has particular PR value is it likely to be considered. Realistically, it is very unlikely that OEM hydrogen vehicles will be available in the Highlands & Islands in the next 4 to 5 years.

A more realistic route to hydrogen vehicles for H&I in the near term may be through smaller manufacturers and suppliers (SME suppliers)

General Motors (Hy-Wire)

Honda fuel cell Civic

Source: Honda Motor Co.

SME vehicle providers provide a more accessible source of vehicles for near term, small-scale demonstration projects

There are a number of small companies (referred to here as SME developers) offering new hydrogen vehicle products and after-market conversions of existing vehicles to run on hydrogen. These vehicles include both fuel cell and H2ICE vehicles.

A range of vehicle types are available through these companies including passenger cars, delivery/commercial vehicles, scooters and niche vehicles (such as fork-lift trucks).

These SME suppliers could act as important providers of hydrogen vehicles in the interim period, prior to large-scale commercialisation by OEM providers.

In addition to availability these projects offer further potential benefits:

• Smaller-scale to suit limited budgets and requiring less infrastructure
• Ability to address niche markets, where OEMs do not operate
• Provide an opportunity for local involvement in support & maintenance, contributing to development of local hydrogen engineering capability.

There are also risks associated with projects based on SME vehicles:

• SME companies are not able to offer the level of support for vehicles that larger OEMs can provide
• The SME companies are less stable than OEMs and may cease operating
• Niche hydrogen vehicle markets may not develop.

Microcab – small fuel cell passenger and delivery vehicles

Source: www.h2mobility.org

Example SME projects – the PURE project

An example of an SME type vehicle project is the development of the small fuel cell passenger car by Aberdeen-based system integrators SiGen, which is now operated by the Pure Partnership.

The basic vehicle is a battery-electric car manufactured by Indian manufacturer Reva Electric Car company.

Sigen have modified the vehicle with the addition of a 1 kW fuel cell, which acts to charge the battery and extend the range that the vehicle can travel.

Hydrogen is stored on board in a metal hydride canister. The vehicle is refuelled with hydrogen generated at the PURE Partnership wind-hydrogen system on Unst, so is an example of zero CO_2 transport.

Reva are themselves planning to develop a fuel cell version of the car, which will initially be trialled in India (see the Case Studies)

The REVA electric car modified by Sigen to include a 1 kW fuel cell as a battery range-extender. The vehicle is operated by the PURE partnership and fuelled by hydrogen generated by the PURE wind-hydrogen system.

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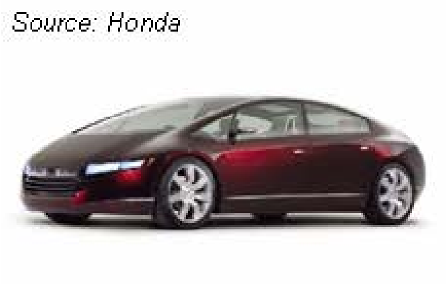
A selection of hydrogen vehicles currently in operation world-wide (fuel cell (FC) and internal combustion engine (ICE))

OEM passenger cars



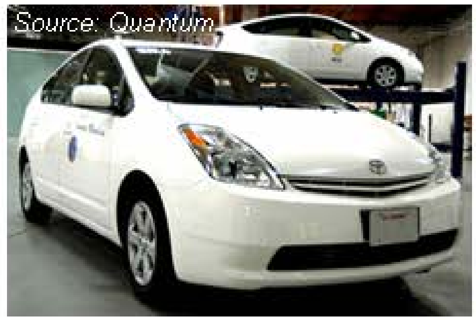
Honda (Fuel cell (FC))

Daimler Chrysler (FC)

GM (Opel/Vauxhall) (FC)

SME vehicles

REVA Electric Car Co. (FC)



Quantum/Toyota Prius (H_2ICE)

ENV bike (Intelligent Energy) (FC)

Hydrogen buses

Hydrogenics tecnobus (FC)

Van Hool (H_2ICE / FC)

MAN (H_2ICE)

Hydrogen vehicles available currently and in the near-term (not exhaustive)

Manufacturer/supplier	Vehicle description	Available from	Minimum purchase (estimate)	Budget cost per vehicle
Low-cost vehicle options				
Quantum Technologies	Modified Toyota Prius with H2 ICE's	mid 2006	3	£58,667
Linde/Proton Motors Fork Lift trucks	Fork lifts for indoor and outdoor operation (ICE)	2006	/	/
Cellex General Hydrogen	Pallet trucks, fork lifts & other warehouse vehicles	2007	Warehouse scale - complete system	
GM/Hydrogenics fork lift truck	Fork lifts for indoor and outdoor operation (FC)	2006/7	/	/
SME provider vehicle options				
ENV bike (Intelligent Energy)	Fuel cell scooter	Late 2007	1	< 10,000
Fuel Cell Vectrix	Fuel cell/battery hybrid fuel cell	2008/9	/	/
REVA fuel cell city car	Electric car likely to have fuel cell as range extender	2006/7	1	/
Microcab alpha prototype	Fuel cell mini taxis/delivery vehicles prototype	Start 2007	5	£50,000
Microcab first manufacture	Fuel cell mini taxis/delivery vehicles first manufacture run	Start 2008	50	£20,000
Materflex cargo bike	Rickshaw type electric assist bicycle	2007	10	£6,000
Viable bus options				
Hydrogenics Tecnobus	Small electric bus modified for hybrid FC operation	end 2006	2	<€400,000
New Flyer/ISE hybrid H2ICE bus	H2ICE hybrid bus - 44 seats Van Hool/New Flyer	2008	3	$800000
UTC FC powered busses (Vanhool)	40 Seat FC hybrid buses	2008	3	£1,000,000
Daimler Chrysler - buses	Citaro busses - next protoype - FC hybridised	2009+	10	£1,000,000
MAN	Potential CUTE type bus rollout program (HHICE)	2007	10	€450000
Proton Motors	20 seat fuel cell hybrid bus	2008	3	/
Proton Motors	20 seat electric bus with fuel cell range extender (5kW)	2008	3	€500,000
OEM H2 passenger cars (Note: OEMs are unlikely to provide vehicles for trials in the next 2-3 years)				
BMW – Hydrogen ICE vehicles	BMW seven series H2ICE - LIQUID FUELLED	2007	/	/
Aprilia – scooters	Aprilia Atlantic Zero Emission	2007	/	/
Daimler Chrysler - pasenger cars	Necar passenger cars	2007+	10	£150,000
Honda	FCX fuel cell Civic (hybridised with ultracapacitors)	2015	/	£250 - £500k
Mazda RX8 hydrogen RE	Hydrogen rotary engine with dual fuel (H2 or gasoline) option	2007 (controlled release as lease car)		

A selection of vehicles that may be particularly relevant to H&I in the near-term are highlighted

Manufacturer/supplier	Vehicle description	Available from	Minimum purchase (estimate)	Budget cost per vehicle
Low-cost vehicle options				
Quantum Technologies	Modified Toyota Prius with H2 ICE's	mid 2006	3	£58,667
Linde/Proton Motors Fork Lift trucks	Fork lifts for indoor and outdoor operation (ICE)	2006	/	/
Cellex	Pallet trucks, fork lifts & other warehouse vehicles	2007	Warehouse scale - complete system	
General Hydrogen				
GM/Hydrogenics fork lift truck	Fork lifts for indoor and outdoor operation (FC)	2006/7	/	/
SME provider vehicle options				
ENV bike (Intelligent Energy)	Fuel cell scooter	Late 2007	1	< 10,000
Fuel Cell Vectrix	Fuel cell/battery hybrid fuel cell	2008/9	/	/
REVA fuel cell city car	Electric car likely to have fuel cell as range extender	2006/7	1	/
Microcab alpha prototype	Fuel cell mini taxis/delivery vehicles prototype	Start 2007	5	£50,000
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Materflex cargo bike	Rickshaw type electric assist bicycle	2007	10	£6,000
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Proton Motors	20 seat fuel cell hybrid bus	2008	3	/
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Operational issues – Operating hydrogen vehicles

Reliability of hydrogen vehicles – any hydrogen vehicle is currently an experimental vehicle and there is therefore an increased risk of operational failure - requiring maintenance. Field trials are required, but reliability will not be as high as for a petrol or diesel engine vehicle. **Fleets should therefore use vehicles in low risk applications.** It is important that the experimental nature of the trials should be well understood and communicated to all stakeholders.

Vehicle range – Although hydrogen is very energy dense on a weight basis, because it is a gas at ambient temperature and pressure it has to be compressed or liquefied to improve its volumetric energy density. This is important as there is limited space on a vehicle for fuel storage and the more energy that can be packed onboard, the greater the range of the vehicle. Liquid fuels such as petrol and diesel are very energy dense on a volume basis and hydrogen vehicles do not currently offer equivalent range on a single refill.

For this reason, technology providers are developing higher pressure storage tanks to enable a greater quantity of hydrogen to be stored onboard (350 bar has been the standard storage pressure for vehicle applications, but 700 bar cylinders are in the pipeline). Liquefied hydrogen is more energy dense than compressed gas (on a volume basis) and some manufacturers have developed vehicles that are fuelled by liquid hydrogen (for example BMW). However, the majority of vehicles developers are focussing on development of compressed gas vehicles.

Operational issues – Operating hydrogen vehicles

Vehicle parking - Hydrogen is a light gas, as a result when it is released, there is a danger that it will collect under roofs, overhangs etc. If hydrogen-safe indoor facilities are not available (i.e. with requisite levels of ventilation and detection), then it may be necessary for vehicles to be kept outside.

Fuel cell vehicles may be sensitive to freezing temperatures. Vehicle manufacturers may specify a minimum allowable external temperature, which may necessitate suitable vehicle garaging. This situation is rapidly improving as fuel cell operating temperature ranges are expanding to lower temperatures.

Vehicle lifetime and depreciation – The lifetime of fuel cell vehicles is likely to be limited by the lifetime of the fuel cell stack, often measured in the number of hours of operation before failure. Fuel cell lifetimes are improving, however at the current time it is still not uncommon for fuel cell warranties to be limited to 1,000 hrs of operation. The lifetime requirement for fuel cells in vehicle applications varies with the type of vehicle, e.g 5,000 hours is sufficient for a passenger car, whereas for a bus operating a regular daily schedule, a lifetime of 20,000 hours is required.

In assessment of the economics of a hydrogen (and in particular fuel cell) vehicle trial, it is necessary to write off the value of the vehicle over the lifetime of the trial (e.g. 2-3 years). The vehicle is unlikely to have any substantial residual value.

Operational issues – Refuelling infrastructure

Infrastructure requirements to support hydrogen vehicles are discussed in detail in the companion information resource on Hydrogen Refuelling and Storage. There is no existing infrastructure in the U.K. (apart from limited demonstration activity), however, there are a range of options available for refuelling.

Selection of the appropriate solution depends on the scale of the demand (size of the vehicle fleet) and geographical spread of refuelling points. A number of options are illustrated below:

Source: Air Products

'Mobile' type refueller:- could be used for 'mobile library' type refuelling, arriving at a depot for a given time window. **1-5 small cars per day**

Source: Air Products

Small static refueller:- can be installed as a temporary or permanent installation. Requires an H_2 supply. **3-10 cars per day**

Source: www.h2stations.org

Large filling station – appropriate for multi-vehicle refuelling. Often includes own H_2 generation from electricity or gas. **10+ cars, 3+ buses per day**

Operational issues – Refuelling infrastructure

Refuelling infrastructure availability – As usage of hydrogen vehicles becomes more widespread, infrastructure must simultaneously develop to support them. However, at present there is only one hydrogen filling station in the U.K. (based in London to support the CUTE bus project). For early hydrogen vehicle trials it will be necessary to operate vehicles in fleets that refuel at a single location, such that the refuelling infrastructure is adequately utilised. The type and capacity of the refuelling solution will depend on the size of the demand.

Refuelling practicalities – Refuelling involves the transfer of a high pressure gaseous fuel into the car's onboard storage tank. Refuelling of gaseous fuels will be novel to most drivers and some training will be required. However, infrastructure providers are developing hydrogen dispensers that are as similar as possible to the existing petrol and diesel dispensers that the public is familiar with.

Due to the highly flammable nature of hydrogen and its low ignition energy, some special precautions are required, for example to avoid generating electrical sparks. In early filling stations, operators were required to wear special clothing, but this is no longer necessary with newer designs. Refuelling times can be longer than for equivalent petrol or diesel vehicles, although times of less than 2 minutes can be achieved by many newer refuelling systems.

A hydrogen dispenser at a refuelling station in Sweden *(source: Ludwig-Bolkow-Systemtechnik)*

Operational issues – Vehicle support & maintenance

Vehicle maintenance

Trial hydrogen vehicles have specific maintenance requirements and it is likely that they will require specialist mechanics to provide the maintenance. Certainly in early trials it is anticipated that maintenance contracts would be obtained from the suppliers of the vehicle and should form part of the procurement negotiation. The need for the vehicle supplier's engineers to provide maintenance results in a high maintenance cost and over time it would be preferable for maintenance duties to be transferred to local contractors. In the case of vehicles provided by SMEs, the suppliers may not be able to provide dedicated maintenance support (due to their size or lack of U.K. presence). In these cases it would be necessary to find a viable local support solution.

Maintenance engineers will require familiarity with compressed gases and in the case of fuel cell vehicles, of fuel cells and electric drivetrains. In addition to trained personnel, hydrogen compatible maintenance facilities are required.

Future engineers

As the levels of penetration of hydrogen vehicles in the region increases, it will be necessary not only for local contractors to become involved in maintenance, but for provisions to be made for training of new engineers.

Operational issues – Vehicle support & maintenance

Maintenance facilities

Specialised facilities will be required for the maintenance of hydrogen vehicles. The specifications of these facilities are fairly onerous. For example a hydrogen maintenance facility must have:

- Good ventilation
- Hydrogen detection throughout
- A strategy for explosions (often requiring explosion relieving walls)
- A full safety procedure to avoid explosion in the event of hydrogen detection
- Limits on other materials stored in the vicinity of the hydrogen (e.g. Oxygen)

Converting an existing garaging facility to allow hydrogen maintenance will require considerable expense for the proprietor. Companies that have previously engaged with alternative fuels (e.g. CNG, LPG, LNG) may have more infrastructure in place and a stronger level of interest in investigating new technologies.

Conversion of garaging / maintenance facilities for servicing of hydrogen vehicles will require compliance with the following directives:

- ATEX directives
- PED (pressurised Equipment Directive)
- EMC (electromagnetic compatibility) Directive
- SEVESO II (Large amounts of hazardous material)

The Health & Safety Executive can further advise on the pertinent regulations concerning use of hydrogen in the workplace. In addition there is a growing body of regulations concerning the safe use of hydrogen onboard vehicles, at refuelling stations and at maintenance and test facilities.

Operational issues – Regulations, codes and standards

There are a number of issues to be solved concerning the safe use of hydrogen vehicles on public roads. Key operational issues include:

- Licensing and approvals of hydrogen vehicles
- Safety at hydrogen filling stations
- Safety of hydrogen vehicles in enclosed spaces, including parking and garaging spaces, tunnels etc.
- Facilities for repairs and maintenance
- Safety in the event of an accident
- Training of the emergency services

At present, a vehicle has to comply with 44 EC directives or equivalent ECE regulations to gain approval for use on roads in Europe (i.e. to gain Whole Vehicle Type Approval). Many of these directives are not appropriate for testing of hydrogen fuelled vehicles.

It is intended that a new Global Technical Regulation (GTR) will be developed to govern the approval of hydrogen and fuel cell vehicles, which will be supported by codes and standards produced by recognised regulatory and standardisation bodies (UN, ISO, IEC).

A target date of 2010 has been set for establishment of the GTR. To do this will require harmonisation of the growing body of work on regulations, codes and standards being carried out around the world, particularly in Europe, the USA and Japan.

In Europe a key platform for this work has been the European Integrated Hydrogen Project which is a partnership between the European hydrogen industry and European Commission. Useful references regarding regulations, codes and standards can be accessed through the EIHP website, www.eihp.org.

Operational issues – Regulations, codes and standards

Hydrogen vehicles

It is intended that a Global Technical Regulation for hydrogen and fuel cell vehicles will be in place by 2010.

Prior to this, two draft UN-ECE (United Nations Economic Commission for Europe) regulations have been published covering the use of compressed hydrogen and liquid hydrogen in vehicles[1,2]. The latest versions of these draft regulations are available from the EIHP website (www.eihp.org).

These ECE regulations are concerned with issues relating to the onboard storage and use of liquefied and compressed hydrogen (they will be superseded by the GTR when in place).

In addition, many codes and standards concerning all aspects of hydrogen use in transport have been developed by a variety of standardisation committees (such as IEC, ISO, SAE, CGA etc). A useful resource for all codes and standards relating to use of hydrogen and fuel cells in vehicles can be found at www.fuelcellstandards.com.

Filling stations and maintenance facilities

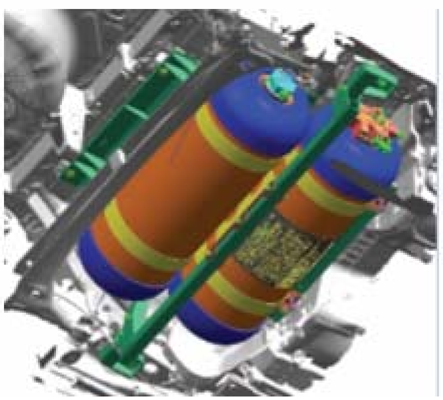
The safety issues, regulations, codes and standards concerning hydrogen filling infrastructure are discussed in the Hydrogen refuelling infrastructure resource document.

Similarly to the case for hydrogen vehicles, there is a need for standardisation and harmonisation of the various codes and standards that are being developed around the world, ideally resulting in internationally recognised regulation. Until then, a number of documents have been produced in Europe to assist development of project:

- EIHP2 Working Draft, Rev.3 – Gaseous Hydrogen Vehicle Refuelling Stations (available at www.eihp.org)
- EIGA Document IGC 15/96/E (Gaseous Hydrogen Installations)
- HyApproval – Handbook for certification of public H_2 filling stations (*planned, see www.HyApproval.org*)

Contents

Quantum modified Toyota Prius hydrogen ICE



Images: ***Quantum Technologies***

Manufacturer:	Quantum technologies provide modification to the Toyota Prius, to operate as a hydrogen hybrid ICE
Current status:	2 vehicles complete, 4 vehicles undergoing crash tests, 30 vehicles on order in the US, 16 ordered for Norway's HyNor project.
Budget costs:	$75,000 for conversions (+£17k for basic vehicle)
Specifications:	150 km range, >80 km per kg, 350 bar H2, 1.6 kg capacity
Earliest delivery date:	mid 2007
Minimum size of order:	3 vehicles
Typical end users	All car fleets: council vehicles, support cars, VIP vehicles, private cars (long term) etc.
Notes:	This is a Quantum product, not officially endorsed by Toyota. Quantum are a well respected supplier of hydrogen tanks and direct injection systems. The reasonable cost and high expected reliability make the Prius an attractive option as an early vehicle to allow deployment in the Highlands and Islands.

MAN hydrogen ICE bus

Images: ***www.brennstoffzellenbus.de***

Manufacturer:	MAN – a hydrogen internal combustion engine based bus
Current status:	Hyfleet: CUTE , 20 vehicles on order for Rotterdam Shell project
Budget costs:	450,000 euros
Specifications:	> 300 km range,
Earliest delivery date:	Mid 2008
Minimum size of order:	5 vehicles
Typical end users	Public bus fleets
Notes:	MAN are a German company, mainly developing buses for the European market. There are issues with respect to converting the existing bus design to Right Hand Drive (estimated to take up to a year of additional engineering). In order top engage with MAN, a substantial UK order would be required perhaps necessitating aggregated purchase with a number of UK centres for hydrogen deployment. As an ICE, the MAN suffers from fairly poor efficiency and without renewable hydrogen can actually increase the overall CO_2 emitted compared with a diesel bus..

Van Hool fuel cell hybrid bus powered by a UTC fuel cell

Source: www.isecorp.com

Manufacturer:	Van Hool bus, modified with ISE hybrid drivetrain and fuel cell from UTC
Current status:	4 vehicles operating very successfully at AC Transit (US), plans for further deployment in California and Europe.
Budget costs:	£1,000,000 (est.)
Specifications:	40 foot bus, Range >450 km, Hydrogen capacity 30-35 kg, top speed 65 mph
Earliest delivery date:	Late 2007
Minimum size of order:	3-5 vehicles
Typical end users	Public bus fleets
Notes:	Van Hool are a well respected Belgian bus company, with maintenance arrangements in the UK, supplying over 4,000 vehicles worldwide.

MicroCab – small fuel cell passenger/delivery vehicles

Source: www.microcab.co.uk

Manufacturer:	MicroCab, partnership with Intelligent energy + others
Current status:	1 complete prototype, second generation completed autumn 2005, first small manufacture run scheduled for 2007.
Budget costs:	£50,000 per vehicle for beta tests end 2005, £20,000 for series manufacture (delivered mid 2007). **Costs very approximate.**
Specifications:	160 km range, 213 km per kg, 350 bar H2, 0.75 kg capacity, 40 mph top speed, ultra-lightweight, 2,3 or 4 seat or freight configurations
Earliest delivery date:	Early 2007
Minimum size of order:	3-5 vehicles (for beta test, end 2005, early 2006), >50 vehicles for manufacturing support (delivery start 2007)
Typical end users	Urban delivery vehicles, urban taxis, disabled transport, site based vehicles (e.g. at airports).
Notes:	MicroCab are a small SME, with associated limitations with respect to cashflow. Any project involving MicroCab must be mindful of ensuring stable cashflow throughout manufacture, delivery and operation of the vehicles.

Reva – small fuel cell passenger car

Source: REVA Electric Car Co.

Manufacturer:	Reva Electric Car Company. 5kW fuel cell supplied by Hydrogenics
Current status:	Prototype. Reva intends to manufacture and trial a fleet of 10-20 demonstration vehicles.
Budget costs:	n/a
Specifications:	n/a
Earliest delivery date:	Reva's demonstration programme is planned to 2008. Vehicles may become more widely available post 2008.
Minimum size of order:	n/a
Typical end users	Urban vehicles and site based transport
Notes:	The Reva demonstration fleet may largely be trialled in India, under a partnering agreement with the Indian Oil Company. However, the PURE Partnership's fuel cell vehicle is a Reva electric car, modified by Sigen to incorporate a 1 kW fuel cell unit .