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Fuel trends in route buses; the impact on vehicle package design

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Abstract

This research reviews fuel trends in current route buses by examining the state-of-the-art development for five alternatives to diesel fuel and subsequent impact on vehicle package design. Natural gas (NG), fuel ethanol (FE), hydrogen fuel cell (FC), hybrid electric vehicle (HEV), and electric vehicle (EV) systems are considered.

The review covers availability, sustainability, system complexity, and local emissions produced during operation. Each fuel system is evaluated with a focus on design opportunities offered to route buses operating on Australian roads. Hydrogen fuel cell and electric vehicle systems display suitable characteristics for route bus operation; zero local emissions produced during operation and capability for energy capture through regenerative braking. However FC systems are a difficult investment for Australian operators due to their associated cost and complexity. Thus, EV systems display the greatest potential benefit to route buses operating in Australia and encourage further exploration through vehicle package design.

Discussion is formed around a knowledge gap identified within current fuel trials, which are applied by way of a retrofit approach over existing diesel vehicle package. Further exploration into potentials of an EV system requires the application of a ground-up approach for designing, testing and refining an EV-centred route bus vehicle package. The research concludes by proposing potential areas of exploration when applying a ground-up approach to an EV vehicle package including saloon floor height, saloon ceiling height, vehicle roof height, arrangement of doors and modularity throughout the vehicle.

1. Introduction

1.1 Route buses

Since the introduction of the first Omnibus in the mid 1820s route buses have remained an important part of many public transport systems around the world, providing a cost effective alternative to private motor vehicles. Sharing a fuel history with the automobile, the progression of the route bus vehicle package is closely linked to the development of the internal combustion engine (ICE). This relationship has allowed route buses to operate independent from costly infrastructure, such as rail networks, providing service to areas, which are neglected by other forms of public transport. As a result many Australians rely on route buses for commuting to and from work, accessing events and connecting to rail networks.

The route buses relationship with ICEs has also proven to be a double-edged sword. On the one hand it has allowed vehicles to operate long hours in daily service without the need for re-fueling and on the other it has created a strong dependency on the fuel system, limiting evolution of vehicle package design. From the invention of a bus dedicated chassis in 1920s (Miller 1941) to the introduction of a low floor area at the

front of modern day route buses there has been very little progress in the design of a route bus vehicle package. This lack of progress can be attributed to the order in which bus vehicles are constructed. Starting with a rolling chassis - designed to suit an ICE - the floor, framework and body panels are then designed and assembled subsequently determining the vehicle length, width and floor height. Proving successful over decades of application, there has been little motivation for revision of this process. As a result any new additions to a route bus vehicle package have been largely implemented through a retrofit approach rather than a dedicated ground-up design.

1.2 Emerging trends in alternative fuels

Recent increases in diesel fuel price, threats on the longevity of oil supply (Association for the Study of Peak Oil and Gas (ASPO) 2009; Moriarty & Honnery 2011) and growing emissions reduction targets (An et al. 2007), have all contributed to exploration of new fuel sources for automotive application. Coupled with an ambitious goal of zero local emissions becoming a topic of discussion, research and development across many transport sectors. Public transport operators have also begun to reassess their vehicle fleet and the fuel systems. As route buses regularly operate in metropolitan environments with frequent braking and roadside stops, local emissions become a particularly important consideration raising concerns over negative health affects for passengers and pedestrians from current diesel ICEs (Schimek 2001).

Very few alternative fuels – that is to say alternative to diesel - have become a commercial reality and even less have gained significant acceptance amongst the route bus industry. This is attributed to a number of issues surrounding alternative fuels, namely financial investment into a new system; lack of established infrastructure and training; lack of refinement and readiness for commercialisation; additional weight associated with emerging systems; access to fuel sources and the resulting price of fuel. As many countries now seek to shed their dependence on fossil fuel and its associated price tag, alternative fuels have seen a resurgence of interest. With large investments into research assisting the advancement of diesel alternatives and helping to refine their associated energy harvesting methods, a point has been reached where real world field trials are currently underway with the aim of commercialisation. Route buses provide an ideal platform for testing alternative fuel systems (Schimek 2001) as they are centrally fuelled at a depot and regularly serviced in order to maintain operational standards, allowing for a high level of control and observation over the vehicle.

Recent progress has made numerous alternative fuels available to the transport industry, though not all have the performance characteristics required for route bus operation. Suitability of fuel systems is assessed on the basis of a fuels availability, sustainability, system maturity and reliability. With alternative fuel systems currently being explored by most major companies within both public and private transport industries, this paper reviews literature on alternative fuel trends evident in bus design focusing on the potentials for route buses to evaluate and refine alternative fuels. Considering five of the more promising alternative fuels to have been explored within the route bus industry, a prediction is forecast regarding a suitable fuel for route buses operating within Australia. Alternative fuels considered include: natural gas (NG), fuel ethanol (FE), hydrogen fuel cell (FC), hybrid electric vehicle (HEV), and electric vehicle (EV), which have all been investigated through testing and in some cases implementation in route buses around the world.

2. Fuel trends

2.1 Diesel fuel

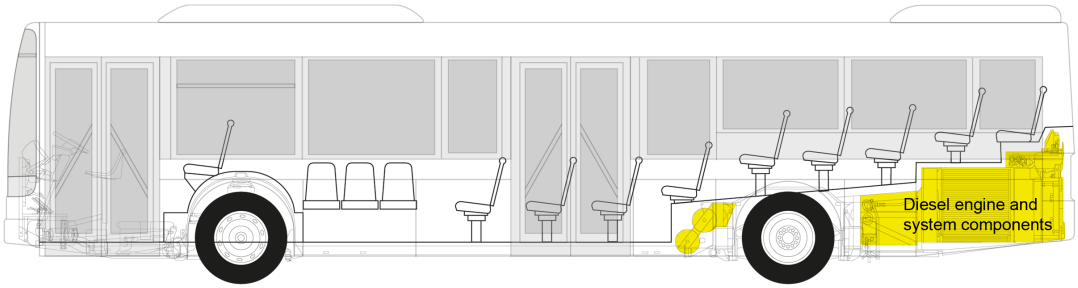
Transport systems around the world have relied heavily on fossil fuels such as diesel to provide power to ICEs in both public and private vehicles since their invention in 1885 (Black 1995; Høyer 2008). Common use and market dependency have allowed the diesel ICE to mature and secure a strong market position, thus making it difficult for emerging alternative fuel technologies to gain acceptance.

Global emissions standards and industry-set reduction targets have facilitated the maturity of ICEs by forcing refinement and advancement of components within the diesel system, therefore further strengthening its position in the industry. Route buses in Europe, for example, have had to conform to European emission standards since the early 1990s and have subsequently seen an improvement in emissions reduction with every new model. As the majority of Australian buses incorporate engines built by European manufacturers, we too have benefited from the enhancements in both performance and emission reduction.

Due to their maturity, reliability and market position, diesel ICE systems currently prevail as the preferred choice amongst Australian route bus operators, substantially outnumbering alternative fuel systems (Government of New South Wales 2012). This market position however comes into question as enhancements in ICE systems reach a development ceiling. ICEs will eventually be unable to meet the stringent emission reductions imposed by governing bodies and maintain development at a sufficient rate to satisfy their customers. The Intergovernmental Panel on Climate Change (IPCC) recently predicted that even with further system refinements, an ICE could never reach the emission reduction requirements for a fuel system in the year 2050 (Ueda, Hirota & Hatano 2010).

Current route bus vehicles operating on a diesel ICE system (Figure 1) are designed with low-floor or low-entry area towards the front of the vehicle for improved accessibility and a raised floor height at the rear, which is positioned directly above the diesel engine and associated system components. Examples of stepless vehicles with entirely low-floor down the centre aisle are common across Europe, however the majority of route buses in Australia still incorporate a raised floor height beyond the rear doors based on the strong influence of a diesel ICE system over vehicle package design. As the Australian Design Rules (ADRs) state a minimum head clearance of 1800mm through the centre of a vehicle (Department of Infrastructure and Transport 2012), ceiling height and subsequent roof height of a route bus are also determined by the current fuel system leaving very little room for change. A majority of diesel system components are located at the rear of the vehicle, which places extra mass on the rear axle, requiring dual wheels and localised reinforcement of the chassis.

Figure 1: Diesel fuel system



2.2 Natural gas

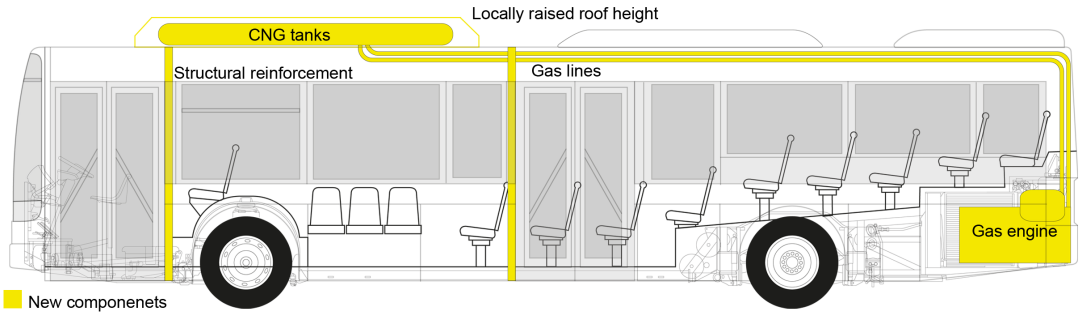
Natural gas systems are well-established in the transport industry and are commonly stored in tanks as compressed natural gas (CNG) on route buses. With numerous manufacturers supplying a variety of components, CNG systems have become a common, commercially viable alternative to diesel fuel systems in Australia. Natural gas has proven benefits over diesel both financially with lower operating costs (McKenzie & Durango-Cohen 2012) and environmentally through reducing green house gas (GHG) emissions by 80% and sulphur oxides by 40% (Barbosa 2011). As CNG systems use an ICE, they require little training for operation and servicing, thus reducing some of the costs associated with converting to a new system. The NSW State Transit Authority (STA) and Perth Transport Authority (PTA) are Australian operators both utilising CNG systems as part of their bus fleet, which provide a common example of route buses powered by natural gas (Figure 2).

A key difference between the diesel and CNG vehicle package is in the large tanks used to contain compressed gas. As these tanks demand more space, when compared to current diesel fuel tanks, they are unable to fit within the existing vehicle package. As a result CNG tanks are mounted on top of the vehicle roof, capped by a specially designed cover, protecting them against direct sunlight and any possible damage from external elements. This retrofit solution not only increases the vehicle height, but also adds over a tonne of extra weight to a localised point on the vehicle roof, requiring reinforcement of the vertical members at the front of a bus adding further weight to the vehicle. All this added weight carries with it an impact on the number of passengers which a route bus can carry, due to the per-axle mass restrictions set by state governments (State Government of Victoria 2013).

Other problems arise when we consider the sustainability and local emissions related to the operation of CNG systems. Though readily available in Australia, natural gas is still a finite resource and is susceptible to similar peaks in production, experienced with fossil fuels, such as diesel. At current rates only 0.1% of the world's natural gas is used to power transport (Botkin 2010), which raises concerns of supply when we consider the amount of natural gas required to power even a portion of future transport systems (Hughes & Rudolph 2011). With Botkin (2010) predicting a best-case scenario for only 80-100 years of transport use, the sustainability of natural gas becomes questionable and places CNG systems at a disadvantage. With local emissions produced during operation, higher global warning potential (GWP) when compared to diesel (Ally & Pryor 2007) and around one tonne of extra-added weight, CNG systems are unlikely candidates for providing a long-term fuel solution for the route bus industry.

In response to the finite nature of natural gas, research is being conducted into the substitution of natural gas with biogas for current CNG systems, thus providing a more sustainable fuel solution. Norway, for example, extracts bio-methane from the Bekkelaget sewage treatment plant in Oslo and uses it to power the city's buses (Johansen 2009). As the methane would otherwise be burnt off by the Bekkelaget plant, this bio-methane fuel is seen as not only neutral in its emissions but also as the answer to a problem which the city currently faces in regards to sewage related pollution. Proving successful, the system is able to power eighty CNG-fitted MAN buses operating in the city of Oslo. With goals now set for converting the remainder of the city fleet in coming years (Johansen 2009), the Oslo case study is a successful example of a locally designed sustainable system as it addresses population density and waste management problems specific to the region. However this system relies on a specific set of circumstances and would not be as viable in cities without similar waste management issues to Oslo.

Figure 2: Compressed natural gas system



2.3 Fuel Ethanol

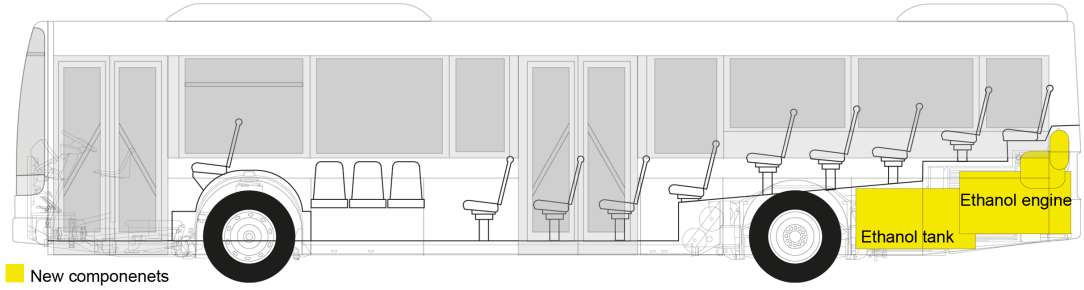
Fuel Ethanol is one of the earliest fuels in the transport industry and has been the subject of exploration since the late 1800s when alcohol fuel was tested to power vehicles after concern rose in Europe over the petroleum supply (Goettemoeller & Goettemoeller 2007). Ethanol is created through the fermentation of plant glucose and was targeted at powering early motor vehicles like Henry Ford's Model-T (ibid). In recent years, it has regained interest within the transport industry, due to its ability to be mixed with fossil fuels allowing a reduction in oil dependency. Currently Swedish bus manufacturer Scania is the largest supporter and supplier of ethanol systems (Figure 3) in the route bus industry, exporting buses to a number of countries including South America, Great Britain and Australia.

Fuel ethanol is designed for use in ICEs and as a result carries minimal impact on vehicle package design when compared to all other alternative fuel systems explored for route bus application. The fuel tank and engine of an FE system occupy the same space as current diesel systems only requiring modifications to the engine and associated system components (Barbosa 2011). This leaves little room to encourage a redesign of the vehicle package and retains current spatial inefficiencies, such as raised floor height at the rear of diesel-fueled route buses.

A large disadvantage for FE is that it requires vast amounts of food crops to be grown, harvested and to produce enough fuel necessary for satisfying demand. Currently the majority of FE production occurs in Brazil and North America with the main plant sources for the fuel being sugarcane and corn (Chiras 2010). Use of sugarcane and corn in FE production has raised concerns over the negative impacts facing manufacturing countries, with regards to food production. To address these concerns, companies such as Swedish Biofuels are investing into alternative sources for ethanol production, in hopes of making the fuel commercially viable with a sustainable long-term future. These new sources create a fuel know as cellulosic ethanol (CE), which can be created out of many organic materials including wood, algae, or grass (Goettemoeller & Goettemoeller 2007). Cellulosic ethanol is seen as a more ethical and sustainable alternative to FE as it is not a threat to food supplies in the manufacturing country.

Unfortunately, the impact on food supply is not the only obstacle facing the implementation of ethanol systems. The production of current ethanol is energy-intensive, requiring a large amount of resources for planting fuel crops and also produces tail pipe emissions including carbon monoxide (CO), carbon dioxide (CO2), volatile organic compounds (VOCs) and aldehydes, which are harmful to both the atmosphere and surrounding pedestrians. A common argument from supporters of FE is that the negative environmental impact is offset by the large amount of vegetation planted in order to produce the fuel. This vegetation would indeed offset some of the emissions on a global scale, however, with local emissions produced during operation still force pedestrians to inhale potentially dangerous substances.

Figure 3: Fuel ethanol system



2.4 Hydrogen fuel cell

First introduced into the transport industry during the 1960's by NASA, hydrogen was used as part of the energy storage system (ESS) in both the Apollo and Gemini space missions (Westbrook 2001). Hydrogen fuel is stored in fuel cells, producing electricity through a chemical reaction between the Hydrogen and Oxygen atoms (Arai et al. 2010). This electricity can then be used to power an electric motor, in turn providing power to the vehicle. The potential of hydrogen fuel has recently surfaced as the subject of investigation gaining interest from many companies across several transport sectors.

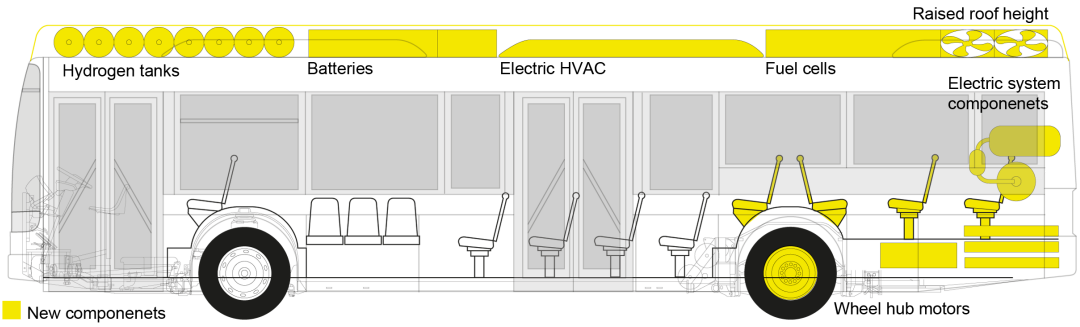
Daimler-Chrysler has been one of the largest supporters of hydrogen fuel technology, testing hydrogen-powered route buses internationally through the Clean Urban Transport for Europe (CUTE) and Sustainable Transport Energy Project (STEP) programs. These programs involve field trials of the Mercedes Benz Citaro buses, which are refitted with hydrogen FCs and tested on conventional bus routes across different cities. The results from the CUTE and STEP programs, though promising, show that hydrogen as a stand alone fuel system lacks efficiency and would require hybridisation with batteries or supercapacitors in order to take advantage of energy recovery (Haraldsson, Folkesson & Alvfors 2005). As a result, Daimler-Chrysler have redesigned their most recent hydrogen Citaro buses to be tested as part of the Sauberbus (Figure 4) trial held in Hamburg, Germany, with a hybrid system incorporating batteries for energy storage and axle motors to take advantage of regenerative braking.

Proterra, who originally began as a start up exploring hydrogen technology in buses, have also recently repurposed their ground-up hydrogen focused design to a largely EV system with hydrogen FC range extender. This results in a hybrid system combining both electric and hydrogen components with features including overhead rapid charge points, allowing for frequent charging at terminals and composite body panels, to help reduce weight by approximately 20-40% and improve the performance of the EV system (Proterra 2012a). Three Proterra buses are currently being trialed in California, USA, with positive feedback from both the passengers and Foothill Transit (Proterra 2012b).

The shear amount of system components currently required to operate a Hydrogen FC system, not only increases the price of a vehicle, but also the complexity of the vehicle package. The Sauberbus trial is able to attain a low floor area along one side of the vehicle through the use of wheel hub motors, though this still requires a corner module at the vehicles rear for the storage of system components. This infringes on interior space, detracting from the floor area for passengers. Even with this module, a majority of the system components, including hydrogen tanks, fuel cells, batteries and associated cooling systems are mounted on top of the vehicle roof (Hochbahn 2012) through a retrofit approach, in turn raising the overall vehicle height.

Seemingly ideal, the hydrogen FC system is currently inefficient and expensive, both in component and servicing costs, requiring hybridisation to improve efficiency. This hybridisation results in a heavier – largely electric – system, demanding a complex vehicle package and greater financial investment from the operator. The reality of such an investment has caused companies like Proterra to shift focus away from the development of purely hydrogen buses and onto a HEV system with hydrogen FC range extender.

Figure 4: Hydrogen fuel cell system



2.5 Hybrid Electric Vehicles

Hybrid Electric Vehicles were originally explored in the early 1900s with the launch of the Electroautomobile in France and were used as a method of extending the range of EV systems (Westbrook 2001). They failed to gain market acceptance due to their high associated cost, which remains a common problem facing current HEV systems. High cost of HEV systems can be attributed to their complexity and number of system components. Incorporating components from diesel and electric systems places a greater demand on vehicle package, bringing with it inefficiencies related to vehicle size and weight.

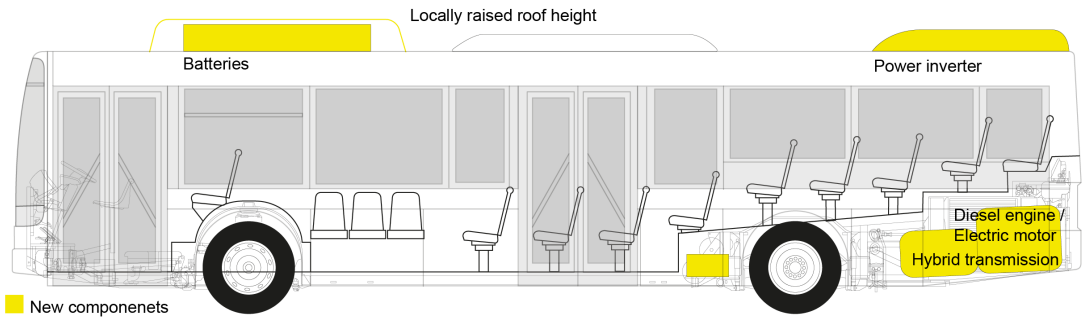
Hybrid electric vehicle systems are commonly used in route buses in either a parallel or a series arrangement, often in combination with a diesel ICE and associated diesel system architecture. They combine an electric motor and ESS – most commonly batteries - retrofitted over a modified diesel vehicle package in order to improve fuel consumption during operation. When arranged in parallel, the electric motor and ICE are able to simultaneously provide power to the wheels utilising both technologies, whereas in a series arrangement, the ICE provides power to an electric motor, which in turn powers the wheels. Hybridisation can help to improve the performance of an existing power system through the use of energy storage and recovery components such as batteries, supercapacitors and flywheels, in conjunction with an electric motor.

Both parallel and series arrangements were the subject of a recent field trial conducted by the Department of Transport Victoria in Melbourne, Australia. The trial involved two major Melbourne operators each running a bus equipped with a HEV system. Ventura tested a 42-seat, low floor DesignLine hybrid in series arrangement using two lithium-ion (Li-Ion) battery packs. Grenda tested a 44-seat, low floor Iveco-Volgren hybrid in parallel arrangement (Figure 5) using a single nickel-metal hydride (Ni-MH) battery pack. Variation between the two vehicles makes it difficult to draw an accurate comparison from this study, however, the reduction in ICE size of the series arrangement showed greater fuel efficiency potential whilst the parallel system proved more reliable with greater performance (EMC Engineering 2012).

Route buses applying HEV technology, Iveco-Volgren hybrid for example, do so by way of a retrofit approach. Retrofitting electric system components within the existing diesel architecture places greater constraints on the vehicle package design, leading

to inefficiencies. The ICE, electric motor and hybrid transmission is housed within the current engine bay area, where as the ESS, battery management system (BMS) and power inverter is stored on top of the vehicle roof. This results in a negative impact on vehicle package through design inefficiencies including; raised floor at the rear of the vehicle; greater vehicle mass due to the extra system components; and an increase in vehicle height due to the extra component storage on top of the existing roof. A retrofit approach reduces the level of training and investment in infrastructure required for a completely new system. This saves costs associated with an entirely new vehicle package, though retains design inefficiencies of a diesel fuel system, limiting the potential for emissions reduction.

Figure 5: Hybrid electric vehicle system



2.6 Electric Vehicles

Electric vehicles produce zero local emissions and have the potential to operate on electricity obtained from sustainable sources. This prospect eliminates dependence on non-renewable fuel sources answering environmental concerns related to transport industry's fuel emissions. EVs have been the subject of exploration since the late 1870's when Werner von Siemens demonstrated an electrically powered trolley in Berlin. Since then, EVs have come in and out of the development scope numerous times, most recently reappearing on the transport grid during the 1990s in answer to environmental concerns and government policies, like the "Zero Emissions" regulation passed by California in 1990 (Høyer 2008). Due to inconsistency in exploration, EV technology has not had enough time to mature, and as a result has remained costly to implement. Sony's release of a lithium-ion battery cell in the early 1990s (Thackeray, Wolverton & Isaacs 2012) combined with a recent trend in HEV exploration has once again shifted research focus over to vehicles powered by electricity leading to advances in both traction motors and ESS.

The electric vehicle industry has seen a resurgence of interest from manufacturers, with over four thousand companies producing components for EV systems in late 2010 (Harrop & Das 2011). Currently Europe, North America, Japan and China are the key manufacturing regions, holding sizable investments in the EV economy and producing a majority of the world's EV system components. This shift is also evident in the route bus industry, which has seen interest from both large manufacturers and smaller start-ups who are currently exploring EV systems and preparing vehicles to be trialed in daily operation.

Chinese manufacturer Build Your Dreams (BYD), who has recently teamed up with German manufacturer Daimler to form BYD Daimler New Technology Co. (BDNT), is supplying two EV route buses for testing through daily operation in Copenhagen, Denmark. Having commenced in 2012, this trial will run for two years and test a purely electric system in daily operation on European roads and if successful the city of Copenhagen, who has set out to be the worlds zero emissions capital by 2025 (BYD 2012), has expressed interest in converting a portion of its bus fleet to EV's

supplied by BYD. Along with this trial, the BDNT venture itself serves as an example of how new technology systems bring with them the opportunity for partnerships allowing the industry to develop and technology to mature.

Based on information obtained from Australian tender documents, operators have an expectation of route buses to perform approximately eighteen hours or 450 km's of daily operation (Government of New South Wales 2010; Government of Western Australia 2010). This requirement positions the ESS of an EV bus as a key area of interest. Batteries are the most common ESS used in EV systems and currently come with concerns regarding range limitations, short life spans and poor capacity in extreme climates. Two companies preparing to address some of these concerns are New Flyer and Mitsubishi Heavy Industries (MHI). Working together on modifying a New Flyer Xcelsior bus to a pure EV system (Figure 6), they are about to commence a two year trial in Manitoba, Canada, testing the effects of colder climates on two MHI buses and monitoring the resulting operation (Mitsubishi Heavy Industries 2012; New Flyer 2012). When complete, these tests will provide a better understanding of performance and energy losses in ESS due to low temperature extremes, helping determine component design and package requirements for colder climate operation.

Another concern of battery performance is the associated range limitation. Research conducted into frequent charging throughout operation helps to address these concerns by extending vehicle range while reducing battery size. With performance improvements predicted by Smith et al. (2011) route buses are ideally positioned to explore this potential due to their controlled route and frequent stops during operation.

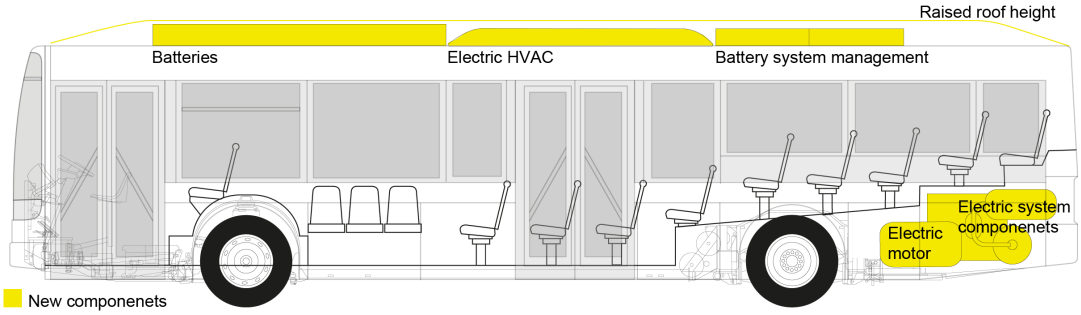
HESS recently developed a vehicle exploring frequent charging, which is based on a trolley bus vehicle package incorporating batteries and a flash-charge EV system designed by ABB. Part of the Trolleybus Optimisation Systeme Alimentation (TOSA) program in Geneva, Switzerland, this trial investigates the potential to quickly charge a vehicle battery at bus stops using a retractable roof-mounted connection, eliminating a need for overhead cables to provide constant power along a route (Gehm 2013). As trolleybuses already operate on electricity, advantages of designing the vehicle package around an electric system are apparent. Aspects such as a low floor throughout the vehicle create more space for standing passengers and improve access for persons with reduced mobility (PRM).

Solaris is another example of route bus manufacturer to explore frequent, or opportunity charging at designated bus stops along a route. Part of the Primove project, Electric Urbino buses are fitted with Bombardier's inductive charging system, also trialed on other route bus vehicles across numerous European cities (Desjardins 2013). Power is transferred to the vehicle wirelessly through a magnetic field created between primary coil buried under the road surface and secondary coil mounted underneath the vehicle floor (Bombardier 2013). This design allows for a reduction in battery size as the vehicle is constantly topping up charge during operation, leading to an overall reduction in vehicle weight and allowing for the possibility to transport extra passengers. The Primove-Urbino vehicle package is designed with roof mounted batteries and a raised interior floor height towards the vehicle rear in order to house electric motor, power receiver and associated electric system components (Bombardier 2012). A raised floor height at the rear of the vehicle limits PRM access and is similar to that of current diesel ICE route buses.

Electric vehicle bus trials are integral to the development of EV systems. As none of the aforementioned studies are a ground-up approach to an EV dedicated route bus, the impact on vehicle package remains unclear. With the exception of HESS, who designed their vehicle around a trolleybus vehicle package, other EV route buses apply electric system components over the existing diesel vehicle package through a

retrofit approach. This approach limits the potential for system performance and ignores new opportunities offered to vehicle package design.

Figure 6: Electric vehicle system



3. Discussion

Alternative fuels currently face numerous challenges, all of which must be addressed before they are able to gain market acceptance. These challenges include financial investment, access to and longevity of fuel sources, system refinement, establishment of infrastructure and training programs. In order to reduce the risk of misused financial investment, an alternative fuel must be sustainable, with assured long-term access to the fuel source. This paper had described alternative fuels available for application in route bus design, and though all show promising signs for providing a future fuel source, the majority currently face limitations preventing commercial application within the Australian route bus system.

Out of the fuels explored, only Hydrogen FC and EV systems have a capability for zero local emissions. When considering the complexity and inadequate performance of current FC systems, it is evident that hybridisation would be required to achieve satisfactory performance characteristics. Hybridisation creates a hydrogen-hybrid-electric system that is not only cost intensive but also restrictive on the vehicle package design through the amount of system components required. This hybridisation results in a system that is environmentally similar to an EV, which operates on electricity from sustainable power sources, though with the added weight of on board FCs.

Though EV systems currently display performance limitations, electricity has the potential to be generated using sustainable methods and therefore provides operators with an assured long-term fuel solution. With potential for improvement in performance, EV systems require further refinement through a dedicated vehicle package designed from the ground-up.

3.1 A ground-up approach

Consistent with other alternative fuel trials, EV route buses are designed through a retrofit approach over architecture originally intended for an ICE system powered by diesel fuel. As a result current EV bus trials store a majority of the system components on top of the vehicle roof, increasing vehicle height and ignoring design potentials offered by an EV system. Consequently the impact of EV systems on vehicle package design remains unclear.

In order to test performance capabilities of components and explore the impact on vehicle package, a ground-up approach is now required to design an EV route bus. Through a ground-up approach the vehicle package is re-evaluated and designed around an EV system allowing further advancement of EV performance and informing component selection based on operating requirements.

An EV tailored system must take into consideration all of the operational requirements, including frequency of stops, duration of service, availability for energy harvesting and storage, thus informing an ideal layout solution for all of the system components. This approach will help to produce an alternative fuel vehicle with zero local emissions and very little street level noise, something that the International Association of Public Transport (UITP) has listed as an area of design that needs to be addressed in route buses (Finn et al. 2011).

Benefits such as a reduction in system components and the flexibility of motor arrangement would allow for the design of a unique EV tailored vehicle package holding advantages over current diesel systems with regards to certain functional aspects. Such aspects include a consistent floor height throughout the vehicle, which would open up the interior space allowing for a reduction in roof height, flexibility for saloon arrangement, reduction in chassis weight, flexibility in door arrangement and the potential for modularity within the vehicle body design. Whilst low floor vehicles are common in Europe the potential package opportunities of electric systems warrant investigation to potentially improve a vehicles operation and serviceability.

4. Conclusion

Numerous challenges face the transition from current diesel systems to an alternative fuel source. Alternative fuels under consideration must be closely analysed ensuring that they have the ability to sustain a future transport industry and provide a suitable fuel system for Australian route buses.

EV systems display potential for long-term sustainability, though require further refinement before they can be widely implemented into commercial transport services. This refinement involves testing for which route buses are an ideal candidate due to their controlled routes and frequent braking during operation.

Current EV route bus trials are applied by way of a retrofit approach, which limits system performance and ignores design potentials of an EV system. A ground-up approach is required to design an EV dedicated route bus and properly explore resulting impact on vehicle package design.

5. Acknowledgments

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References

Ally, J & Pryor, T 2007, 'Life-cycle assessment of diesel, natural gas and hydrogen fuel cell bus transportation systems', *Journal of Power Sources*, vol. 170, no. 2, pp. 401-11.

An, F, Godon, D, He, H, Kodjak, D & Rutherford, D 2007, *Passenger vehicle greenhouse gas and fuel economy standards: a global update*, The International Council on Clean Transportation, USA, China, Germany.

Arai, A, Kanzaki, Y, Saito, Y, Nohara, T & Saika, T 2010, 'A Fuel-Cell Electric Vehicle with Cracking and Electrolysis of Ammonia', *SAE International*.

Association for the Study of Peak Oil and Gas (ASPO) 2009, *ASPO Newsletter No 100 May*, viewed 15th May 2012, <http://www.peakoil.net./aspo-newsletter%3E.

Barbosa, FC 2011, 'Sustainable Transit Bus Systems. A Focus on Traction Technologies', paper presented to SAE BRASIL International Congress and Exhibition, São Paulo, Brasil, <http://dx.doi.org/10.4271/2011-36-0011%3E.

Black, A 1995, *Urban mass transportation planning*, McGraw-Hill series in transportation McGraw-Hill New York, USA.

Bombardier 2012, *Primove bus: Going electric*, Bombardier, viewed 04th October 2012, <http://primove.bombardier.com/application/bus/%3E.

—— 2013, *The technology behind primove*, Bombardier, viewed 29th August 2013, <http://primove.bombardier.com/about/technical-principle/%3E.

Botkin, DB 2010, *Powering the future: A scientist's guide to energy independence*, Pearson Education Inc., New Jersey, US.

BYD 2012, *Copenhagen is introducing the first full-size pure electric buses from BYD*, viewed 26th, July 2012, <http://www.byd.com/auto/17064780.html%3E.

Chiras, D 2010, *Green transportation basics*, New society publishers, Canada.

Department of Infrastructure and Transport 2012, *Vehicle Standard (Australian Design Rule 58/00 – Requirements for Omnibuses Designed for Hire and Reward)*, Commonwealth of Australia, Australia.

Desjardins, J 2013, 'Implementation of PRIMOVE inductive charging for electric buses in passenger operation', paper presented to UITP World Congress and Mobility & City Transport Exhibition, Geneva, 26-30th May, <http://www.kpvv.nl/KpVV/KpVV-Overige-Content/KpVV-Overige-Content-Media/Bijlagen-Bijeenkomsten/UITP-2013-Pre0122-Desjardins_Jeremiepdf.pdf%3E.

EMC Engineering 2012, *Report on the outcomes of the Victorian hybrid bus trial*, Department of Transport Victoria, Australia.

Finn, B, Heddebaut, O, Kerkhof, A, Rambaud, F, Sbert-Lozano, O & Soulas, C 2011, *Buses with high level of service - fundamental characteristics and recommendations for decision-making and research*, Europe.

Gehm, R 2013, 'ABB 'flash charges' electric bus in 15 s', *SAE OHE*, no. August, pp. 12-3.

Goettemoeller, J & Goettemoeller, A 2007, *Sustainable ethanol*, Prairie Oak Publishing, Missouri, USA.

State Transit Authority 2010, *STA tender 2010/01 Volgren with Volvo*, by Government of New South Wales, Government of New South Wales.

ST Authority 2012, *Bus fleet*, by ——, vol. 2012, Government of New South Wales.

PT Authority 2010, *Supply and delivery of buses to the Public Transport Authority of Western Australia*, by Government of Western Australia, Government of Western Australia.

Haraldsson, K, Folkesson, A & Alvfors, P 2005, 'Fuel cell buses in the Stockholm CUTE project—First experiences from a climate perspective', *Journal of Power Sources*, vol. 145, no. 2, pp. 620-31.

Harrop, P & Das, R 2011, *Electric vehicles 2011-2021 cars, buses, two wheelers, industrial, commercial, mobility for disabled, military, marine, other*, IDTechEx, United Kindom.

Hochbahn 2012, *The SauberBus outlined*, Free and Hanseatic City of Hamburg, viewed 20th September 2012, <http://www.sauberbus.de/wps/wcm/connect/0ffc0700474b3efc86b7d789fcb2c1a6/111101+SauberBusDownload_final_EN.pdf?MOD=AJPERES%3E.

Høyer, KG 2008, 'The history of alternative fuels in transportation: The case of electric and hybrid cars', *Utilities Policy*, vol. 16, no. 2, pp. 63-71.

Hughes, L & Rudolph, J 2011, 'Future world oil production: growth, plateau, or peak?', *Current Opinion in Environmental Sustainability*, vol. 3, no. 4, pp. 225-34.

Johansen, OJ 2009, 'Sewage biogas fuels public transport buses in oslo', *World water and environmental engineering*, vol. 32, no. 2, March/April 2009, pp. 47-9.

McKenzie, EC & Durango-Cohen, PL 2012, 'Environmental life-cycle assessment of transit buses with alternative fuel technology', *Transportation Research Part D: Transport and Environment*, vol. 17, no. 1, pp. 39-47.

Miller, JA 1941, *Fares, please! A popular history of trolleys, horsecars, streetcars, buses, elevateds, and subways*, Dover Publications, New York, America.

Mitsubishi Heavy Industries 2012, *All-electric transit bus operational testing to begin in manitoba, canada, powered by MHI lithium-ion rechargeable batteries*, viewed 08th, July 2012, <http://www.mhi.co.jp/en/news/story/1206041542.html%3E.

Moriarty, P & Honnery, D 2011, *Rise and Fall of the Carbon Civilisation*, 1st Edition edn, Springer-Verlag London Limited, London.

New Flyer 2012, *New Flyer unveils first all-electric transit bus prototype*, viewed 08th, July 2012, <http://www.newflyer.com/index/2012_06_01_e_bus%3E.

Proterra 2012a, *About the EcoRide BE35*, viewed 08th, July 2012, <http://www.proterra.com/index.php/products/productDetail/C22/%3E.

—— 2012b, *Electric buses for big California test*, viewed 08th, July 2012, <http://www.proterra.com/index.php/mediacenter/companynews/electric_buses_for_big_california_test/%3E.

Schimek, P 2001, 'Reducing emissions from transit buses', *Regional Science and Urban Economics*, vol. 31, no. 4, pp. 433-51.

Smith, R, Shahidinejad, S, Blair, D & Bibeau, EL 2011, 'Characterization of urban commuter driving profiles to optimize battery size in light-duty plug-in electric

vehicles', *Transportation Research Part D: Transport and Environment*, vol. 16, no. 3, pp. 218-24.

V roads 2013, *Mass & dimension limits for buses*, by State Government of Victoria, vol. 2013, State Government of Victoria,.

Thackeray, MM, Wolverton, C & Isaacs, ED 2012, 'Electrical energy storage for transportation-approaching the limits of, and going beyond, lithium-ion batteries', *Energy & Environmental Science*, vol. 5, no. 7, pp. 7854-63.

Ueda, M, Hirota, T & Hatano, A 2010, 'Challenges of Widespread Marketplace Acceptance of Electric Vehicles - Towards a Zero-Emission Mobility Society', *SAE International*.

Westbrook, MH 2001, *The Electric Car: development and future of battery, hybrid and fuel-cell cars*, IET Power and Energy, The Institution of Engineering and Technology, United Kingdom.