LOW-ZERO EMISSION BUS TECHNOLOGIES IN URBAN CENTRES IN SCOTLAND

Kirsty Davison, Judith Thomson
Steer Davies Gleave

INTRODUCTION

Air pollution can have serious implications for human health, plant and animal life, and materials and structures. In both developed and rapidly industrialising countries, the major historic air pollution problems have been created by high levels of smoke arising from the combustion of fossil fuels such as coal for domestic and industrial purposes. Today, traffic emissions pose a significant threat to clean air, both in terms of the pollutants they produce and the volume in which they are emitted.

Petrol and diesel-engine motor vehicles emit a wide variety of pollutants, principally carbon monoxide (CO), oxides of nitrogen (NOx), volatile organic compounds (VOCs) and particulates (PM_{10}), which have an increasing impact on urban air quality. Carbon Dioxide (CO_2) is also produced as a by-product of combustion in a vehicular engine, and whilst CO, NOx and VOCs also directly or indirectly contribute to global warming, CO_2 has the greatest global warming potential from vehicle exhausts.

Whilst buses provide the main mode of public transport across the west of Scotland, the variation in the age and profile of fleets in operation means they are a large emitter of local and global air pollutants. Exhaust emissions are directly related to the operation of the engine: the fuel type, temperature of combustion and engine efficiency largely dictate the type of emissions produced, whilst slow speeds and idling engines generate the by-products of incomplete combustion and are generally more deleterious to human health. Buses however, by providing an efficient alternative to car travel in terms of passenger volumes, and by using the latest technology diesel engines and alternative fuel technologies can also contribute to air quality improvement objectives.

In conjunction with a growing acceptance that climate change is emerging as one of the greatest challenges for modern society and that the world will soon experience a peak in its oil production, the motivation for lower emission vehicles and alternative fuel technologies has never been stronger.

In relation to the above, a feasibility study of hybrid and low to zero emission buses was undertaken to minimise the impact of bus exhaust emissions on human health and the environment within the Glasgow City Centre Air Quality Management Area (AQMA). The study also considered the implications of hybrid/ low emission bus operations within the wider Glasgow conurbation.
This paper summarises some of the results of analysis and appraisal of the hybrid, electric, hydrogen and biodiesel bus technologies. It aims to provide an overview of low emission vehicle technologies, how suitable each

technology is for use within Glasgow City Centre and how the developed methodolgy lends itself to the wider application of assessment for other urban centres in Scotland.

METHODS

A data gathering and collection exercise was undertaken: comprising a literature review and interviews with relevant industry stakeholders. The literature review addressed the following subjects: policy framework; study context (an overview of the operating conditions within Glasgow City Centre as well as any other regulatory conditions and/ or constraints); hybrid buses; electric buses; hydrogen buses; and biodiesel-fuelled buses.

Interviews with the relevant industry stakeholders allowed evaluation and qualification of the data obtained in the literature review and provided insight to the key benefits and challenges of the various alternatively fuelled vehicle types.

Vehicle technologies were considered in terms of their operational, maintenance and infrastructure requirements as well as the environment and terrain within which the buses would operate. Consideration was also given to emissions both at the point of source and the point of use.

A full strengths, weaknesses, opportunities and threats (SWOT) analysis was undertaken of each of the vehicle types considered in the study. The SWOT analysis, in conjunction with the literature review and stakeholder experience was used to undertake a Vehicle Analysis and Evaluation. This evaluates the various vehicle technologies explored in the study against a range of comparable characteristics within the following key operational categories:

- Fuel;
- Operability Requirements;
- Emissions; and
- Cost.

A copy of the Vehicle Analysis and Evaluation can be obtained from the author or SPT.

RISKS AND CONSTRAINTS

Interviews and discussions with key and industry stakeholders were undertaken on a confidential basis, due to the sensitivities of commercial operations and industry competition. Certain details of the study, therefore, cannot be made publicly available.

A key risk associated with the data presented in the study is that the information provided by each bus operator/ manufacturer varied in terms of the level and type of details they were able to provide. The data was therefore comprised of analytical, technical and anecdotal information and presented accordingly.

A key factor identified, although not strictly a risk, was that many of the technologies explored are continuing to evolve at a very fast pace whilst new ones are emerging. The technology is constantly advancing and where trials are taking place, manufacturers are reviewing the findings and tweaking the technology in response. This has a bearing on the bus industry as a whole: as the technology advances and increased trials are undertaken this can give rise to new, previously undetected issues.

RESULTS AND DISCUSSION

The results of the discussions/ interviews and experiences relayed by the industry stakeholders are relatively consistent with the data published and printed on hybrid and low emission vehicle technologies. That said, there are marked differences in the preferences of various operators and manufacturers with the exception of hydrogen fuelled vehicles, which are not generally considered to be commercially or practicably viable for a number of years.

The following paragraphs summarise some of the key findings of the study in relation to each of the low emission bus technologies considered. As described above, a constraint of the study was the use of commercially sensitive data and therefore the findings below present the authors synopsis of each low emission vehicle technology in light of both published and anecdotal stakeholder interviews.

Hybrid buses

Hybrid buses are a relatively new technology, however, a number of trials have been undertaken by leading manufacturers in the industry including Wrightbus, Alexander Dennis Ltd, Volvo and Allied.

Hybrid buses run in a similar manner to conventional buses, using an internal combustion engine in conjunction with an electric battery. This provides a decrease in diesel fuel costs as well as lower exhaust emissions with no additional infrastructure costs and, as yet, there are no significant extra maintenance costs identified. Hybrid buses are generally cheaper, lighter, have relatively low maintenance and a good operating range in comparison to other low emission vehicles on the market. Hybrid buses are able to run in challenging terrain and although this will lead to higher fuel consumption, the use of regenerative braking can off-set some of the energy lost by storing the energy gained from braking.

Whilst hybrid buses commit to the continuing reliance on oil there are advantages to be had with advances in technology making diesel cleaner as well as the possibility of biofuel use. These could further enhance the emission reduction value of these vehicles.

Despite this, however, the electric battery needs to be changed probably at least once in the lifetime of the vehicle. There are also discrepancies in the published and printed literature on the emission reduction levels of hybrids as well as the lifetime and weight of batteries. As advances in battery technology

move towards an increased use of lithium – a non renewable mineral, extracted from the earth's surface – environmental concerns over mining and extraction will exist as does the issue of long-term viability. Additionally, the global price of oil is a factor which needs to be considered.

Hybrid buses are regarded by many of the leading bus manufacturers as the way forward for low emission technologies in the short to medium term. Trials suggest that hybrid vehicles are commercially viable whilst providing a real reduction in emissions. The debate continues between hybrid vehicle manufacturers as to the use of series and parallel hybrids. The study did not find sufficient sound evidence to comment on this, albeit selection of the drive train used should be decided when considering the specific operating requirements of each bus route.

Electric buses

Electric buses are zero emission at the point of use. They are quiet with low vibration, low fuel costs and have the potential to be zero emission at both the point of use and the point of source if renewable fuel technologies are employed. Electric buses require extra infrastructure associated with re-charging batteries. This can mean that individual buses need to be parked at re-charging stands during the night, and this can be space intensive.
Whilst electric buses may have a higher capital cost than conventional diesel electric buses they cost less to run on a day-to-day basis with the cost of recharging considered to be negligible. If the electricity is produced from renewable energy sources the fuel technology could potentially be considered as genuinely zero emission from the point of source. As the proportion of renewably sourced electricity provided to the national grid is increased, this further enhances the appeal of electric vehicles as a genuinely sustainable technology.

Electric buses require a change in their battery usually at least once throughout their lifecycle. The cost, recharging times, recharging methods and lifetime of the battery depends on the type of battery used. Additionally, the operating time and power of each bus also depends on the types of batteries used: some concerns exist over the long-term viability of the materials used to produce batteries.

Electric vehicles traditionally have a limited range and have, in the past, had issues with different types of terrain. Technology is advancing quickly, however, and these issues are now less significant than in the past. New and quicker ways to charge batteries and reduce their weight are being investigated to allow longer operating times and improved operations.

Electric buses have undergone a number of successful trials in the United States and should be considered as a commercially viable alternative to conventionally fuelled diesel buses, however, issues over batteries and recharging infrastructure need further investigation through continuing trials.

Hydrogen buses

Hydrogen is viewed as the fuel of the future with hydrogen-fuelled buses producing no vehicle emissions at the point of use. In general terms, it is considered to be a readily available fuel (depending on the source/ extraction), and is extremely efficient.

Hydrogen can be produced using renewable sources, however, the bus industry has identified that the commercial production of hydrogen from renewable sources is not readily available or practicable at the present time. The intensive energy input required to produce the presently 'available' hydrogen is particularly onerous, rendering hydrogen a fuel for consideration or trial, but not immediately viable for widespread commercial use.
The costs associated with hydrogen buses and the additional infrastructure required are extremely high in comparison to conventional diesel buses, requiring separate refuelling stations as well as new maintenance skills and safety protocols for engineers.

Whilst bus industry stakeholders have not cited the safety of hydrogen as an issue, the public perception of hydrogen as a fuel needs further consideration.
At present, hydrogen is an extremely expensive way to achieve emission reductions. It is also a technology which is in its infancy and although trials have been carried out there is a long way to go before the risks and the costs are at a level which are commensurate with the associated emission reductions.

Biodiesel buses

Biodiesel has the potential to be 100% biodegradable and non toxic. Biodiesel use is now competitive in terms of cost and availability when compared to conventional diesel and can be used in existing bus fleets with few additional maintenance tasks required. Depending on the blend, biodiesel may require some additional infrastructure associated with the storage of the fuel.

Not all biodiesels are the same. By definition, they are substitutes for fossil fuel derived diesel but production is ambiguous because it can be produced using so many different substances and sources. Whilst it may offer some emission reductions at the point of use compared to standard diesel, these are thought to be limited with regard to NOx emissions, which pose a key air quality threat. Huge debate also exists as to the emissions reductions it generates at the point of source. There is also an observed issue with the substitution of crops for food and, if mineral fertilisers (such as nitrogen produced using electric energy intensive processes) are used, then the biofuel is even less sustainable. Therefore, the source and transportation of the biodiesel needs to be given due consideration.

The point of use emission reduction claims made by biodiesel producers also differ substantially and therefore should only truly be considered on a case for case basis.

Biodiesel from local sources could end the reliance on fuel from other countries as well as utilising many waste products and locally sourced ingredients while contributing to the local economy. However, the volumes which biodiesel can be produced, distributed and stored would also have to be examined on a case for case basis given that the characteristics of the fuel are variable depending on the source.

At present biodiesel is being used successfully at different strengths in a number of large fleets at commercially competitive prices. The introduction of the Renewable Transport Fuel Obligation (RTFO) in April 2008 is expected to engender significant CO_2 savings. Whilst a low blend of 5% biodiesel will be incorporated into all standard diesel, the implications of this across the UK are significant.

VEHICLE ANALYSIS AND EVALUATION

The methodology adopted in this study can be effectively applied to other urban (and rural) environments across Scotland.

The preliminary phases of the study focused on data gathering and review of transport and planning policy, locational and geographical characteristics and area-specific bus services and operations, allowing a full appreciation of the regulatory and operational framework of buses in Glasgow City Centre.

The secondary phase of the study comprised discussions and interviews with a range of stakeholders including: Glasgow City Council; bus operators; bus manufacturers; biodiesel manufacturers/ suppliers; and environmental groups/ organisations. These discussions served to inform a knowledge base of low emission buses and determine the current and future aspirations of local and national government, and operators and manufacturers with regard to low emission buses.

Interviews with bus operators and manufacturers were used to validate the findings of the literature review. This informed a detailed SWOT analysis which comprised findings from both published technical data as well as “on-the-ground” practical experience.

The vehicle analysis and evaluation technique was a bespoke tool developed specifically to ensure that each low emission vehicle technology was appraised within the context of the key objectives of the study (health and environment improvements), within the operating characteristics and constraints specific to the Glasgow City Centre locale and comparatively to existing standard diesel buses. The key operational categories of fuel, operability requirements, emissions, and cost were disaggregated into more detailed “comparable characteristics” or parameters, which could be evaluated discretely on a cradle-to-grave basis.

The Scottish Transport Appraisal Guidance (STAG) impact “scoring” technique was adopted to evaluate the comparable characteristics for each

low emission vehicle technology. The following was used to determine the type and scale of impact:

- Positive Major 3+
- Positive Moderate 2+
- Positive Minor 1+
- Neutral 0
- Negative minor -1
- Negative moderate -2
- Negative major -3

The resultant vehicle analysis and evaluation matrix allows readers to hone-in on the parameters of interest and understand at a glance how each technology compares to others and/ or standard diesel engines. The vehicle analysis and evaluation table therefore indicates where short-falls and opportunities exist for each of the low emission technologies and how these can be used to instrument health and environmental improvements over the short, medium and longer term.

CONCLUSIONS

The study conclusions are summarised below. Further details can be obtained from the *Hybrid, Low to Zero Emissions Bus Study, 2008.*

External interventions

- SPT should work in partnership with Glasgow City Council with regard to the public transport aspects of air quality management within the City Centre;
- The feasibility study into the Low Emission Zone (LEZ) for Glasgow City Centre proposed by Glasgow City Council should consider both detailed traffic counts and source apportionment of emissions, to fully understand the key locations where buses are contributing to air quality issues and where improvements can be made;
- SPT should work in partnership with Glasgow City Council and the Traffic Commissioner to monitor the recent changes in powers afforded to the Traffic Commissioner with regard to the inclusion of environmental considerations in the licensing agreements for bus operators with a view to increasing the obligations on operators as well as considering the environmental attributes of licence agreements for taxis;

Develop an environmental strategy for buses within Glasgow

- It is recommended that SPT prioritise their objectives for buses within the short, medium and longer term and develop an environmental strategy or indeed, management plan, to instrument the actions and improvements that can best achieve those objectives;

Develop a hierarchy of intervention

- SPT should lead on the development of new and emerging technologies in relation to reducing air quality emissions within Glasgow City Centre;
- The greatest level of intervention would be to influence the route network and fleet at a grassroots level. Operators should be encouraged to acquire more hybrid vehicles. This could be undertaken in partnership with GCC and through the development of Quality Bus Partnerships which should place a higher emphasis on environmental concerns;
- Along with industry partners, SPT should lead on the potential development and introduction of *truly sustainable* 100% biodiesel, taking due cognisance of all the positive and negative aspects;
- In conjunction with industry partners, SPT should give further consideration to the merits of electric vehicles and fuel cell technologies and their potential to fulfil a discrete and particular market segment of the bus industry, within a holistic approach to achieving improved air quality. This may take the form of SPT being involved in and/ or supporting further research into battery technologies or, for example, a pilot scheme for hydrogen technology; and

Adopt a holistic approach with regard to development, the environment and bus operations in the City

- SPT should work in partnership with key stakeholders involved in the development of Glasgow City Centre to ensure efficient and environmentally sound bus operations through the City. Development aspirations for the City should incorporate the use of low emission buses wherever practicable to do so, to achieve improved accessibility, sustainability and improved health and quality of life objectives.

PROGRESS

As a result of the study, SPT:

- Has funded the conversion of two serial diesel electric hybrid buses to undertake extensive trials under full operational conditions while under contract to SPT;
- Are awaiting delivery of a new Mobile Travel Centre which provides vital access to travel information to remote communities. The vehicle is based on a low floor bus chassis and is powered by a serial diesel electric hybrid power pack;
- Are currently conducting intense trials on two fully battery powered vehicles. One is a van-based vehicle being used by the bus stop maintenance support team, thereby robustly testing intense start/ stop city operations. The other is based on a mini-bus, amongst its uses of which includes the positioning of survey and regulation staff on longer journeys throughout the SPT area, to test durability of the battery solution; and

- Has begun discussions with a technology supplier and a number of chassis manufacturers to research a unique and innovative complete supply chain solution for hydrogen powered buses.

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REFERENCES

Hybrid, Low to Zero Emissions Bus Study (2008), Steer Davies Gleave