Hydrogen Bus Alliance

Strategy for 2010–2015 Alliance activities on hydrogen fuelled public transit buses

27 August 2008

CONFIDENTIAL

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Contents

Strategy status

This is the final version of the Hydrogen Bus Alliance strategy. This document has been prepared by the Alliance secretariat, and revised based on initial input from Alliance members.

Scope

Note that this document is concerned with the Alliance's main activity, namely commercialisation of full sized hydrogen buses. However, it is recognised that a range of bus platforms can support the overall goal of hydrogen bus commercialis-ation and that the main challenge is in developing hydrogen fuelled bus drivetrains, which can be compatible with buses from midi (or shuttle) buses up to larger articulated buses.

Confidentiality

Please treat this document as CONFIDENTIAL and limit circulation to Alliance members only.

Currency

Please note that all costs are provided in US dollars as the majority of Industry Dialogue responders used dollars as their primary currency.

Exchange rates assumed are:

1 GBP = $2 US
1 $CAN = $1 US
1 € = $1.5 US

1 Summary of the Hydrogen Bus Alliance Strategy

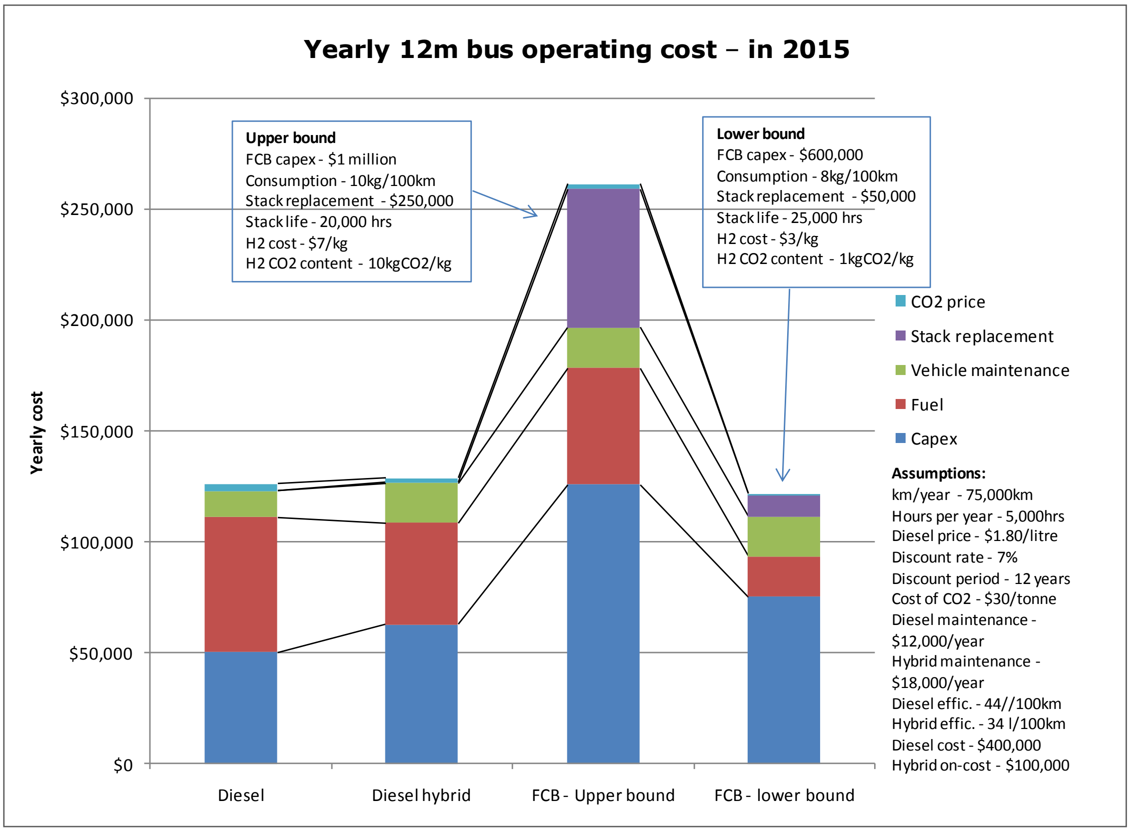
Hydrogen buses have the potential to play a role in reducing local pollution in cities and in reducing global pollution from carbon dioxide emissions. In addition, hydrogen buses can be a major enabler for the widespread penetration of hydrogen technology for all modes of transport.

The Hydrogen Bus Alliance is a grouping of 10 cities and regions with a strong political and financial commitment to encourage the commercialisation of hydrogen bus technology. This document analyses the potential for commercialisation of hydrogen buses by 2015 and provides a strategy for Alliance activities in the period.

1.1 Industry Dialogue responses

The Alliance carried out an extensive Dialogue with Industry between September 2007 and March 2008. The Dialogue involved detailed responses from over 20 major players in the hydrogen bus and fuelling infrastructure industries.

The data from the Dialogue is best summarised in the graph below, which shows the yearly cost of owning and operating a standard 12m bus at the higher and lower limits of costs for buses and hydrogen fuel which were provided by industry.



The Industry Dialogue process revealed a wide range of views about the likely cost of owning and operating a fuel cell bus by 2015. The lifecycle analysis shows that at the upper bound of 2015 cost projections from industry, the technology is a long way from achieving a commercial breakthrough, assuming today's energy and carbon pricing framework in 2015.

However, as the costs of owning and operating buses reach the lower bound of plausible cost projections, the technology will compete with both diesel and diesel hybrid buses. Specifically, to achieve a commercial proposition relative to diesel buses, the 2015 hydrogen bus requires that:

- Bus suppliers are able to reduce prices to the lower end of their projected range (the Dialogue process suggested that the lower bound price for a fuel cell bus would be $100,000 more than the cost of a diesel hybrid bus – this is based on a bottom up analysis of the components required for a fuel cell bus).
- By 2015 maintenance costs for fuel cell buses have become comparable with diesel hybrid vehicles (excluding stack replacement costs).
- By 2015 fuel cell stack lifetimes exceed 25,000 hours and have a replacement cost below $50,000 – or equivalent lifecycle stack replacement costs.
- Bus efficiencies exceed 8kg/100km for a 12m bus on a typical urban route.
- Hydrogen demand at bus depots exceed 50 buses per day (1,000kg/day) and hydrogen suppliers have sufficient confidence to amortise equipment over long periods (15 years) – this should lead to delivered hydrogen costs (untaxed) between $3 and $5/kg.

The targets are ambitious and at the lower bound of projections provided by industry in the Industry Dialogue process. **To achieve bus commercialisation by 2015, the Alliance strategy needs to focus on developing routes to the lower bound price targets provided by industry.**

The commercial proposition offered by hydrogen buses is also sensitive to factors unrelated to hydrogen technology development, in particular the cost of diesel and the cost of capital. The above commercial targets would be relaxed for operators paying over $2/litre for diesel (at bus depots) and for operators with low discount rates (less than 7% and with discount periods over 12 years).

There is also potential for material reductions in CO_2 from public transit using hydrogen buses. At today's fossil based hydrogen CO_2 intensities, there is already a marked reduction in CO_2 emissions over diesel buses (>30%) when using fuel cell hybrid vehicles and a small improvement over diesel hybrid buses. As lower CO_2 intensity hydrogen becomes available from a variety of potential sources, **the bus industry can move toward zero carbon propulsion**. Aside from the potential CO_2 benefits from operation of hydrogen buses, there are also substantial local benefits, including elimination of all local pollutant emissions and substantial reductions in the problems associated with noise and vibration of buses.

1.2 Deployment scenarios

A simple analysis suggests that to achieve the aspirations of the hydrogen bus industry supply chain between 800 and 1,600 buses will need to be procured by 2015. The total cost of this deployment is strongly dependent on the price reduction curve for the vehicles and the ability to cluster demand into a limited number of centres, to reduce infrastructure cost. The cap-ex estimates range from $450 million to over $1.4 billion for the combined deployment activity to 2015 [note that currently committed global fuel cell bus deployment costs exceed $100 million within the Alliance and well over $150 million globally].

The Alliance has considered its potential role in the period to 2015 and concluded that **the level of deployment by Alliance cities will be highly sensitive to the ability of industry to provide real and transparent price reductions in the period to 2015**. Three scenarios for price reduction were considered and the likely Alliance response is summarised below:

Scenario	***Response***
The **status quo** – hydrogen bus prices do not reduce beyond the existing cost levels (i.e. $1.6 million to $2 million for fuel cell buses)	Limited activity beyond the already planned deployment projects, which will prove that hydrogen buses can meet the need of full time bus operation.
The readily '**anticipated**' development, where fuel cell bus prices reduce to $1 million by 2012/13, but show no progress beyond this level by 2015	Cost reductions to this level in the 2010–2013 period would allow the Alliance, with the support of international funding bodies, to expand deployment activities, in a 'co-ordinated deployment' of up to 100 buses. Beyond this, however, further deployment is unlikely.
The '**lower bound**' price reduction, in which fuel cell buses can be offered to the market by 2015 at a cost which exceeds the cost of a diesel hybrid by less than $100,000.	The Alliance could commit to substantial deployment. On average each city could commit to take 50 buses by 2015, with associated large scale refuelling systems at depots. This commitment would be contingent on working with suppliers to develop a mechanism to ensure stable and transparent price reduction in the period. This corresponds to over 500 buses by 2015, expanding as Alliance membership grows. Beyond 2015, the Alliance cities could also commit to a regular share of their fleet procurement (Alliance cities currently buy 1,400 buses per year).

Note that these numbers could include a range of bus types, from midi- or shuttle buses through to articulated 18m buses.

Under the lower bound scenario above, the Alliance would be committing to a substantial share of the required hydrogen bus deployment volume in the period. When combined with deployment projections under other international programs, including the California Zero Emission Bus mandate and bus deployment activity in Korea, China and Japan, it would appear that there is **potential to meet or exceed the required bus deployment volume, provided clear paths to cost reduction are demonstrated.**

1.3 Alliance strategy

A three-stage Alliance deployment strategy is proposed. The three stages of deployment are:

2009–2011 Early fleets of hydrogen buses (notably in Berlin, Hamburg, London and BC Transit) – up to 50 12m buses are already committed under Alliance member programs. In addition, members of the Alliance with existing or imminent fuelling infrastructure will actively pursue procurement of fuel cell midi- or shuttle buses.

2011–2013 A large co-ordinated deployment activity (approx. 100 buses), focused around international support schemes, such as the EC's JTI and the other national programs.

2013–2015 and beyond A forward procurement strategy which links cost reduction to committed volumes of sales (200–400 buses between 2013 and 2015). In addition, beyond 2015, a commitment to procure hundreds of hydrogen buses each year could be achieved provided cost and performance targets are met. This procurement activity requires further consultation with industry to ensure best possible configuration.

The majority of the buses would be deployed in the 2013–2015 period. This would represent a relatively small fraction of the buses procured by Alliance members over the same period, but will form a foundation on which the hydrogen bus industry could develop.

Increasing Alliance membership will increase the value of such an exercise.

2009–2011 First deployments

Fleet deployment activity will validate hydrogen buses for public transport in fulfilling identical contractual requirements to those of a standard diesel bus. These deployments are already contracted and the main role of the Alliance will be to share information on the trials within the Alliance and also to communicate results to the wider bus end user community.

2011–2013 Co-ordinated deployment project

The Alliance believes it is possible to configure a major co-ordinated bus deployment activity in the 2011 to 2013 period. This deployment of approx 100 buses among Alliance members' fleets will require the support of the hydrogen bus industry and the various national and international stakeholders. The Alliance will take the lead in:

a) co-ordinating demand;
b) discussions with industry on configuring the program; and
c) discussion with national and international funding programs, for example the European JTI, to support the initiative.

The international funding bodies are important in this period to help share the burden of the high capital costs of buses to be deployed. The hydrogen bus industry must demonstrate that despite high costs in the period, there is a route to achieving the 2015 cost targets discussed above.

The Alliance will seek to configure the deployment program so that all Alliance cities and regions can participate. This will require an approach which spans the various continents represented in the Alliance (and hence the varied funding programs).

Initial discussions with the JTI have suggested that the Bus Alliance is one of the most logical places for co-ordination of such a project. The next step for the Alliance will be to scope out in more detail how such a co-ordinated deployment could work and to work with industry to define the appropriate interface with them and funding bodies to map out an acceptable program.

2013–2015 and beyond Committed procurement

The Alliance also believes it is possible to use procurement activities to facilitate the required price reductions. The Alliance will develop a comprehensive forward procurement approach for the 2013 to 2015 period. This will be developed in parallel with the 2011–2013 deployment project above. The formal procurement will commit to procure a given number of buses from the bus industry provided commercial and performance targets are made available and can be written into contracts.

Configuring a procurement of this type will require more discussion with the hydrogen bus industry. A series of key questions are set out in this document. In summary, the Alliance would like to understand industry reaction to a possible procurement involving:

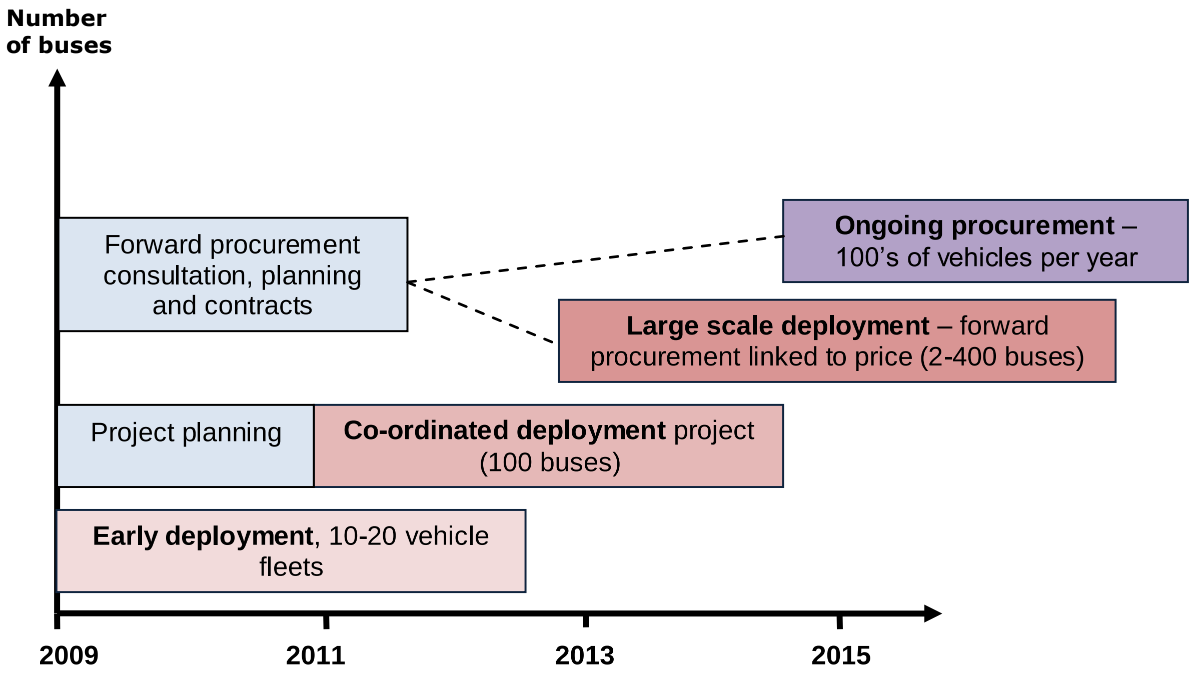
- 200–400 buses in the period 2013–2015
- Continuous commitment to procure 100s of vehicles every year beyond 2015
- 10 bus depots, with up to 50 buses per depot by 2015
- A clear link to performance improvements over the period (12.5km/kg, 20,000 hours fuel cell stack lifetime)
- A clear link to achieving aggressive cost reductions towards a 2015 price of $100,000 more than the cost of an equivalent diesel hybrid bus
- An intention to pay as close a possible to the 2015 price for every bus procured in the period
- A loose framework agreement, allowing Alliance members access to centrally negotiated commercial terms
- More than one supplier for all aspects of the supply chain

Key questions for the Alliance include:

1. Does the effort involved in co-ordinating such a procurement justify the end result?
2. Are the price reductions realistic by 2015?
3. Is the size of the procurement sufficient to catalyse supply chain investment from industry – if not, what scale would be appropriate?
4. How is such a procurement framework best configured?
5. Where is the procurement best focused – on individual components (e.g. FC stacks) or at the OEM level?
6. What are the roles of international bodies in such an exercise (for example, the EC or the European Investment Bank)?

The next step in developing the procurement is to solicit responses to this procurement opportunity from industry. We are interested in one to one discussions with industry in relation to this document. We will also hold a ‘pre procurement’ meeting with relevant industry stakeholders.

The strategy is summarised in the diagram below:



Infrastructure

For hydrogen fuelling infrastructure, there appears to be limited benefit to a common procurement program. Rather, individual cities and regions will need to develop plans which centralise hydrogen bus deployment in hydrogen depots with large filling systems (ideally over 50 buses per day). The main benefit within the Alliance will be in sharing data on the different approaches and in attempting to ensure technical and practical lessons learnt are shared.

1.4 Next steps

1 Internal debate on the initial strategy paper, agree general principles of 2010–2015 strategy (August 2008).
2 Discussion with national and international funding bodies regarding 2011–2013 co-ordinated deployment (Summer 2008).
3 Consult with industry on the shape of any procurement strategy, discuss legal implications and suitable structure within the Alliance (September 2008).
4 Alliance members to internally review feasibility of procurement programs suggested in the strategy paper (e.g. a 50 bus depot per member by 2015), and obtain initial political commitments (by August 2008).
5 Alliance to review legal implications of the strategy (Summer 2008).
6 Consult with Alliance partners – Clinton Climate Initiative and C40 Cities (Summer 2008).
7 Review Alliance resource requirement for delivering the strategy (Summer 2008).
8 Develop Alliance expansion strategy (Autumn 2008).

2 Introduction

Buses fuelled with hydrogen have the potential to meet a wide range of policy goals for city administrators. In particular, hydrogen buses have no tailpipe emissions (except water) and, with clean hydrogen, can lead to dramatic cuts in CO_2 emissions from public transit fleets. In addition, hydrogen buses are likely to be a key early adopter of hydrogen technology and hence will encourage the spread of hydrogen vehicle technologies which have the potential to fully decarbonise the transport system.

As a result of these drivers, a number of international cities and regions with large bus fleets have formed an alliance on hydrogen buses. These cities and regions represent leading adopters of new bus technologies in their respective continents and plan to act as leaders in the move to cleaner fuels for urban public transit. At present, the Alliance represents a cumulative fleet of over 14,000 buses and an average yearly purchase of over 1,400 city buses each year. A number of other cities and regions are keen to join the Alliance and we expect the size of the combined fleet to grow accordingly.

The Alliance includes the public transit agencies from:

- Amsterdam (GVB)
- Barcelona (TMB)
- Berlin (BVG)
- British Columbia (BC Transit)
- Cologne (Regionalverkehr Köln)
- Hamburg (Hamburger Hochbahn)
- London (Transport for London)
- Madrid (EMT)
- South Tyrol
- Western Australia – (Public Transport Authority of Western Australia)

All these cities and regions are characterised by high level political support for hydrogen bus deployment programs and active programs to demonstrate new hydrogen buses by 2011. The cities and regions all intend to move towards procuring hydrogen buses on a continuous basis, as hydrogen buses move towards commercial viability in the 2010–2015 timescale.

In support of the overall objective of assisting hydrogen bus commercialisation, the Bus Alliance launched an Industry Dialogue process in September 2007. The results of this assessment have now been analysed. This document builds on the Industry Dialogue responses to develop a strategy for the Hydrogen Bus Alliance in the period 2010–2015.

3 Current hydrogen bus activities within the Bus Alliance

Early hydrogen bus trials have demonstrated the viability of carrying bus passengers in cities using hydrogen. Of particular note was the CUTE project, which involved many Alliance members. The project involved trials of three EvoBus 12m fuel cell buses in 10 cities. The buses operated very reliably and were popular with the public. Hamburg continues to operate a fleet of nine fuel cell buses.

These trials demonstrated the viability of hydrogen fuelled vehicles in passenger carrying operation. However the buses were not operated to the same standards as a conventional city bus. In particular, the range of the vehicles was shorter than acceptable and hence the buses had shorter operational days than a conventional diesel bus. They were also extensively monitored and maintained by highly specialist staff.

The next generation of buses will nearly all make use of a hybrid drivetrain. The CUTE buses had relatively high fuel consumption, as the fuel cell buses were not hybridised. For fuel cell buses, a hybrid drivetrain not only increases efficiency, but also allows a smaller fuel cell to be installed, reducing cost.

All members of the Hydrogen Bus Alliance are actively pursuing next generation hydrogen bus deployment programs. Recently announced programs include:

- BC Transit – contract for 20 12m hybrid fuel cell buses (from New Flyer) to provide transit service before, during and after the 2010 winter Olympic games in Whistler
- London – order for 10 12m buses with 5 powered by fuel cells and 5 by hydrogen internal combustion to provide a complete London bus route (all in hybrid configuration)

Other cities will announce near term deployment activity shortly. These early deployment activities are aimed at taking the next logical step on the route to hydrogen bus commercialisation. The next generation deployments will validate vehicles in full operational service. This implies:

- Up to 20 hours operation per day
- 364 days fleet operation per year
- Complete bus routes reliant on hydrogen technologies
- Rapid refuelling of all vehicles at depots
- Integration within existing diesel depots
- At least five years service with full warranties (in the case of BC Transit, the procurement specified a 20-year vehicle service life)

Having achieved a successful operational deployment, the Bus Alliance cities and regions will be ready to move towards commercialisation in partnership with the hydrogen bus industry.

3.1 Current state of the art

Based on the vehicles to be deployed in Alliance cities in 2009/10, it is possible to provide an indication of the current state of the art for the next generation of 12m hydrogen buses.

	Fuel cell buses	**H2ICE**
Cost	Approx. $2 million	Approx. $1 million
Drivetrain	Hybridised	Direct drive and hybrid
Buses available	Single deck, artic planned	Single deck
Fuel consumption	10 km/kg	7km/kg (in hybrid configuration)
Warranties	Up to 12,000 hrs fuel cell	Equivalent to diesel bus
Power	75–150kW FC stack	150 kW
Refuelling time	<10 mins	<10 mins
Hydrogen cost	$10–20/kg (discussed below)	$10–20/kg (discussed below)
Range	>300km	>300km

The above state of the art for 12m hydrogen buses shows that there has been considerable progress towards improving such buses since the CUTE bus trials. Notably the fuel consumption of fuel cell buses has been shown to range from 25–50% better than an equivalent diesel bus (depending on the diesel baseline). Also, the warranties for fuel cells have improved substantially. However, there are still major barriers to widespread adoption of fuel cell buses. In particular:

- Capital cost – costs must fall close to diesel vehicles before bus operators will be able to make any commercial case for adopting the vehicles. An equivalent 12m diesel bus costs in the range $300,000–$500,000. There is still a significant requirement for cost reduction.
- Warranties and lifetimes – for fuel cells, lifetimes need to rise above the current 10,000 hours to become compatible with bus overhaul times – approx 5 years (or over 20,000 hours) is a minimum requirement.
- Bus availability – a wider range of vehicle choice is required, with a greater availability of vehicles from more suppliers. Currently within the Hydrogen Bus Alliance, there is a greater demand for hydrogen buses than availability of suppliers willing to supply. Only three major bus OEMs are supplying any 12m hydrogen buses and these are being supplied in very limited numbers for early fleet deployments. Smaller SME (Small and Medium Sized Enterprise) based vehicles are also available, but these tend to have their own supply constraints.
- Bus size – the majority of hydrogen buses currently being manufactured are based on 12m buses. There is a demand for both smaller (midi sized) and larger (articulated) buses. Double deck designs would also be welcomed, though the Industry Dialogue has highlighted constraints around double deck designs (relating to incorporating hydrogen storage).

4 The future for hydrogen buses – Industry Dialogue responses

4.1 Dialogue description

A detailed dialogue with industry was launched by the Hydrogen Bus Alliance in September 2007. The Dialogue process was based around a detailed questionnaire and follow up questions with key industry players concerning likely development in hydrogen buses to 2015. Anonymous responses were received from industry players throughout the industry. Specifically:

Hydrogen fuelling

- 2 major energy companies
- 4 industrial gases companies
- 2 fuelling infrastructure component providers

Buses

- 6 bus OEMs
- 3 fuel cell stack manufacturers
- 2 system integrators
- 2 hydrogen tank manufacturers

The Industry Dialogue process revealed a mix of views on the future for such buses. In particular, OEM companies tended to be less optimistic about the short term prospects for the hydrogen bus industry than the component suppliers (particularly fuel cell manufacturers and system integrators). The discussion below is based on the responses to the Industry Dialogue.

4.2 Future bus prices

The Industry Dialogue suggests that there are two approaches to estimating the future price of a fuel cell bus. The first is a top down approach involving discussions with bus OEMs and system integrators, who would then estimate the price of a packaged bus based on today's costs and typically including some of the one-off engineering costs associated with the buses. These tend to err on the side of caution and lead to the upper bound costs shown in the graph below. The top down assessments from the Industry Dialogue have suggested that achieving a price reduction to $1 million for a 12m fuel cell bus (from approx $2 million today) will be relatively straightforward by 2015, but that reductions beyond this level remain challenging and will require commitment to volume manufacture within the supply chain.

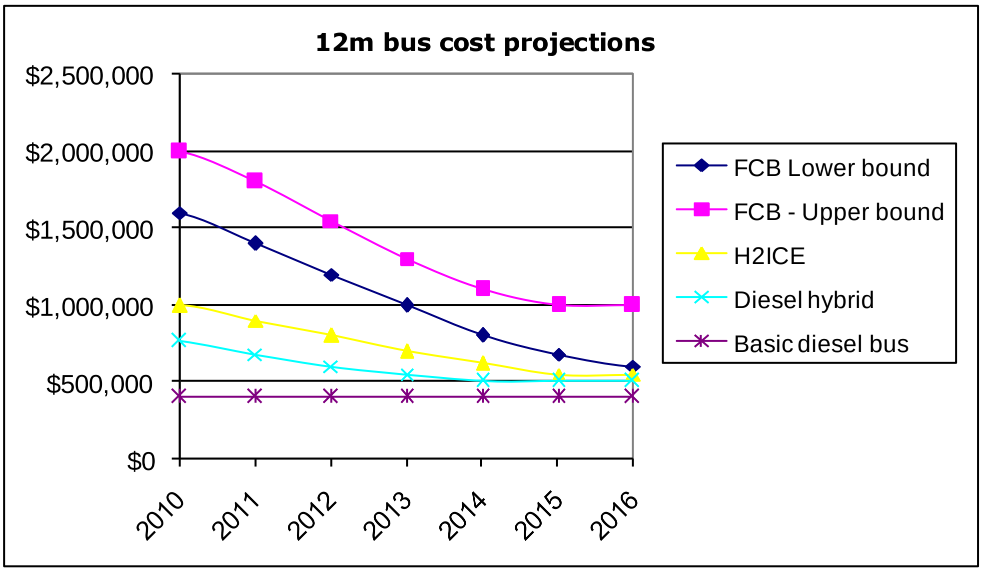
The second approach involves a bottom up assessment where the costs of the components are assessed. A bottom-up approach suggests that the cost of a fuel cell bus should be based on the cost of a diesel hybrid drivetrain. Additional costs will arise from the fuel cell itself and the hydrogen storage and distribution system. Many observers in the Industry Dialogue stated that on this basis, it is reasonable to expect the fuel cell and H_2 tank costs to fall below $120,000 by 2015, even for >100 kWe stacks. This would make a fuel cell bus price only $100,000 more than that of a diesel hybrid vehicle.

A separate exercise conducted by the Clinton Climate Initiative produced a narrower range of potential near-term 12m fuel cell bus prices. The Clinton methodology was similar to the Alliance's bottom-up approach in that it focused on component suppliers and integrators rather than bus OEMs. The data was generated by asking suppliers to estimate the cost trajectories of their bills of materials and value-adding processes as volumes increase and become more predictable in the coming years. The final result of the exercise is an indication that there is room for bus prices to fall into the \$700,000–\$800,000 range by the time the market is able to absorb 1,000 12m units annually.

In addition to the standard 12m buses discussed above, the Bus Alliance believes that other buses may offer benefits for advancing the development of hydrogen fuelled drivetrains. Specifically, smaller midi- or shuttle buses may reduce the over-all cost of the fuel cell bus package (making the technology easier to access for customers), whilst larger articulated buses may allow easier fuel cell integration and greater passenger carrying capacity. The Clinton Climate Initiative and the Bus Alliance are currently working to better quantify these potential advantages.

Clearly there is a significant uncertainty over future bus prices. This uncertainty is problematic for the Alliance, as it makes strategic planning difficult in the period to 2015. Greater clarity from industry will be required to enable the Alliance to make firm plans with respect to future hydrogen bus procurement. This is discussed in more detail in subsequent chapters.

The graph below highlights the upper and lower bound projections for the likely cost of a 12m fuel cell bus, a H2ICE bus and the competitor diesel and diesel hybrid vehicles by 2015. The cost projections are directly based on responses from the Industry Dialogue. The upper bound fuel cell costs represent a readily achievable cost, which manufacturers claim could be available in the next two to three years with a volume order (100 units). The lower bound costs represent a stretch target, based on bottom up analysis of the components within a fuel cell bus.



Cost projections for a 12m bus, based on Industry Dialogue responses (assumes continued increase in orders) – costs are based on buses deployed in the year stated.

To achieve these cost reductions, there are two main factors:

Development of technology over time – Hydrogen technology develops over time and this reduces cost and improves the performance of hydrogen technologies. As a relatively immature sector, hydrogen technology is developing very rapidly towards commercialisation. For fuel cell buses, time is probably the most important factor in achieving commercialisation. It will be necessary to develop and test new fuel cell stack designs which can achieve the cost and performance requirements for commercialisation. Industry Dialogue responses suggest that the next generation of fuel cell stacks (available 2012–2013) will be a genuinely commercial offer, capable of hitting the $100,000 lower bound price target above.

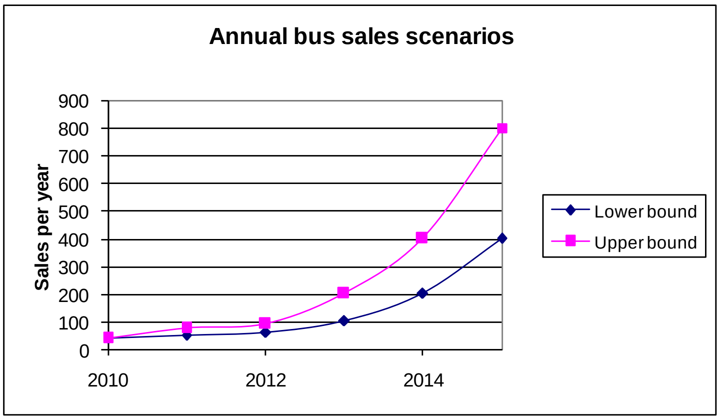
Volume of orders – Volume helps lower cost by allowing manufacturers (and their supply chain) access to more cost-efficient mass manufacturing techniques. Volume is not felt to be a key driver over the next 2–3 years, but will increase in importance by 2012–2013. One fuel cell manufacturer provided a wish list for numbers of units sold in the period leading up to 2015:

Year	Sales	Year	Sales
2010	20	2013	50
2011	25	2014	100
2012	30	2015	200

The same manufacturer has raised the possibility of bringing forward the 2015 costs to cover the entire 2010–2015 period, provided a sufficiently robust contractual framework is in place to guarantee orders.

Conclusion: there appears to be merit in discussing fuel cell bus orders with suppliers over the entire period to 2015; this could reduce the barriers to bus procurement at the start of the 2010–2015 period.

If it is assumed that two to four fuel cell suppliers will be active in the period, it is possible to establish an upper and lower bound projection for the level of demand for hydrogen buses which would be required to drive the cost reductions discussed above. The graphs below illustrate upper and lower bound demand levels. These will be discussed in more detail later in the report.



Assumed bus sales scenarios required to achieve the cost reductions discussed.

Conclusion: a successful Bus Alliance strategy will lead to sales in the 100s per year by 2015, with prospects for continued growth in demand.

4.3 Continuous order vs. a single order

One of the other aims of the dialogue was to explore the possibility for a single order for 50–100 buses achieving a marked reduction in hydrogen bus cost. Responses from system integrators and work by our partner organisation the Clinton Climate Initiative suggested that a one-off order of this type could achieve a cost reduction of 20–25% from the basic cost of a fuel cell bus. Whilst this is an impressive reduction, for the current costs of 12m hydrogen buses this does not constitute a sufficient reduction to achieve commercialisation of the technology.

Furthermore, most suppliers emphasised the importance of ordering vehicles on a continuous basis. A one-off order does not allow the supply chain to invest to ramp up production techniques to the levels required to achieve genuine commercial cost reductions.

Conclusion: the Bus Alliance strategy should focus on defining a continuous order flow rather than a single mass procurement.

4.4 Efficiency

Hybrid fuel cell buses have already demonstrated very low fuel consumption figures both in the US (AC Transit) and in Japan (Toyota Hino). Fuel cell bus efficiencies over 10 km/kg have been demonstrated in passenger carrying service. This compares to between 4 and 6 km/kg equivalent for a typical diesel bus.

In practice, fuel cell buses will compete with diesel hybrid buses and trolley buses for a share of the ‘alternative bus’ market. Diesel hybrids are developing rapidly and typically provide a 20–30% fuel economy benefit compared to a basic diesel bus. Fuel cells used in hybrid configuration should offer fuel economy improvements between 30–50% compared to a typical diesel vehicle.

Manufacturers project that overall vehicle efficiencies over 12.5 km/kg are possible for a typical urban route by 2015. These improved efficiencies will come from increase in fuel cell stack efficiency (to over 50% from approx 45% today) and improvements in overall drivetrain configuration.

[NB bus consumption varies significantly according to the bus route and climatic conditions. There is limited publicly available data for fuel cell buses on standard cycles. The new trials should address this issue.]

Conclusion: there is potential for further improvements in hydrogen bus efficiency and these should be driven through performance specification in any Bus Alliance procurement strategy.

4.5 Batteries and super-capacitors

As discussed above, it is becoming clear that a fuel cell bus would ideally involve a hybrid drivetrain; this allows for efficiency gains through regenerative braking, dampens the spikes in demand seen for the fuel cell and also allows for a smaller fuel cell.

However, there are major concerns over the availability of appropriate battery technology. Currently batteries cause the greatest problems in diesel hybrid and fuel cell hybrid drivetrains; the main issue is rapid degradation and unexpected failure of batteries. This problem is seen around the world. Substantial automotive R&D is under way to improve the viability of batteries for passenger cars as well as for heavy-duty vehicles. It is expected that this will lead to improved lifetime performance.

Conclusion: the Bus Alliance should monitor progress in battery technologies, to inform procurement approaches.

4.6 On-board hydrogen storage

The Alliance takes the view that a well designed, efficient hydrogen bus can achieve the required range (>300 km) for most bus locations using 350 bar on-board storage.

4.7 Warranties and lifetimes

The main issues for fuel cell bus lifetimes will be the fuel cell and the batteries.

The **fuel cells** deployed in the CUTE project demonstrated lifetimes in excess of 4,000 hours. The current generation of stacks have warranty offers in the range 10–12,000 hours. Fuel cell manufacturers are confident that the next generation fuel cell stacks will be produced with lifetimes in excess of 20,000 hours. The exact warranty offer will then be a matter for commercial negotiation.

It is possible to gain some confidence in the likely lifetime of fuel cell stacks for buses based on the improvements in lifetimes in stationary fuel cell products (using PEM fuel cells). Stationary fuel cell stack lifetimes have already exceeded 20,000 hours and are projected to exceed 40,000 in the near future.

Universally fuel cell manufacturers feel that achieving the required 20,000+ hour lifetime for PEM fuel cells will not pose an insoluble technical challenge in the period to 2015.

Battery lifetimes will likely be driven by the conventional hybrid passenger car and bus markets, where substantial efforts are under way to develop long-life batteries for hybrid buses as well as hybrid passenger cars.

Conclusion: it is believed that fuel cell manufacturers will resolve their own issues around fuel cell lifetime within the time period of this strategy. This will lead to lifetimes over 20,000 hours. Long-life products should be one of the performance specifications included in any Bus Alliance strategy.

4.8 Maintenance issues

Once commercially mature, the maintenance of a fuel cell vehicle will need to cost the same as a diesel hybrid bus to avoid excessive operating cost penalties. There are a number of barriers to achieving this:

- Cost of components, regular checks etc. – hydrogen buses are currently looked after very carefully. This leads to high maintenance costs. As technologies mature, it is imperative that manufacturers take steps to minimise unnecessary maintenance steps in their maintenance programs for hydrogen buses.
  Conclusion: this is a performance indicator for any procurement specification.
- Absence of skilled personnel – maintaining a hydrogen vehicle requires specialist knowledge about hydrogen gas, fuel cell systems and also high voltage vehicle drivetrains. In most Alliance countries there is a shortage of these skills. Alliance members will need to work with local skills authorities to ensure that training programs exist to bring through the right calibre of technicians to work on hydrogen buses.
  Action: each Alliance member will work with national authorities to promote skills development and training.
- Maintenance facilities equipped to handle hydrogen are currently very costly. The codes and standards associated with handling hydrogen inside can require either expensive modifications to existing facilities or new facilities designed with costly additional specifications. There is a need for further work on codes and standards for hydrogen bus maintenance facilities.

Action: Hydrogen Bus Alliance will promote international work on maintenance facility codes and standards for hydrogen buses. The work will be aimed at safely reducing the cost of handling hydrogen vehicles indoors.

5 Hydrogen fuel

Buses have the potential to play a very significant role in galvanizing investment in the hydrogen economy of the future. Bus operations will consume relatively large volumes of hydrogen. Assuming a hydrogen demand of approximately 20kg per bus per day, it can be seen that for the 50+ bus depots of the future, over 1 tonne of hydrogen will be required every day. This is two orders of magnitude higher than the levels of hydrogen currently dispensed even at the largest passenger car re-fuelling stations. This is the scale of BC Transit's hydrogen station to be established in Whistler in summer 2009, which will be the largest refuelling station in the world by hydrogen throughput.

Bus demand will be sufficient to allow investment in high-cost infrastructure solutions (i.e. the throughput of hydrogen is sufficient to justify the investment), yet the demand is centralised so that the infrastructure only needs to be deployed in a single location. The size of the demand is particularly important for companies planning off-site hydrogen production capacity. For example, the European liquid hydrogen manufacturing capacity is approximately 10 tonnes per day. If 10 x 50 bus depots are built across Europe, this would use up all of the liquid hydrogen production capacity. By deploying large volumes of demand, buses allow for increases in the scale of off-site hydrogen production facilities.

Yet, hydrogen fuel has the potential to be a major obstacle to the commercialisation of hydrogen buses. Expensive hydrogen can push the lifecycle economics of hydrogen buses past the point of affordability. Under-developed technology also causes problems; in the CUTE project, fuel infrastructure problems caused greater down-time than issues with the buses themselves. It is generally agreed that the historic level of investment in the development of fuel solutions is dwarfed by the investment in attractive hydrogen vehicle solutions. Investment in hydrogen fuel development will need to catch up to avoid being the critical obstacle to hydrogen bus commercialisation. Currently the availability of hydrogen fuel infrastructure components is limited. The lead times for many key components stretch into years (notably reformers, hydrogen cylinders and liquid hydrogen tanks). There is a need to develop the supply chain capacity alongside developments in refuelling technology.

5.1 Supply modes

Based on the dialogue responses and partner experience, there appear to be three major options for hydrogen fuel supply:

Road-delivered hydrogen (liquid) – in order for hydrogen to arrive by road in the volumes required for hydrogen bus operation, the product must be liquefied. Both the BC Transit and London fuelling stations will rely on delivered liquid hydrogen. Liquid hydrogen facilities have a small footprint, are inherently flexible in output, and can be scaled quickly to cope with increases in demand. The downside of liquid hydrogen is that the liquefaction process is energy-intensive and costly.

Delivered hydrogen (pipeline) – the pipeline approach involves several different options. At one end of the spectrum is a dedicated, purpose-built pipeline linking a source of supply with a locus of demand such as a bus depot. A second option is the complete or partial conversion to hydrogen of an existing natural gas pipeline. Finally, there is partial build-out of a pipeline to a central dispensing hub from which tube trucks can carry gaseous hydrogen short distances to multiple usage venues.

On-site production – hydrogen can be produced on-site from reformation of natural gas or from electrolysis of water. Electrolysis of water offers the potential for low-carbon hydrogen through the use of green electricity; however, reformation of natural gas will produce a lower cost of hydrogen. In both cases there is a concern over the footprint required when large volumes of hydrogen must be produced and stored at bus depots.

In the longer term novel chemical and metal hydrides may provide another delivery mode. These are not currently mature. The Alliance will watch progress in these areas with interest.

5.2 Hydrogen fuel economics

Three elements make up the cost of hydrogen fuel dispensed at a bus depot: the cost of production, the cost of transportation, and the cost of storage and dispensing. In the first two cases, the different methods that can be applied embody trade-offs between fixed and variable costs. In general, the lowest-cost solution will be one that minimizes variable cost and then drives down the fixed cost per unit dispensed by maximizing the lifetime volume of fuel that flows through the assets.

Factors affecting the economics for each of the main options are discussed below.

Pipelines – the lowest variable cost, highest fixed cost method for delivering hydrogen produced remotely to a bus depot will be a pipeline. By carrying a gas at moderate pressure, pipelines avoid the energy losses inherent in a liquid delivery system. Direct-to-depot pipelines also avoid the labour involved in all phases of over-the-road transport. Capital costs of pipelines are substantial, however, with per km costs running in the range of $1–2million. Hence, pipeline solutions will only appear where capital cost can be minimized and/or lifetime volume maximized. The former situation can pertain for sites near oil refineries and chemical works with their own hydrogen infrastructure and/or where an existing gas pipeline can be converted to hydrogen. Bus Alliance member Cologne recently completed a study into the cost of delivered hydrogen at a municipal bus depot near a large chemical facility. The study concluded that pipeline delivered hydrogen costs could be below €3/kg, compared with costs over 50% higher from delivered hydrogen solutions and more than three times higher for on-site production.

Only in exceptional cases will the capital cost of a pipeline be borne in the main either directly or indirectly by a bus operator. In most cases, the immediate investment will be made by private-sector investors whose return will be generated by sales to multiple customers. This circumstance leads to the collaborative mindset that Alliance members will have as they work with hydrogen suppliers, city officials, and other customers toward the goal of affordable hydrogen.

Liquid hydrogen – liquid hydrogen solutions have both relatively high fixed costs (for liquefaction and liquid storage and handling equipment) and relatively high variable costs (for over-the-road transport). In cases where hydrogen cost at the source is low, the full cost of liquid hydrogen can be moderate, with the potential to reach costs below $5/kg using today's technology. Whether costs can go below $3/kg is debatable and will depend on local energy costs and the cost of the hydrogen originally generated. Technology improvements in central liquefaction facilities could reduce costs by reducing the energy required to liquefy hydrogen (from today's 30–40% to 15–20% of the energy content of the fuel). In addition, capital cost reduction through increases in volume of hydrogen infrastructure equipment procured (notably liquid hydrogen trailers) could also reduce cost considerably.

The economics of liquid hydrogen solutions need not be affected by the participation or lack thereof of other customers since bus depots will typically receive full truckload shipments. Recent advances in on-board compression/decompression technology create the possibility of maintaining affordability even with less-than-truckload purchases.

On-site production – there are two main modes for on-site production: electrolysis of water and reformation of natural gas.

For electrolysis technology, there are clear constraints on the cost of hydrogen likely to be available at bus depots. Best electrolysers have a conversion efficiency of 70%. If electricity is delivered at a cost of $0.10 per kWh (a realistic cost of electricity delivered to a bus depot), then the cost of the electricity component of the hydrogen is $4.70/kg, before even the cost of the equipment, maintenance etc have been included in the costs. This suggests that a cheap source of electricity will be required to justify electrolysis on cost grounds alone, or rises in fossil fuel process relative to the price of electricity, which would make higher-cost hydrogen out-compete fossil-derived hydrogen and the incumbent fuels.

Hydrogen from reformed natural gas could be produced considerably cheaper. The fuel component of the hydrogen cost (assuming $0.04/kWh delivered natural gas cost) is only $1.90/kg. The US DoE believe that current designs for on-site production from natural gas could lead to dispensed hydrogen costs below $3/kg by 2015 provided that demands exceed 1,500 kg/day.

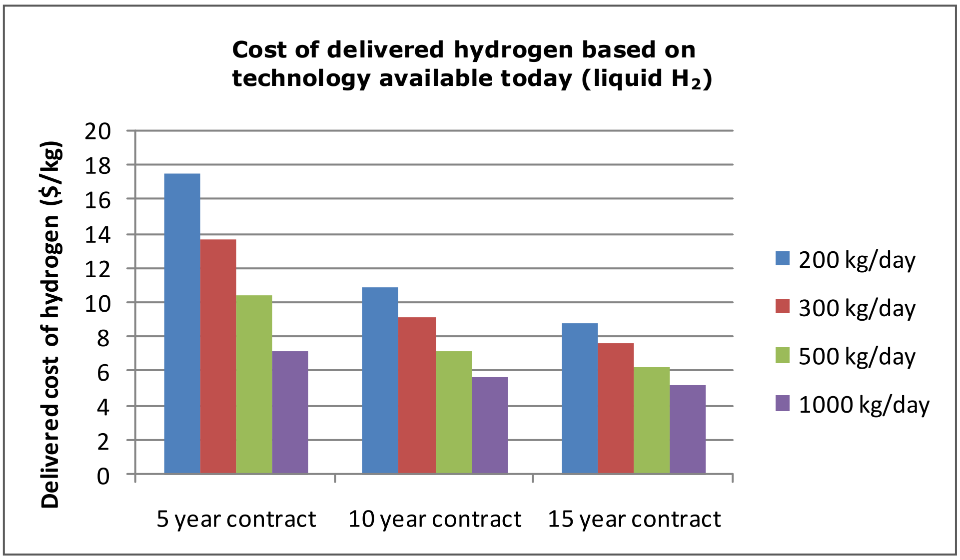
Conclusion: developments in on-site production from natural gas could reduce on-site hydrogen costs for this delivery mode by 2015 or serve an environmental objective (discussed below).

Conclusions: at reasonable demand volumes (50 buses) and with longer term certainty (15 years), it is feasible to expect hydrogen prices below $5/kg, tending towards $3/kg by 2015 for the more attractive locations (NB these prices will vary with the natural gas market price). These prices apply for three different supply modes – delivered liquid, pipeline (where capital investment can be minimized and/or spread across sufficient demand) and on-site production from reformed natural gas. Prices from electrolysis are strongly dependent on the local electricity price and will be higher than the natural gas based sources except for locations where very low-cost electricity is available (e.g. Canada), or when an energy supply can take advantage of grid balancing properties of electrolysers.

5.3 On-site dispensing infrastructure

The two main factors which affect the magnitude of the on-site storage and dispensing costs are volume of demand and longevity of supply contracts. These costs can be substantial, given the relatively high capital costs that are associated with equipment that will often be dedicated to one customer. Amortising these costs over a longer period or over a greater throughput (e.g. by allowing access to the other consumers of hydrogen) is essential if they are to be made affordable.

The graph below is based on actual (2008) delivered liquid hydrogen costs, based on refuelling equipment which can be procured and installed today. The graph shows the effect of varying the delivered volume of hydrogen each day and also the length of contracts signed. The graph clearly illustrates how the same equipment could reduce the hydrogen cost from today's values ($16–20/kg), associated with low hydrogen demand in the low 100s of kg/day, to substantially more affordable levels.



Graph showing the effect of contract term and daily demand on the total hydrogen price – assumes today's costs for liquid hydrogen delivery, including dispensers for compressed hydrogen on-board vehicles (350 bar).

The graph above is encouraging. Even using today's equipment, if the demand can be increased to approx. 50 buses and the level of contractual certainty around the equipment increased (from 5 to 15 years), hydrogen can be purchased at a cost below the cost of taxed diesel fuel in many Bus Alliance countries. This conclusion is valid at most bus depots in industrialised countries as it is based on the supply of liquid hydrogen which is widely available. (NB see below for a discussion of the costs of the various supply modes.)

With technology improvements, these costs should reduce further.

In practice, achieving the required long-term certainty in demand will be a challenge for Alliance members. Most Alliance members have procurement legislation limits on the timescales over which contracts can be signed for any supplier (for example both the London and the BC transit refuelling contracts are signed for only five years). It is also not necessarily an equitable solution that Alliance members should be asked to carry all the risk of hydrogen technology development over a 15-year period. This is an area where H_2 suppliers, national governments, international bodies and the Bus Alliance can work together to help provide certainty and share risk appropriately.

Conclusion: the Bus Alliance strategy should be based around refuelling facilities at depots with concentrated demand (ideally above 50 buses or 1,000kg/day).

Conclusion: the Bus Alliance should work with H_2 suppliers to develop models which allow costs of refuelling facilities to be amortised over longer than 5 years. These discussions should also draw in governmental agencies.

5.4 CO_2 reduction potential for different supply modes

A main driver for exploring hydrogen buses is the reduction in CO_2 emissions from bus transit. Any Bus Alliance strategy will have failed if there is not a push towards low-carbon hydrogen supply.

The three lowest-cost hydrogen routes identified above all currently use natural gas as their source of hydrogen. The process of generating hydrogen from natural gas leads to an emission of carbon dioxide. Alternative processes using electricity have CO_2 emissions strongly dependent on the CO_2 intensity of the electricity itself. Where electricity has low carbon content (e.g. Canada with a high hydro-electric penetration), the hydrogen has virtually no CO_2 emissions; for conventional US or European grids (with high penetrations of coal), the CO_2 emissions can substantially exceed those of the natural gas based routes.

Solutions exist to reduce the CO_2 of all the delivery solutions discussed above. There are a number of papers which explore the potential CO_2 benefits of hydrogen technology, and this analysis is not repeated here.* The table below shows some of the measures available to reduce CO_2 from the delivery modes discussed above.

Delivery mode	$kgCO_2$/kg of hydrogen (approx)
Pipeline from central production (from natural gas) – North European grid mix	10–11
ADD Use renewable electricity for compression	9–10
ADD Use biogas, waste hydrogen or capture and store CO_2	0–1
Note: **Cologne** will make use of effectively zero-carbon hydrogen which is currently wasted	
Liquid hydrogen derived from natural gas – North European grid mix – 300 km delivery	14–16
Note: **Berlin** are currently using this solution	
ADD Use zero-carbon electricity for liquefaction	9–10
Note: **London** will use green electricity to minimise the footprint of their refuelling solution	
ADD Use clean source of hydrogen – renewable electrolysis, biogas or capture CO_2 from H_2 production	0–1
Note: **BC Transit** use ultra low CO_2 hydrogen from electrolysis in Quebec (very low grid CO_2 intensity) – transport distance (4,000+ km) increases emissions	
On-site production from natural gas	12–13
ADD green electricity for compression	10–11
ADD clean natural gas e.g. biogas	0–1
Note: this solution is likely limited to niche locations.	
On-site production from electrolysis – North European grid mix	>20
ADD green electricity	0–1
Note: this solution will be deployed by **Hamburg**	

* For example, the CONCAWE study – http://ies.jrc.cec.eu.int/wtw.html

In the longer term other options may become available such as direct nuclear hydrogen production or biological production. These could both lead to ultra-low CO_2 production but are not relevant to the timescales discussed in this strategy.

To put the well to tank CO_2 numbers above into context, it is worthwhile to consider the overall lifetime emissions of a hydrogen bus compared to a diesel bus and a diesel hybrid bus. The graph below shows the emissions of a conventional 12m bus with 4 different drivetrains over a typical urban cycle (diesel, diesel hybrid, H2ICE hybrid and fuel cell hybrid). In all cases, estimated fuel consumption figures for 2015 are used.

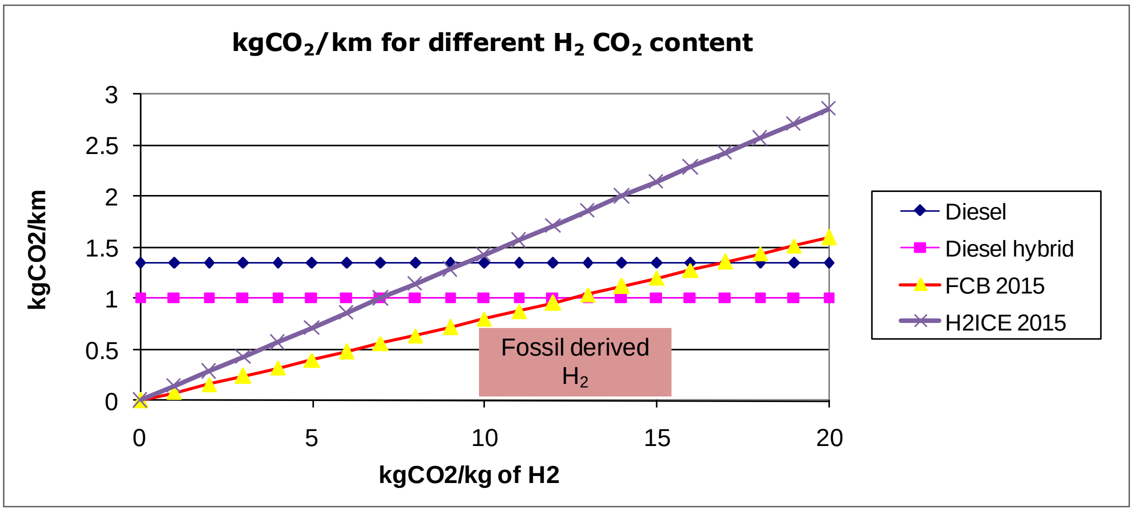


Illustration of the well to wheel CO_2 emissions for a 12m single deck bus for four different drivetrains in 2015, for different CO_2 content hydrogen. The assumptions on fuel economy are – diesel 45l/100km, diesel hybrid 34l/100km, fuel cell hybrid 8kg/100km, H2ICE hybrid 14kg/100km.

The graph illustrates the importance of the CO_2 intensity of hydrogen on the overall CO_2 emissions case for hydrogen buses. At today's CO_2 levels for fossil fuel based hydrogen (10–15 $kgCO_2/kg$), fuel cell hybrid buses achieve a significantly better emissions performance than a diesel bus. Even using today's fossil fuel derived hydrogen, fuel cell buses achieve an equivalent or better performance relative to diesel hybrid buses. As the CO_2 intensity of hydrogen falls below 10 $kgCO_2/kg$, hydrogen fuel cell buses will have an increasingly superior emissions performance relative to diesel hybrid buses.

For H2ICE vehicles, the hydrogen intensity of the fuels must fall well below today's fossil fuel based hydrogen intensities towards the intensities of waste hydrogen, CCS derived, biogas derived or hydrogen from green electricity before a clear CO_2 case is available.

Conclusion: each Bus Alliance city should work with infrastructure partners to develop hydrogen supply solutions with well to tank CO_2 below 10$kgCO_2/km$. This ensures a superior CO_2 emissions case to diesel hybrid vehicles for fuel cell buses.

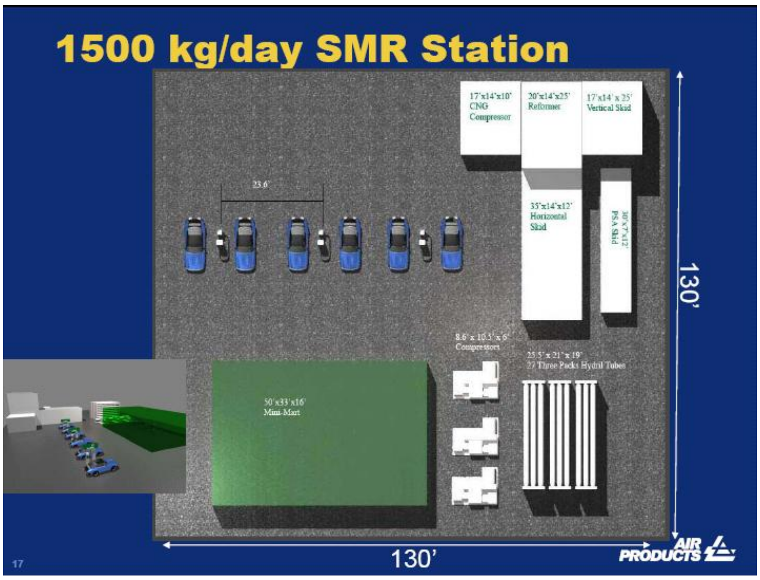
In the longer term, refuelling infrastructure providers need to demonstrate that they have local solutions to further reduce CO_2 intensity of hydrogen towards zero carbon hydrogen. In practice, the Industry Dialogue process suggests this will require:

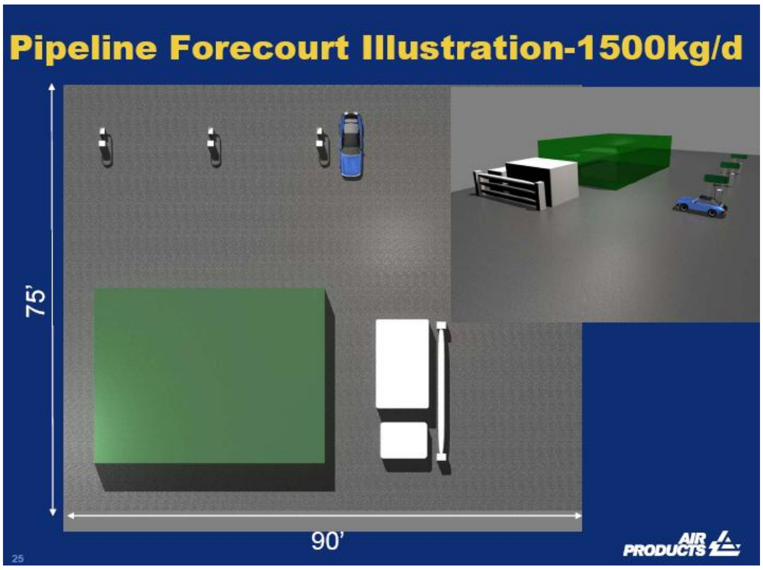
- Waste hydrogen – requires access to waste hydrogen which is currently vented, only available in niches (e.g. in Cologne).
- Renewable/nuclear electricity – increases the cost of hydrogen except in niche locations with low-cost green electricity (e.g. Canada).
- Carbon Capture and Sequestration (CCS) – projects demonstrating the technological viability of the CCS approach are at an early stage. The scale required for CCS based H_2 production probably exceeds 500 tonnes per day of hydrogen.
- Biogas or other biological processes – will require some technological development and greater availability of bio-feedstock.
- Direct nuclear production – requires technological development.

5.5 Footprint

A final issue which will affect the viability of different hydrogen supply modes for bus depots will be the footprint of the equipment. Of the three hydrogen supply modes discussed above, the pipeline solution has the lowest footprint, as there is no need to store hydrogen on-site or to produce it. The liquid option has a lower footprint than an on-site solution, as on-site production technologies require room for production equipment as well as compressors and substantial compressed hydrogen storage to buffer output from the production units.

The diagrams below illustrate the likely footprint for the three supply modes, when considered for a 1,500 kg/day forecourt filling operation for passenger cars. This is similar to the demand required for refuelling 50–75 hydrogen buses. On-site production has a clear penalty from a footprint perspective.





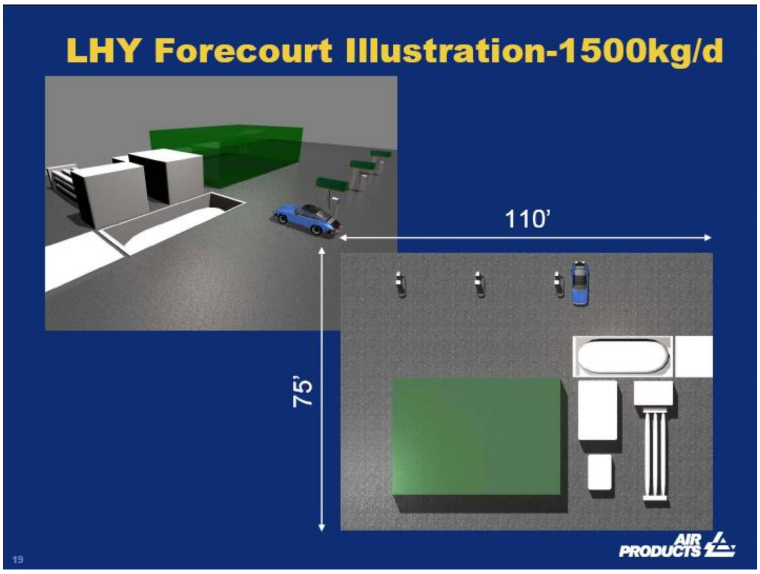


Illustration of footprints for different hydrogen filling solutions at a demand of 1,500 kg/day.

For a number of urban cities with space constraints, these footprint issues are likely to pose constraints for hydrogen supply options. For example, footprint issues played a major role in London's decision to select a liquid supply route for their 10 bus deployment project.

Conclusion: footprint requirements are likely to be higher for a hydrogen filling facility on bus depots than for conventional diesel, and some extra space will be required in new bus depot designs. Of the various solutions available, the additional footprint for pipeline and liquid options are likely to be acceptable in most locations. However, the on-site production methods will need to reduce footprint to be applicable in all bus depots.

5.6 Fill times

The current state of the art for hydrogen bus fast-fuelling is 10 minutes for a complete fill.

A fill time of less than ten minutes for a complete fill is believed to be acceptable for the majority of bus depots. However, conventional diesel buses refuel in under 5 minutes. The Dialogue responses suggest that moving towards 5-minute fill times may be achievable with technological development.

Reducing fill time can increase the cost of the refuelling solution, so a balance is required between making minor alterations to bus fuelling patterns and fill times.

In some Alliance cities, bus operators are developing a slow-fill solution for hydrogen fuelling. In this case, the fill would occur over a 4-hour window; this reduces the requirement for on-depot fuel storage and high throughput compressors and hence leads to lower-cost, less bulky fuelling infrastructure. Other cities have expressed concerns over the operational practicality of systems of this type and more experience is required in the deployment of these slow-fill systems.

Conclusion: the Alliance should work towards 5-minute fill times through performance specification and dialogue with equipment providers during any procurement exercise.

6 Whole life costs of hydrogen buses

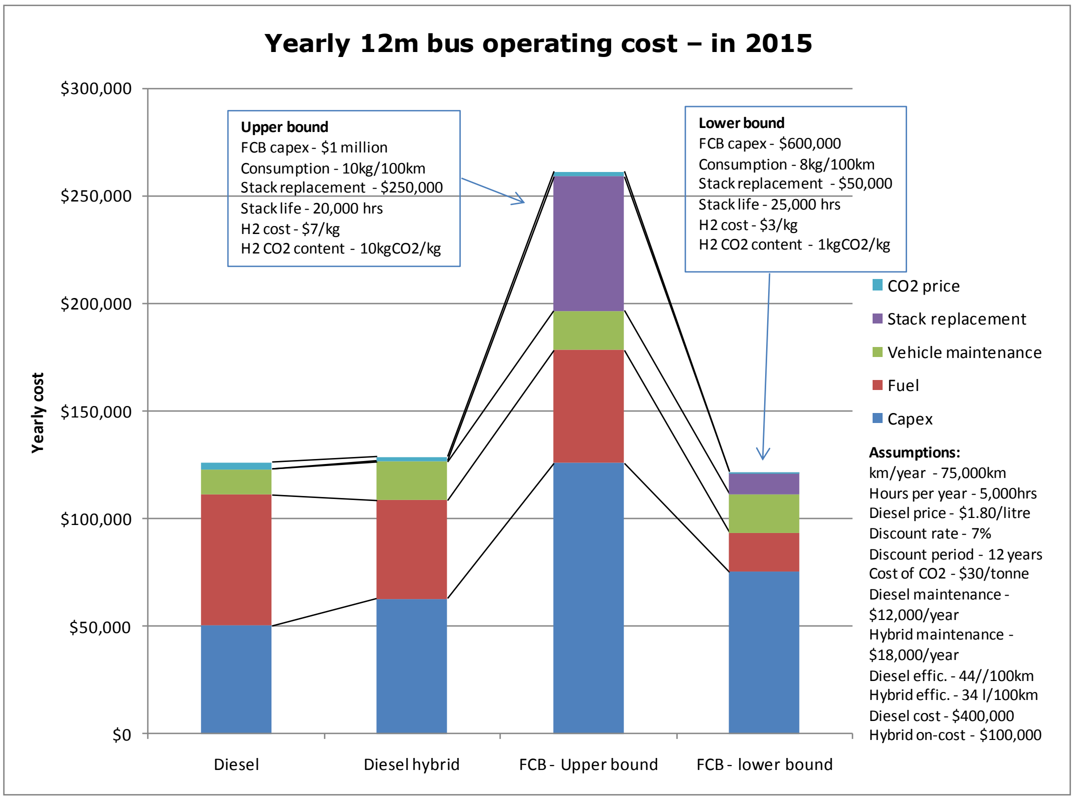
The analysis below considers the lifecycle implications of operating a 12m hydrogen bus compared to diesel and diesel hybrid alternatives in 2015. Assumptions about cost of money, fuel consumption of diesel and diesel hybrids vary between the Alliance members. Here a median position is presented which encompasses the Alliance members' different assumptions.

2015 projected costs and performance for 12m bus

Diesel bus cost Diesel hybrid additional cost (2015)	$400,000 ADD $100,000
Diesel bus fuel economy Diesel hybrid fuel economy	44 l/100km * 34 l/100km (25% improvement)
Cost of capital (discount rate) Discount period	7% 12 years
Distance travelled per year per bus Operational hours per year per bus	75,000 km 5,000 hrs
Diesel cost to bus operators – includes taxes	$1.80/litre
Fuel cell bus cost 120 kW stack (upper bound) Fuel cell bus cost 120 kW stack (lower bound) H2ICE	ADD $500,000 to diesel hybrid cost ADD $100,000 to diesel hybrid cost ADD $100,000 to diesel hybrid cost
Diesel bus maintenance cost per year Diesel hybrid maintenance cost per year (2015) Hydrogen bus basic maintenance per year	$12,000 $18,000 $18,000 (includes H2ICE engine replacement cost if applicable)
FC stack replacement cost – upper bound FC stack replacement cost – lower bound FC life (upper bound) FC life (lower bound) FC power output	$250,000 $50,000 20,000 hrs 25,000 hrs >100 kWe
FC Bus fuel consumption (hybrid)	8 kg/100 km
H2ICE bus consumption (hybrid)	14 kg/100km
Maintenance costs	It is assumed that by 2015 maintenance costs for all vehicles will be equal

* Note that these fuel efficiencies represent a European style bus on flat urban routes. Other Alliance operators see significantly higher fuel consumption for both diesel and diesel hybrid buses.

The graph below plots the lifetime cost of 12m hydrogen bus operations versus the diesel alternatives for the assumptions above. The graph shows the components making up the yearly cost of operation for the different bus technologies available. Costs include annualised capital costs, fuel costs, maintenance, stack replacement and a cost of carbon.



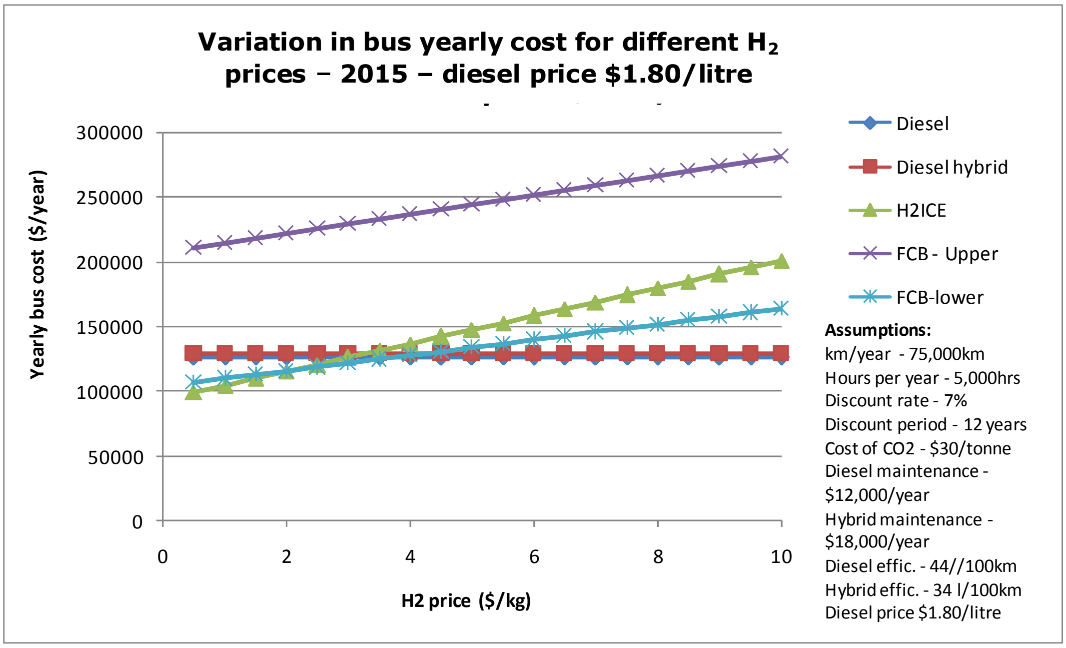
Total yearly operating cost for different bus options. The graph shows the upper bound ('easily' achievable) cost for fuel cell buses alongside the lower bound 'stretch' target for fuel cell buses, which could be achievable only with concerted development and deployment activity. Note that these costs are for the buses only and do not include costs of drivers, depots, overheads etc. These are assumed identical for all bus types.

The graph shows that a stretch price of $600,000 for a 12m fuel cell bus (and stretch assumptions regarding stack lifetime and replacement cost) happens to coincide with the point of lifecycle cost parity between fuel cell buses and diesel equivalents. Once fuel cell buses pass this point, they have a good chance of attaining self-propagating demand in the marketplace based on a combination of their economic and environmental merits. On the other hand, failure to meet the stretch targets for cost reduction and performance would mean that bus operators will struggle to make a commercial case for operating further hydrogen buses. For buses costing $1 million per vehicle, the capital costs dominate the economics and no fuel economy improvements will allow the fuel cell buses to overtake diesel options as a preferred option. Furthermore, the upper bound has a very high annual cost for fuel cell stack replacement. Without reductions in this cost, even reductions in the capital cost of vehicles will be swamped by the additional maintenance costs of replacing fuel cells.

However, if the stretch targets for fuel cell buses are met (i.e. $600,000 per bus and $50,000 for stack replacement, with 25,000 hour life), there does appear to be an economic case for operating hydrogen buses. Indeed with low hydrogen prices, it is conceivable that hydrogen bus operating costs could eventually fall below those of diesel equivalents (this will be dependent on relative fuel prices, see below).

6.1 Sensitivity to fuel prices (hydrogen and diesel)

The above chart showing the yearly lifecycle costs for different 12m bus types is sensitive to the cost of hydrogen and also the cost of diesel fuel. The graph below shows the effect of hydrogen price on the total yearly operating cost (i.e. including amortised capex, maintenance costs, fuel costs etc.) for the different bus types.

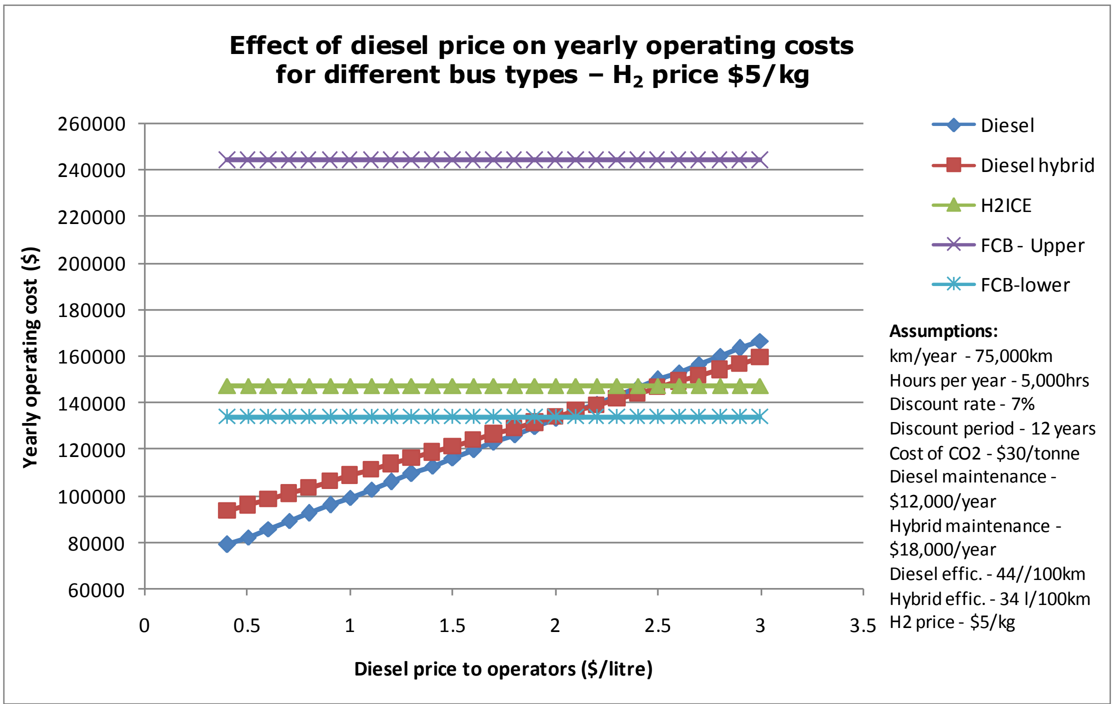


Variation in 12 m bus lifecycle costs (fuel and capital only) for different drivetrains for a range of delivered hydrogen prices.

The graph clearly shows the importance of both hydrogen cost reductions and capital cost reductions for the buses themselves. For the lower bound fuel cell bus cost (i.e. $100,000 above the cost of a diesel hybrid in 2015), there appears to be a clear lifecycle benefit when the hydrogen price delivered to vehicle falls below $4.50/kg. This cost is believed feasible provided bus depots have sufficient volume of demand and also long enough commercial contracts. However, for the higher cost fuel cell bus (approx. $1million per bus), it is difficult to make a clear lifecycle case for any cost of hydrogen (i.e. even if hydrogen is provided for free).

At the projected costs for the H2ICE vehicle, lower fuel costs are required than for the fuel cell bus to break even. Costs below $3/kg are required before a clear lifecycle benefit exists over the diesel equivalents.

The cost of diesel is also an important parameter in the overall lifecycle cost comparison for the different bus types. The graph below shows the effect of variations in the diesel price paid by operators on each technology.



Lifecycle costs for the diesel and diesel hybrid buses are similar, with a general increase with fuel price. For high fuel prices, the diesel hybrid has a lower lifecycle cost than the basic diesel bus and vice versa.

As the diesel price rises above $1.80/litre, the lower bound fuel cell bus becomes an increasingly attractive proposition (provided hydrogen prices remain around $5/kg). This illustrates the potential value of hydrogen as a partial hedge against the effects of rising fossil prices (though it should be noted that for current methods of production, hydrogen price is closely related to fossil prices).

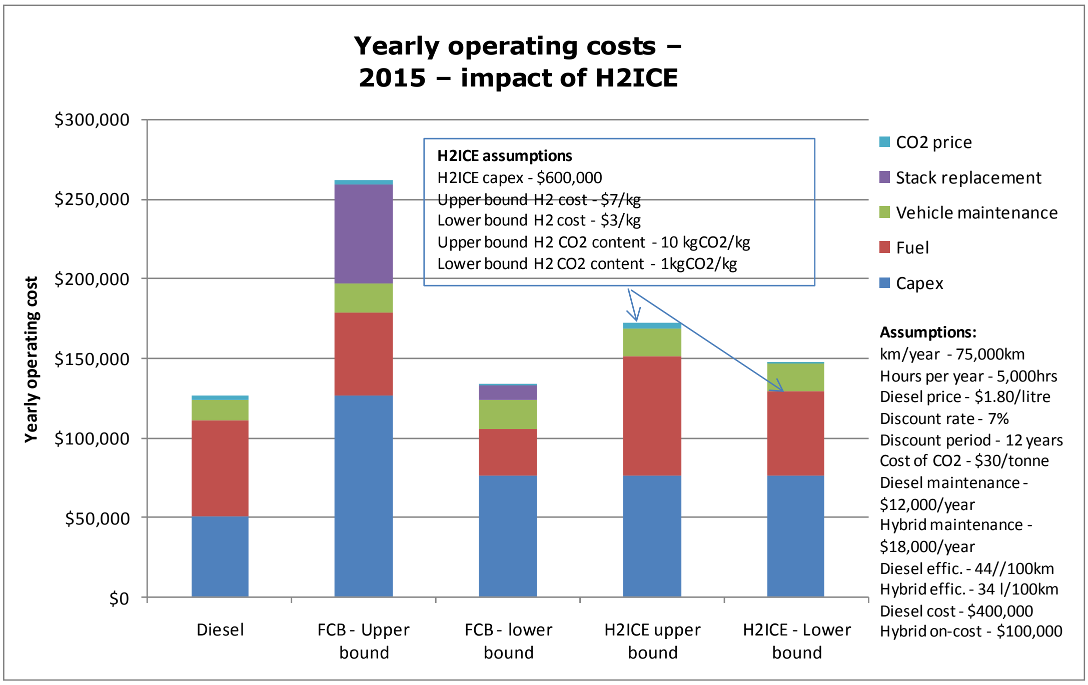
Conclusion: provided that a) 12m hydrogen fuel cell bus costs fall so that by 2015 they cost approx $100,000 more than the cost of a diesel hybrid, b) lifetime and maintenance costs are comparable, and c) hydrogen costs have dropped below $5/kg to the operator, then there is an economic case for a shift to hydrogen-fuelled buses from 2015.

Conclusion: the economic argument for hydrogen buses is sensitive to fossil fuel prices. Diesel prices at depots over $2/litre will substantially strengthen the economic case for hydrogen buses, provided hydrogen costs remain at approx $5/kg. At a diesel price of $3/litre, hydrogen buses could be over 25% cheaper to operate than diesel or diesel hybrid buses.

The above costs are believed feasible based on the preceding analysis (chapters 4 and 5). The most challenging aspect will be achieving best-case reduction in the capital cost and fuel cell stack replacement parameters of the hydrogen bus. This analysis therefore provides an economic justification for a bus procurement strategy over the period 2010 to 2015, provided that strategy has a clear path to the lower bound cost reductions required for economic viability.

6.2 Role of H2ICE buses

The graph below shows the cost of operating an H2ICE bus, against the fuel cell bus costs discussed above. The H2ICE bus shows more sensitivity to the cost of hydrogen than the fuel cell bus, due to higher fuel consumption. The cost of hydrogen fuel alone could put the H2ICE bus outside the range of typical diesel vehicle operating costs. A cost over $7/kg is enough to cause an additional yearly cost of $50,000 relative to a diesel bus. However, for low hydrogen prices, the lifecycle cost is approximately equal to that of the diesel vehicles.



Comparison of the yearly lifecycle cost of fuel cell buses and H2ICE in 2015.

The main advantage of the H2ICE is the certainty in costs. The range of 2015 lifecycle costs is much smaller than that for the fuel cell bus. This is due to greater certainty over engine costs compared with the fuel cell costs. This illustrates the potential of the H2ICE vehicle to overcome the high initial cost barriers for deployment of fuel cell buses and act as an 'affordable' stepping stone to hydrogen fuel cell buses.

The Bus Alliance does not currently have a united position on the role of H2ICE buses versus fuel cell vehicles. A number of cities/regions are pursuing H2ICE buses in preference to fuel cell buses (South Tyrol, Barcelona). By contrast, some cities have ruled out operation of H2ICE buses, favouring a transition directly to fuel cell vehicles (BC Transit, Hamburg). All cities are clear that the technology which offers the lowest lifecycle cost and CO_2 emissions for operators will eventually be selected. All Alliance cities agree that the long-term potential of fuel cell buses is higher than H2ICE buses due to their improved fuel consumption and zero emissions. However, the high cost of fuel cell vehicles is a deterrent, which could provide a niche for H2ICE for some years to come.

Conclusion: H2ICE buses will be included within Alliance activities until fuel cell buses clearly offer a superior economic proposition for operators

6.3 Valuing externalities (CO_2 and local pollution)

The analysis above only includes an economic value for CO_2 emissions and does not account for any of the costs of local pollution. These values are notoriously difficult to quantify and will differ widely in different countries. Even the price of CO_2 emissions used in the analysis ($30/tonne) is very variable, as the cost of CO_2 fluctuates widely on international CO_2 emission trading markets.

In future, governments will be under pressure to increase the price of CO_2 as well as create a formal value for local pollutants. A recent EC paper suggests that it would be possible to place a value on NO_x particulates (PM) and hydrocarbons (NMHC) such that the lifecycle impact of a Euro IV diesel bus would be as shown in the table below.

Vehicle type	Vehicle price	Lifetime cost for					Vehicle price + lifetime costs
		Fuel	CO_2	NOx	NMHC	PM	
Bus (1 million km)	**150.000 €**	313.500 €	30.210 €	87.780 €	2.622 €	9.918 €	**594.030 €**

From EC PwC assessment of lifecycle costs of externalities for a Euro IV diesel bus – information is provided for illustration only – NB vehicle prices used in this study are lower than observed by the Bus Alliance (typically €250,000+ for a 12m bus).

The cost of all externalities for a hydrogen bus would be zero, constituting a potentially large incentive for a shift to hydrogen fuel cell buses. If incentives are valued at this level, this could allow the cost of a hydrogen bus to increase relative to a diesel bus by as much as $100,000.

Conclusion: the Bus Alliance should monitor developments in regulations aimed at valuing externalities and aim to rapidly introduce these prices within their fleet procurement decisions once mandated.

7 Uptake scenarios 2010–2015 period

This section suggests how uptake of buses might proceed globally in the 2010–2015 period, to ensure commercial viability of hydrogen buses by 2015. The next section considers the potential role of the Bus Alliance within these uptake scenarios.

The bus cost projections discussed in chapter 4 rely on a sustained increase in demand for vehicles. The hydrogen cost projections in chapter 5 rely on a large number of vehicles at a single depot, with long-term guarantees of the hydrogen demand being sustained.

The exact number of bus orders which are 'required' in the period to 2015 is difficult to estimate. Clearly the number of orders will need to be sufficient to justify continued investment by the supply chain. It will also need to ramp up over the 5 year period, to ensure that production capacity is increased to the point of preparing the hydrogen bus market for commercial sales. Based on one fuel cell supplier's 'wish list' for the period and other responses from the Industry Dialogue (from OEMs and the bus supply chain), it is possible to bound the 'required' uptake of fuel cell buses.

The table below assumes between two (lower) and four (upper) fuel cell suppliers are active in the market. It is then assumed each supplier will 'require' an uptake profile similar to that supplied during the Industry Dialogue (the table is modified in the early years to reflect the lack of available OEMs).

	Lower bound	**Upper bound**
2010	40	40
2011	50	70
2012	60	100
2013	100	200
2014	200	400
2015	400	800
TOTAL	**850**	**1610**

Upper and lower bound for yearly global sales of hydrogen buses in the 2010–2015 period.

The hydrogen cost calculations above and the Industry Dialogue responses strongly suggest that these buses would be best grouped in centres of demand, rather than spread widely across a large number of cities. Ideally over 50 buses would be deployed per filling system. If it is assumed that the above deployment occurs in filling systems, each of which fill an average of 50 vehicle each, this implies that even to cope with the buses bought in the 2010–2015 period, 17–32 hydrogen bus filling systems will be required.

It is possible to estimate the costs of a deployment of this type, using the bus cost projections in chapter 4. The tables below show the total additional capital costs for fuel cell bus procurement (i.e. the additional capex over the costs of deploying equivalent diesel buses).

	Total capex – lower bound uptake	Total capex – upper bound uptake
2010	$48,000,000	$48,000,000
2011	$50,000,000	$70,000,000
2012	$48,000,000	$80,000,000
2013	$60,000,000	$120,000,000
2014	$80,000,000	$160,000,000
2015	$112,000,000	$224,000,000
TOTAL	**$398,000,000**	**$702,000,000**

Lower bound bus costs

	Total capex – lower bound uptake	Total capex – upper bound uptake
2010	$64,000,000	$64,000,000
2011	$70,000,000	$98,000,000
2012	$69,000,000	$115,000,000
2013	$90,000,000	$180,000,000
2014	$140,000,000	$280,000,000
2015	$240,000,000	$480,000,000
TOTAL	**$673,000,000**	**$1,217,000,000**

Upper bound bus costs

Additional capital costs of fuel cell bus deployment (above a diesel bus), assuming upper and lower bound fuel cell bus costs.

In practice there will be more capital costs associated with the deployment of hydrogen infrastructure. Ideally, this will be borne by infrastructure companies and amortised into the hydrogen cost. However, it is worthwhile to estimate the total capital costs associated with each 50-bus depot. Assuming a $5million capital cost per depot, this translates to $85–160million of additional infrastructure capital cost over the period.

Finally, there will be additional operational expenditures. Provided that the capital cost of the hydrogen equipment is covered in the uptake program, the hydrogen costs will be lower than the equivalent diesel supply. Other operational costs will come from fuel cell stack replacement and additional maintenance costs associated with unfamiliarity of the technology. These are not estimated here.

The indicative uptake scenario suggests that there are additional capital costs associated with the 2010–2015 bus deployment program of between $500 million and $1.3 billion, to fund both bus purchase and new hydrogen infrastructure.

These costs are global and will need to be shared between all stakeholders. The next section discusses the potential role of the Alliance in a deployment program of this type.

8 Developing a strategy for the Bus Alliance 2010–2015

The analysis above suggests that for hydrogen buses to become commercially viable and make a compelling economic case for operators by 2015, a number of steps are required. Specifically, by 2015:

1. Prices for 12m buses should be on course to reduce to no more than $100,000 more than the price of diesel hybrid buses. It may not be possible to reach the $100,000 target by 2015, as this is the lower bound price projection. However prices must be close to this level by 2015 and show clear potential to reduce below the target price.
2. Maintenance costs should be equivalent to diesel hybrid buses (excluding stack replacement).
3. Stack lifetimes should exceed 25,000 hours and replacement costs fall below $50,000 – of course, if replacement costs fall significantly below $50,000, it would be possible to reduce the lifetime expectations and maintain the same overall lifecycle costs. This may be required to be compatible with the global development of stacks for passenger cars, which have shorter lifetime requirements than buses.
4. Hydrogen filling stations should be deployed in large depots, using approximately 50 buses per filling system.
5. 12m hydrogen buses should achieve fuel efficiency above 8kg/100km on a typical urban cycle.
6. Infrastructure providers should have sufficient certainty to amortise filling station capital costs over 15-year periods.
7. This should lead to (untaxed) hydrogen costs of $3–5/kg.
8. Hydrogen CO_2 intensity should be below 10kgCO_2/kg, with near-term plans in place to move to a zero CO_2 supply.

Based on our Industry Dialogue, all the above points are believed viable provided that globally:

a) Between 800 and 1600 buses are deployed in the period.
b) There is long term certainty of demand after 2015 at the performance metrics above.
c) 17–32 bus depot filling systems are deployed with an average of 50 buses per hydrogen filling system by 2015.

The Bus Alliance could play a number of roles in delivering the above. Specifically:

1. Deploying the next generations of vehicles and proving the technology as a viable 'workhorse' for bus operators worldwide (2009–2011). Communicating the results of these trials widely.
2. Ensuring that the price and performance targets required for commercialisation are properly communicated to industry.
3. Ensuring that price and performance targets are met through a comprehensive procurement process which commits suppliers to price reduction and performance improvement.
4. Committing to procurement of a share of the required buses in the 2010–2015 period – this fraction could act as the foundation for the global deployment in the period, but is unlikely to include all the 'required' vehicles in the period.

5 Planning for a share of the required hydrogen bus depots for the period.
6 Procuring long-term hydrogen supply contracts over the period 2010–2015.
7 Expanding Alliance membership to ensure increased take-up of hydrogen buses and depots in the period.

Of the above points, 1, 2 and 7 are already objectives of the Bus Alliance and do not require further analysis. The key issues for the other points are a) what size of procurement exercise could the Alliance commit to, and b) how should that procurement be structured to ensure that it delivers the results required by 2015 and also meets the diverse needs of the various Alliance members.

8.1 What size of procurement could the Alliance commit to?

Current status

The Bus Alliance currently includes 10 members, with a combined annual bus purchase of 1,400 buses per year.

Five members of the Alliance (BC Transit, London, Hamburg, Cologne and Berlin) have or have committed to bus depot filling facilities which could be expanded to be suitable for 30–50 vehicles each at relatively low cost.

In addition, two members of the Alliance have announced orders for a total of 30 hydrogen buses to be deployed in the 2009–2010 period, with another 30 expected to be announced soon.

The total cost of the two announced projects is approx $100 million over their complete life.

In addition, other cities (not currently included in the Alliance) have committed to a further 30+ buses over the same period.*

The first 1–2 years of the 'required' bus deployment activity therefore seem to be already committed, according to the 'required' bus volumes discussed in chapter 7 above.

Any procurement program will need to accept that there is a STOP/GO point after a year of these trials, where if the technology has not proven sufficiently reliable (and/or efficient) then there will be a need to reappraise the larger vehicle procurement programs.

Beyond 2011

Beyond 2011, there is less certainty around the plans of the Alliance. Between 2010 and 2015, the Alliance will procure a total of 7,000 new buses. Whilst the Alliance recognises that a premium for hydrogen buses will be required in the period, the number of hydrogen buses which can be procured in the period will be strongly influenced by the lifecycle cost profile of those buses.

To better understand the potential role of the Bus Alliance in developing the commercialisation of hydrogen fuelled buses in the period to 2015, three scenarios have been considered by the Alliance cities:

* For example AC Transit recently announced an order for up to 21 buses with UTC and Van Hool.

1 The status quo – in which hydrogen bus costs do not reduce beyond the existing price levels of between $1.6 million and $2 million for fuel cell buses and approx. $800,000 to $1 million for an H2ICE vehicle.
2 The readily 'anticipated' development, in which fuel cell bus prices reduce to $1 million by 2012/13, but show no progress beyond this level.
3 The 'lower bound' price target, in which fuel cell buses can be offered to the market by 2015 at a price which exceeds the price of a diesel hybrid by $150,000 or less.

The Bus Alliance cities have considered their likely response to developments against each of these scenarios.

1. The status quo – if bus prices do not reduce beyond their current level, then there is little prospect for further uptake by Alliance cities. The currently planned deployment projects are aimed to prove that the technology can meet the needs of conventional bus operators. Beyond these projects, there is little value to bus operators in further high-cost demonstration projects until there is a clearly demonstrated potential for lifecycle cost reduction.

2. The readily 'anticipated' price level of approx. $1 million per bus is not sufficient to create a long-term case for operating hydrogen buses on a lifecycle cost basis. This means that the Alliance cities will not be able to commit to a long-term market for buses at this price.

However, price reductions to these levels in the period 2010–2012 would be sufficient to demonstrate progress in reducing prices towards the 2015 targets. The Alliance believes that it would be possible to construct a co-ordinated deployment project of approx. 100 12m buses at these price levels. This would require a significant national or international funding program (such as the EC's JTI) to provide match funding for the price of the buses.

The justification for a further deployment of 100 buses would rest on suppliers demonstrating the path to the price targets required for fuel cell bus commercialisation.

3. If suppliers are able to demonstrate that they can achieve the price reductions required to reach a lifecycle cost equivalent to diesel hybrid vehicles by 2015, the Alliance would be in a position to provide a substantially higher level of commitment to fuel cell bus procurement. If the bus suppliers are in a position to lay out a forward procurement contract with price reductions linked to volume of demand in the period to 2015, the Alliance can respond with significant volumes of vehicle orders.

Specifically, the Alliance will commit that each member would be prepared to operate on average 50 buses by 2015. These would be operated at dedicated depots with associated refuelling facilities.

Under scenario 3 above, the Alliance would be committing to a substantial share of the required hydrogen bus deployment volume in the period. In addition to deployment under other international programs, including the California Zero Emission Bus mandate and bus deployment activity in Korea, China, Japan, and India, it would appear that there is **potential to meet or exceed the required bus deployment volume, provided clear paths to price reduction are demonstrated.**

8.2 How to structure a bus deployment activity?

It is worthwhile to consider two stages of any bus deployment activity, which are linked but which can be pursued in parallel.

Between 2011 and 2013

A number of large international funding programs exist, which can mitigate the costs of hydrogen buses to the consuming agencies. Perhaps the largest example is the EC's Joint Technology initiative (JTI) which might provide up to 50% of the costs of hydrogen buses under a co-ordinated deployment project. The JTI has a significant budget (€10s of millions to support bus projects of this type). The Alliance cities could commit to up to a 100-vehicle deployment in this period. This 'co-ordinated deployment' project would preferably be international in scope, sharing lessons across continents as well as within continents (i.e. the Alliance would expect that non-EC Alliance members could participate in some way in a project funded by the JTI).

The Alliance is prepared to immediately commit to initiating a deployment project of this type. This will involve:

a) co-ordinating demand within the Alliance and other cities and regions
b) discussions with industry on designing the program
c) discussions with industry to configure the program to accelerate commercialisation and also fit with the 2013+ strategy (see below)
d) discussion with the European JTI and other international funding programs to support the 'co-ordinated deployment project'.

For a project of this type, the Alliance would expect to see fuel cell bus costs at the 'upper bound' level suggested for 2015 in the lifecycle analysis above, i.e. $1million per bus.

Initial scoping discussions with representatives from the JTI program suggest that it may be possible to use a pseudo-procurement exercise to obtain the buses within any 'co-ordinated' deployment program.

The next step on the route to a co-ordinated deployment project is to begin to map out the 100-bus deployment within the Alliance cities, to demonstrate the viability of this model to all hydrogen bus stakeholders. This should be followed by a detailed discussion with industry.

From 2013 to 2015 and beyond

The international funding bodies are unlikely to have resources to commit to the numbers of bus orders required beyond 2013. From 2013 onwards, the Alliance cities will need to make use of a comprehensive procurement to further reduce costs and to achieve lifecycle costs equivalent to diesel and diesel hybrid vehicles.

Estimating numbers of vehicles under this procurement is challenging as the number of vehicles which can be procured will depend on the vehicle and hydrogen costs which industry is prepared to offer. To provide an indication, on average each Alliance city is prepared to accept the concept of a single hydrogen bus depot capable of taking up to 50 buses, giving a theoretical deployment of 500 buses by 2015.

Beyond 2015, the Alliance would be prepared to make a commitment to procure a large number of hydrogen buses each year, provided key cost and performance targets have been met. The Alliance currently procures 1,400 buses each year. If the lifecycle economic and environmental case can be made, a fraction of this number could be allocated to hydrogen. Hundreds of buses per year could conceivably be included in any forward procurement commitment. Seven years away from 2015, these commitments will no doubt be vague on both sides, but the Alliance believes it is worth exploring the value of a commitment to procure a continuous number of buses from a set point in the future.

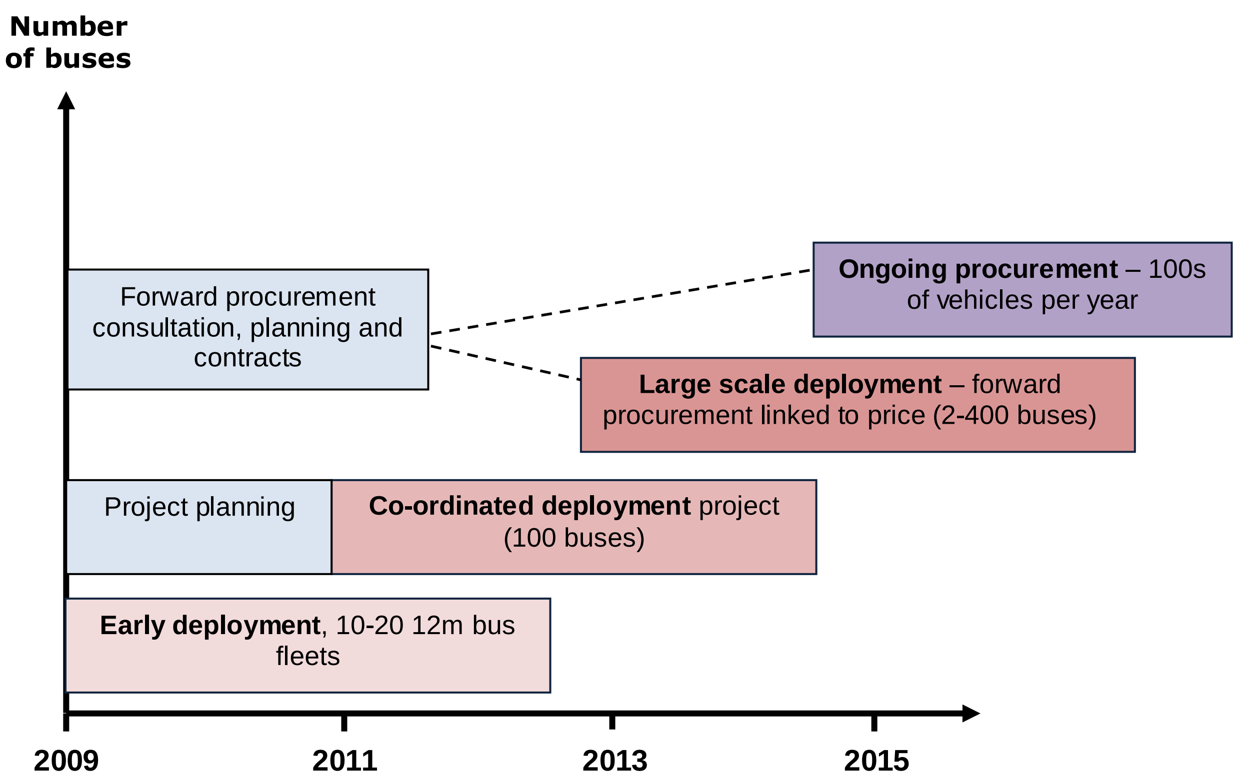
Should the Alliance membership increase as expected, the numbers involved in any procurement exercise will increase accordingly.

The Alliance wishes to enter into discussions with industry and other stakeholders on how such a procurement program might be configured to accelerate hydrogen bus commercialisation.

Conclusion: the Alliance has the potential to provide combined demand for buses, which would make a material impact on bus commercialisation in the period to 2015. There is a lack of clarity on how such a comprehensive forward-procurement might be best constructed and the Alliance wishes to consult with industry on their views on how this could be best achieved.

8.3 Summary of strategy

The diagram below provides a schematic of the main stages of the Alliance strategy.



9 How should a procurement be structured – key questions

If a large deployment program is to occur, it is relevant to bus deployment in the period from 2011. There are two stages to the procurement – a 'co-ordinated deployment' project from 2011–2013 and a comprehensive procurement period from 2013.

There is significantly more uncertainty around the procurement phase from 2013 onwards. The Alliance will seek opinions from industry and other stakeholders on the key issues for both the co-ordinated deployment and the procurement stages. The text below raises some of the key issues and questions. The Alliance would hope to discuss these issues individually with industry players. The Alliance will also welcome the entire industry to attend a pre-procurement event to discuss the issues raised.

9.1 Framework agreement

Attempting to co-ordinate bus procurement between 10 or more cities will be highly challenging. Previous attempts at international procurement have fallen over due to the variety of bus specifications required in different countries and the inflexibility of procurement approaches. Any approach to joint procurement will need to allow flexibility to cope with different regional requirements.

The Alliance does not believe that it will be possible to create a tight formal procurement package to cover this period. Instead a framework agreement, with call off contracts (perhaps linked to volume) would appear more appropriate.

The mechanism established by the Clinton Climate Initiative may well serve as a useful template here. In this approach, an agreement is reached that any of the members of the C40 Cities, a group facilitated by the Clinton Climate Initiative, may have access to a certain set of commercial terms from suppliers, provided certain volume requirements are met. In the same way, Alliance members could be given access to a set of commercial terms for a post-2013 procurement, which would be agreed centrally by the Bus Alliance.

Question: can hydrogen bus industry stakeholders propose a structure or a procurement framework which allows all parties to benefit from the aggregation of demand proposed here?

9.2 Complete bus or supply chain?

There are two areas where procurement could be targeted – at complete vehicles, or at components within the supply chain (e.g. fuel cell system and hydrogen tanks).

Because the bus industry includes a number of manufacturers who build bodies on top of chassis provided by other manufacturers, it may be possible to develop a procurement methodology which ensures low-cost components can be supplied to local body builders, who can in turn meet the local specifications. The procurement would focus on fuel cell systems, systems integration components and hydrogen tank suppliers. Aiming at the supply chain simplifies the regional problems (e.g. BC Transit and London will both use the same fuel cell stack and hydrogen tanks), but it does not ensure whole vehicle cost reductions.

The alternative is to develop a procurement framework for complete buses. The Citaro bus used by Daimler Chrysler for the CUTE trial was successfully deployed in over 10 cities worldwide. Engaging with global bus suppliers such as Daimler may also allow a whole vehicle approach to cost reduction through procurement.

Question: there appear to be merits in approaching both the supply chain (fuel cell, tank manufacturers and integrators) and OEMs with proposals for common procurement. Do industry stakeholders have a view on which option is most valuable and workable?

9.3 Ensuring competition

Creating monopolies for any aspects of the supply chain is not in the long-term interest of the Bus Alliance. It is therefore essential that any program ensures that more than one supplier is able to compete for orders.

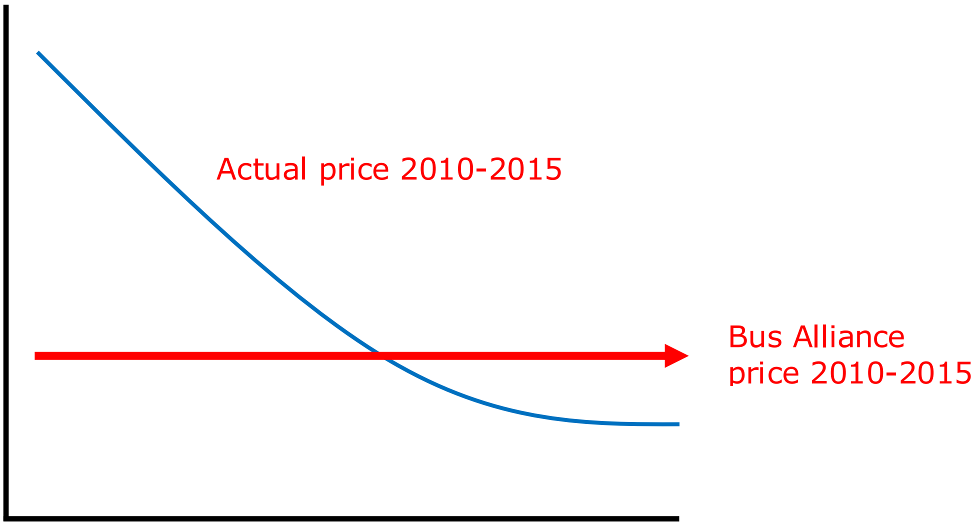
Conclusion: any procurement approach should aim to include more than one supplier.

9.4 Ensuring cost reduction and performance improvement

The logic for pursuing a strategy for hydrogen bus procurement through the Bus Alliance is predicated on performance improvement and cost reduction for hydrogen buses at the more optimistic end of projected levels. The procurement strategy must therefore be able to lock-in aggressive performance and costs towards the lower bounds of those predicted by industry.

1 Perhaps the easiest way to ensure that these targets are met is to simply state the cost and performance targets as a pre-condition for a large scale procurement program. For example the Alliance could commit to the purchase of 500 buses between 2010 to 2015 (at 10 depots), provided that it does not pay more than $600,000 for a bus and not more than $5/kg for hydrogen, and that the various technical parameters are met. International funding bodies and the suppliers themselves would then be responsible for achieving the cost reduction.

2 Another mechanism to ensure cost reduction would be to agree on a price for all 500 vehicles (or components) at the start of the 2010–2015 procurement framework. This price would lock in the future cost reduction, but would be higher than the predicted costs for the technology at the end of the procurement. The diagram below illustrates this principle:



A deal of this type would require significant legal effort to ensure that suppliers were content that the buses ordered for the latter stages would materialise and also to ensure that the performance requirements were actually met by industry. In the Industry Dialogue, a number of supply chain companies expressed a willingness to sign up to a deal of this type.

3 Another option might be to enter some form of reward framework with suppliers, where the high capital costs of initial vehicle procurement at the start of the period are repaid on order of larger numbers of vehicles towards the end of the procurement period.

A number of other mechanisms could also be available, including Forward Procurement Commitments (committing to procure at specific cost and volume levels), or a large state-sponsored funding program (e.g. from the European Investment Bank), with costs agreed up front.

The Industry Dialogue did not produce great insight into the types of procurement mechanism most appropriate to industry, apart from welcoming the concept of an ongoing commitment to procure vehicles. It will therefore also be necessary to consult with industry on the procurement mechanisms most appropriate and feasible for them.

Question: what mechanisms can industry stakeholders suggest to ensure cost reduction in a large-scale procurement of this type?

9.5 Infrastructure procurement

For infrastructure, there appears to be limited benefit to a common procurement program. Rather individual cities and regions will need to develop plans which centralise hydrogen bus deployment in hydrogen depots with large filling systems (ideally over 50 buses per day). The main benefit within the Alliance will be in sharing data on the different approaches and in attempting to ensure technical and practical lessons learnt are shared.

Question: do industry stakeholders agree with the above statement on infrastructure supply and the benefits of aggregated procurement?

9.6 Is the alliance the right mechanism for a procurement framework?

The Industry Dialogue responses were very positive about the potential of the Bus Alliance to achieve a material impact on hydrogen bus commercialisation. It is clear that many members of the hydrogen bus industry see aggregated and long-term demand as key to achieving bus commercialisation. The Alliance therefore appears to be a useful starting point, given the presence of a large number of committed customers.

Currently the Bus Alliance does not have the resource or the legal stature to establish a genuine procurement framework. Substantial work would be required to establish an appropriate structure to allow the Alliance cities and regions to act as a united group. The Alliance therefore needs to understand that in working as an Alliance there is the potential for material impact on hydrogen bus commercialisation to justify this effort.

Question: do industry stakeholders believe that the co-ordinated approach to procurement justifies the end (i.e. will material cost reductions be accelerated through this type of activity)? If so, are the cost numbers in this document plausible?

Question: what scale of demand is appropriate for this type of activity? Does the Alliance need to focus on expanding membership to add value to an initiative of this type?

Questions: do industry stakeholders believe the Alliance is the most appropriate mechanism for a procurement of this type? Are other international entities available which would be more appropriate?