DRAFT

LowCVP Bus Working Group

Low Carbon Bus Technologies

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1. Introduction

This document outlines the available technologies to proceed towards low carbon buses for delivery of the UK Government target of 600 new buses p.a. in 2012. Note that the LowCVP Bus Working Group
A 30% lower GHG is required relative to a standard Euro 3 diesel bus. The LowCVP Bus WG have derived a characteristic GHG level for a wide range of vehicle inertias.
Table 1 summarises the main features of each system. Table 2 summarises progress in introduction of the technologies to the UK and potential suppliers.
The following have been tracked:

- Capital cost premium relative to the standard diesel vehicle
- Fuelling infrastructure cost premium
- Government incentives
- Vehicle on-board fuel storage
- Fuel renewability
- Energy efficiency
- Barriers
- Emissions
  - NOx
  - Particle mass
  - Particle number
  - Noise, vibration & harshness

2. Technologies

2.1 Battery-electric

- Only qualifies as a low carbon bus if charging electricity is renewable
  - Policy issue regarding use of renewable electricity for transport
  - Fuel 100% renewable
  - Very cheap fuel – even in competition with duty rebated ULSD
- Highly energy efficient
- Difficulty to operate large fleet re-charging systems (space and time)
- Bus stop inductive systems costly infrastructure and difficult to operate due to alignment requirements and stopping time
- Typically range is not suitable in competition with standard diesel for most routes unless battery packs are exchanged with consequent delays plus additional batteries costs
- Permanently in zero emission mode
- Battery replacement intervals and cost at issue
- NVH better than diesel

2.2 Diesel-electric

- Early examples are achieving target 30% CO_2 saving
- Fuel saving terrain dependent – each route may need optimisation of control strategy
- Economics affected by BSOG with very late break-even date due to high capex and battery replacement costs
- Uncertainty regarding battery life in service

- Possible zero emission mode for inner city
- Retains existing fuelling infrastructure
- NVH better than standard diesel
- Several vehicles already in service in UK

2.3 Bio-gas

- Use of bio-gas from natural sources in combustion saves escape of methane to atmosphere (21 times worse than CO2 as GHG)
- Application to buses affected by the following:
  - BSOG makes diesel relatively cheap
    - Fuel duty zero tax rated for bus operation
    - Rising natural gas prices currently may affect economics further
  - High capex
  - High cost of fuelling infrastructure
    - Limited grant support from UK Government through EST
  - Difficulty in application to low floor double decker
    - Location of tanks
    - Loss of seats
  - Lack of vehicles in UK
- Loss of energy due to compression to 250 bar circa 6%
- Liquefaction process loses circa 12% of energy
  - Loss of fuel due to boil-off if vehicle unused
- Spark ignition gas engines NVH better than diesel

2.4 Bio-diesel

- Barrier caused by high price of quality product c.f. ULSD
- Reluctance of OEMs to allow greater than 5% blend with ULSD due to history of problems with low quality fuel
- Limitations in potential supply
  - UK derived RME maximum of 5% of total ULSD consumption
- Note that approximately 12 buses running on 5% bio-diesel / 95% ULSD blend would be the equivalent of a single low carbon bus (30% GHG overall saving)
- Bio-diesel now qualifies for BSOG
- NVH same as standard diesel

2.5 Bio-ethanol

- May be used with a cetane improver in modified diesel engines
- Liquid fuel with ease of adaptation to existing bus types and re-fuelling infrastructure
- Etamax D fuel is 53.5% renewable (92% ethanol by mass)
  - There may also be a small CO2 improvement at tailpipe compared to standard diesel
- NOx & Pm are similar to diesel with full SCR + Pm trap aftertreatment
- Fleet running in Sweden with possible expansion into other parts of Europe
  - Total lifetime cost competitive to diesel under Swedish fiscal regulations and current fuel costs
- Fuel may be made in UK from sugar beet
  - Flexible fuel car announced by Ford in UK could lead to establishment of fuelling infrastructure and supply
- Not currently within BSOG but attracts 20p / litre fuel duty differential but uses circa 60% more litres than equivalent diesel
- NVH similar to standard diesel

2.6 Energy storage systems

- Difficult to envisage 30% fuel saving from use of, say, flywheel technology but could be used in combination with other technologies

- Possible zero emission mode for inner city
- Potential NVH improvements according to technology

2.7 Vehicle structures & weight saving

- Extremely difficult to envisage that this approach in itself could supply 30% fuel consumption saving but may be used in conjunction with the other technologies
- Possible approaches include:
    - Aluminium chassis – note that primary aluminium has large CO_2 overhead
    - Low rolling resistance tyres
    - Engine downsizing
        - Lower weight
        - Lower friction
- NVH similar to standard diesel

2.8 Hydrogen

2.8.1 General issues

- Similar problems in application to vehicle as bio-gas with regard to location and weight of fuel tanks
- Requires very high cylinder pressures (c 700b) to achieve reasonable range
    - The compression energy loss alone would be 13%
    - Such high H_2 gas pressures present significant sealing problems
- Liquefied hydrogen loses some 30% energy in the liquefaction process alone
    - Loss of fuel due to boil-off if vehicle unused
- Fuelling infrastructure is very expensive but there are limited Government grants now available through EST
- Vehicles permanently in zero emission mode
- Source of hydrogen important but since tailpipe CO_2 is zero all types would qualify as a low carbon bus
- Hydrogen zero fuel duty tax rated
- Difficulty in application to low floor double decker
    - Location of tanks
    - Loss of seats

2.8.2 H2ICE

- Engine technology based on that of CH_4 types
- Poor efficiency with relatively high NO_x due to hot running
- Spark ignition gas engines NVH better than diesel
- Examples running in Berlin

2.8.3 H2FC

- Currently very high capex
- PEM fuel cell may need replacement in life of bus adding to overall costs
- CUTE vehicle 3 tonnes heavier than diesel Citaro equivalent contributing to poor overall efficiency compared to diesel
- 3 buses running in London

Table 1   Bus Low Carbon Technology - Summary

Technology	Capital cost premium	Fuelling infrastructure cost premium	Government incentives	Fuel on-board storage	Fuel renewability	Energy efficiency relative to standard diesel E3 bus	Barriers	Emissions relative to diesel with SCR & Pm trap aftertreatment
Battery-electric	£35k		VED = zero Infrastructure grants Fuel duty = zero	Batteries	100%	Much better	Range	NOx=zero Pm=zero Particle no.= zero NVH=better
Diesel-electric	£60k - £90k	zero	Fuel duty = - 80%	ULSD + batteries	None	+ 30%	Capex BSOG	NOx=same Pm=same Particle no.= same (with aftertreatment) NVH=better Zero emission mode possible
Bio-gas	£30k	£250k - £500k	Fuel duty = zero Infrastructure grants	Compressed = 200b/250b Liquefied = - 162 C		Worse	Capex BSOG Fuel cost Tank installation on DDs No CH4 bus supply in UK	NOx=same Pm=same Particle no.= much higher NVH=better
Bio-diesel	None	None	Fuel duty = - 80%	as ULSD	c 50%	Same	OEM 5% blend limit Fuel cost	NOx=same Pm=same Particle no.= same NVH=same
Bio-ethanol		None	Fuel duty = - 48% Infrastructure grants	as ULSD	c 50% EtamaxD=53.5%	Much worse	Capex BSOG Fuel cost	NOx=same Pm=slight increase Particle no.= much higher NVH=same
Energy storage systems			None	ULSD	None	Much better		
Vehicle structures & weight saving			None	ULSD	None	Better		NOx=better Pm=better Particle no.= same NVH=same
H2ICE	£40k	£3000k - £600k	Fuel duty = zero Infrastructure grants	CH2 = 350b now 700b later LH2 = - 253 C	0% to 100% according to source & process but zero CO2 at tailpipe	Much worse	Capex BSOG Fuel cost Range Tank installation on DDs	NOx=higher Pm=lower Particle no.= higher? NVH=better
H2FC	£200k++	£300k - £600k	Fuel duty = zero Infrastructure grants	CH2 = 350b now 700b later LH2 = - 253 C	0% to 100% according to source & process but zero CO2 at tailpipe	Much worse CUTE = - 55%	Capex BSOG Fuel cost Range Tank installation on DDs	NOx=zero Pm=zero Particle no.= zero NVH=much better

Table 2 Bus Low Carbon Technology – UK Progress

Technology	Supplier	Number in service	Locations	GHG saving p.a. tonnes
Battery-electric				
Diesel-electric	ENECO / Optare WrightBus Designline Volvo ADL	10 6	Merseyside, Manchester, Bristol, London London	
Bio-gas				
Bio-diesel	Greenergy Green Spirit Fuels Rix			
Bio-ethanol	Scania			
Energy storage systems	ZF Torotrak			
Vehicle structures & weight saving				
H2ICE	MAN			
H2FC	DaimlerChrysler	3	London	

3. Further work

- Update of Table 2. – progress of low carbon technologies in UK
- Whole life cost of operation for each technology with determination of break-even timescale if applicable
- Whole life cycle GHG audit for each technology including energy efficiency

4. References

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4. European Well-to-Wheel Study – CONCAWE & Eucar & EC JRC - 2003
5. Well- to- Wheel Okologische und Okonomische Bewertung von Fahrzeugkrafstoffen und antrieben – Schindler & Weindorf (L-B Systemtechnik) – 2003
6. Well-to-Wheels Evaluation of production of Ethanol Wheat – FWG-P-04-024 - 2005
7. Swedish Ethanol Bus Consortium (various documents)
8. CUTE H2FC Bus Technical Overview – DaimlerChrysler - 2003
9. Fiscal Incentives for Bus Operators – David Martin (Ecovector Consulting) – BWG-P-05-13 – 2005