THE FUTURE OF WELLINGTON’S BUS FLEET

The environmental and health implications of different upgrade options for Wellington’s bus fleet

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Lucia Sobiecki and Ralph Chapman
Victoria University of Wellington

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Lucia Sobiecki is a candidate for the Masters of Environmental Studies at Victoria University of Wellington.

Ralph Chapman is Associate Professor and Director of the Graduate Programme in Environmental Studies at Victoria University of Wellington [http://www.victoria.ac.nz/sgees/about/staff/ralph-chapman](http://www.victoria.ac.nz/sgees/about/staff/ralph-chapman); and a co-director of the New Zealand Centre for Sustainable Cities [http://sustainablecities.org.nz/members/ralph-chapman](http://sustainablecities.org.nz/members/ralph-chapman).
In the interests of transparency, this preface summarises a helpful exchange between Greater Wellington (Andrew Cooper, Programme Director, Bus Services Transformation) and the authors (Lucia Sobiecki & Assoc Prof Ralph Chapman) of The Future of Wellington’s Bus Fleet (‘the report’).

Events following the report being sent to the Sustainable Transport Committee of GWRC were:

- 11 May: presentation by the report’s authors to Sustainable Transport Committee of GWRC
- 17 May: Andrew Cooper (GWRC) provides letter with comment on the report
- 19-24 May: Concurrence reached on comments below, of GWRC and Sobiecki & Chapman.

Key points raised by GWRC¹, and Sobiecki and Chapman’s responses, are as follows:

1. The report’s first scenario (the ‘do nothing’ scenario) does not form part of the future view of GW. Scenario 1 is included as a do-nothing or ‘business as usual’ scenario to provide a baseline against which other scenarios may be assessed. Our report notes that although this scenario was provided by GWRC, this is not GWRC’s presently preferred scenario.

2. The report should acknowledge that trialling electric buses with the intention of adopting them is in fact GW’s strategy. This is acknowledged in Section 4.1 of the report, and by Scenario 2 (which is based on GWRC’s strategy) which shows a transition to a fully electric fleet. The report focuses on the environmental/health outcomes of different transition options to a fully electric bus fleet. Scenario 2 is compared to Scenarios 3 & 4 which involve more hybrids in the transition to fully electric. The latter involve higher costs but better environmental/health outcomes.

3. The report should acknowledge the biggest savings in CO₂ reductions come from getting people out of cars, which requires efficient public transport. We endorse this, but believe the further gains from greater use of low-carbon bus technologies should not be overlooked.

4. Buses are responsible for only ~1% of the region’s GHGs, while total transport is ~37% of the region’s GHGs. Agreed, but climate change is an urgent matter, and every 1% counts. It’s important to focus where policy decisions can have leverage: GWRC cannot persuade individual car users to cut emissions. Its focus should be where it has the most clout.

5. The report acknowledges that costs matter, but does not demonstrate or place into context the economics of the scenarios. Our report’s purpose, while recognising cost factors, was to make transparent the environmental and health dimensions of the bus upgrade options.

6. Wrightspeed, though exciting, is not a proven technology in buses. We agree and have already noted this in our report: we are working with performance claims that are as yet unproven, so there is an element of uncertainty in the profiles for Scenario 4.

7. The report refers to exemplar cities that are bigger, more polluted and have national policies / external funding to back their ambition. Wellington is small, but, as with many other cities, parts of the city centre are vulnerable to air pollution from diesel engines. Central government funding to help improve air quality and cut carbon emissions is warranted.

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¹ In shortened form except where quoted.
8. GW notes that the statement (foot p.19) of the report is in fact where GW sits –recognising both environmental, health and liveability goals and cost constraints. Yes, the question is the weight put on cost vs other factors, in choosing among bus fleet options.

9. ‘GW will be explicitly valuing the emissions profile (both greenhouse gases and harmful pollutants) of each fleet tendered in its forthcoming RFT for bus services. This will directly incentivise a lower emissions fleet and contribute to the selection of preferred tenderers. This is part of GW’s strategy that has not been acknowledged in the paper.’ We were not aware that GWRC had publicly announced this. We are delighted that this is the case.

10. Wellington’s weak road pavements constrain deployment of battery buses until batteries become significantly lighter. Replacing Euro 3 and 4 diesels with battery electrics from 2020 would constrain bus sizes and raise costs. We recognise this issue but are optimistic that an option may emerge that optimises within the weight, performance and cost constraints.

11. All gains after the 2018 replacement of old diesels are ‘moderate’ but costly gains. We agree but underline the need to set out explicitly the options’ environmental/health effects.

12. The report works off limited data on emissions of high capacity buses: GW can assist on this. We do not have the resources to further extend the report’s analysis but would strongly encourage GWRC to publish data on the emissions impacts of using high capacity buses.

13. The report relies (in places) on data from the published PwC report but more up to date data are now available e.g. COPERT data on bus emissions. Our report worked off the most recent data available from GWRC in January 2016. We would encourage GWRC to rapidly publish updates on bus emissions (including fleet implications) so that public understanding of environmental and health effects can be as informed as possible.

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The Greater Wellington Regional Council (GWRC) sets the direction for public transport in the Wellington region. The GWRC aims to increase public transport patronage in Wellington through a number of improvements to the network, including introducing a new bus network and Bus Rapid Transit in Wellington city, and upgrading Wellington’s bus fleet. The GWRC contracts bus operators to run the bus services in the Wellington region on its behalf. The GWRC does not own the buses, and therefore its role is to set expectations and conditions for the bus fleet, and ‘compensate’ bus operators for their capital investment. The type of bus used to upgrade Wellington’s bus fleet will influence Wellington’s GHG emissions, air quality and noise levels in the city. These are all important factors to take into account when considering the desirability of Wellington’s urban centre as a place to live and work. The GWRC’s strategy for upgrading Wellington’s bus fleet sends an important message regarding the council’s commitment to mitigating climate change and its concern for public health, and it should, among other things, be consistent with the GWRC’s climate change commitment to ‘act to reduce GHG emissions across all its areas of influence’ (GWRC, 2015a).

This report first provides a brief picture of the bus fleet strategies that have been adopted by a range of leading international cities, which are already trialling or adopting clean bus technologies. These cities are implementing ambitious plans to clean up their bus fleets in response to increasingly stringent GHG emission reduction and air quality targets. Well ahead of Wellington, some of these cities are already trialling battery electric buses and operating sizeable hybrid bus fleets. Wellington can learn from these cities if it wants to be an internationally competitive, progressive and sustainable city.

This report goes on to discuss a range of bus technologies that could be used in Wellington. This includes modern diesel buses, biofuel buses, hybrid technologies, hydrogen fuel cell buses, trolley buses and battery electric buses. There is a strong case from a health and environmental perspective, for Wellington to aim to have a fully electric bus fleet in the future. This would reduce Wellington’s GHG emissions, improve air quality, reduce noise pollution and positively influence the liveability of the city and the health and wellbeing of Wellington’s citizens.

This report compares the GWRC’s current bus replacement strategy with a number of other upgrade options, including a scenario incorporating Wrightspeed hybrid technology. The GWRC’s current strategy is not ambitious. It is particularly concerning that the GWRC plans on replacing the oldest diesel buses and the trolley buses in the fleet with modern diesel buses, with the exception of 10 hybrid diesel-electric buses. The GWRC has not given an explicit date for Wellington’s bus fleet being fully electric. This could mean that it is a long time before significant emission reductions are made, adversely affecting Wellington’s ability to meet its climate mitigation targets and air quality in the city.

The GWRC could have a far more ambitious strategy. The GWRC’s earlier plan to replace all of the oldest diesel buses and trolley buses with hybrid buses would be a considerable improvement on their current strategy. They could also be trialling battery electric buses with the intention of adopting them as soon as possible. The GWRC’s strategy needs to be not only economical but also give proper consideration to the impact Wellington’s bus fleet will have on public health, the environment, and Wellington’s liveability and image as a progressive, sustainable city.
1. INTRODUCTION

Climate change is unequivocally being driven by human activities. The Intergovernmental Panel on Climate Change (IPCC) has stated that the “continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems” (IPCC, 2014a, p. 56). The reduction of greenhouse gas (GHG) emissions is vital for mitigating the impacts of climate change. In 2010, transport was responsible for approximately 23 percent of total energy-related global carbon dioxide ($CO_2$) emissions (IPCC, 2014b). The transport sector is therefore a key area of focus for climate mitigation.

Transport is also a major source of air pollution in urban centres. Air pollution is a significant health issue in many cities around the world. It increases the risk of stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases (World Health Organization, 2014). The World Health Organization (WHO) has estimated that outdoor air pollution caused 3.7 million premature deaths worldwide in 2012 (World Health Organization, 2014). There is growing evidence that air pollution contributes to an even more diverse set of diseases. For example, a recent study by Margolis et al. has shown that prenatal exposure to air pollution can lead to behavioural problems in children (Margolis et al., 2016). Reducing local harmful emissions from the transport sector is vital for improving air quality and public health.

Encouraging people to leave their cars at home in favour of taking public transport is a significant way of lowering GHG emissions and reducing air pollution. These benefits can be both direct and indirect, as public transport quality can influence urban development patterns (Bailey, Mokhtarian, & Little, 2008; Litman, 2011). To encourage more people to use them requires public transport systems to be efficient. An efficient public transport system can not only reduce transport emissions and improve air quality but can also alleviate traffic congestion, decrease the number of road accidents, reduce energy consumption and dependence on oil, and reduce noise pollution. Further, cities can also make themselves more desirable, resilient and internationally competitive as places to live and work by providing an efficient public transport network.

While public transport is less carbon-intensive than car travel, it can also be a significant source of GHG emissions and air pollution. The majority of the world’s bus fleets still operate using fossil fuels and therefore contribute a considerable amount to GHG emissions. These buses are also a significant source of air pollution, particularly in urban centres where they operate in higher concentrations. City authorities have the power to reduce GHG emissions and improve air quality through incorporating low and zero emission buses into city fleets. The adoption of innovative technologies such as hybrid, electric and hydrogen fuel cell buses shows a clear commitment to mitigating climate change and improving public health. The number of cities around the world investing in clean bus technologies is growing, with leading cities already trialling and adopting low and zero emission buses.

Transport is a major source of GHG emissions and air pollution in Wellington. The transport sector contributed approximately 37 percent of Wellington region’s total gross emissions for the 2012/2013 financial year (GWRC, 2015a). It is therefore vital that Wellington focuses on reducing transport emissions in order to mitigate climate change. While air quality is generally good in Wellington, research indicates that air quality standards are
violated in wind sheltered areas of the city which have high traffic densities and steep road gradients (Uhrner, Randal, & Howden-Chapman, 2013). As more and more people come to live in Wellington’s inner city, air quality becomes increasingly vital for both health reasons and for quality of life. By reducing local harmful emissions from the transport sector, Wellington could improve air quality, public health, and city liveability.

The Greater Wellington Regional Council (GWRC) sets the direction for public transport in the Wellington region and aims to create an efficient and reliable system that is both financially and environmentally sustainable. The GWRC is planning to increase public transport patronage through a number of improvements to Wellington’s public transport network. This includes introducing a new bus network and Bus Rapid Transit in Wellington city, and upgrading Wellington’s bus fleet (GWRC, 2014b). The GWRC contracts bus operators to run the bus services in the Wellington region on its behalf. Therefore, the GWRC sets conditions for the bus fleet that bus operators provide. The main health and environmental benefits of Wellington’s public transport network come from shifting people out of cars and onto public transport. However, the type of bus used to upgrade Wellington’s bus fleet will affect Wellington’s GHG emissions and air pollution, particularly in areas that have a high concentration of buses.

The type of bus will also affect noise levels in the city, which is important when considering the desirability of the urban centre as a place to live and work. The GWRC’s strategy for upgrading Wellington’s bus fleet sends an important message regarding the council’s commitment to sustainability, climate change mitigation and its concern for the health and wellbeing of Wellington’s citizens. It also affects Wellington’s image and whether it is considered a progressive and sustainable city – a place ‘where talent wants to live’ to paraphrase the late Sir Paul Callaghan.

This report will first provide a brief picture of the bus fleet strategies that have been adopted by international cities that are leading the clean bus revolution, and what Wellington can draw from their example. This is followed by a brief analysis of a range of bus technologies that could potentially be adopted in Wellington. Finally, this report evaluates the GWRC’s current bus replacement strategy as well as a number of other upgrade options, and offers some recommendations.

The purpose of this report is to provide the GWRC and interested members of the public with an analysis that adds to the information already available. It aims to assist the GWRC to form a strategy for upgrading Wellington’s bus fleet that is not only economical but also healthy and environmentally sustainable.
2. THE INTERNATIONAL PICTURE

2.1. INTRODUCTION

The majority of bus fleets in the world operate using diesel as it is considered affordable and reliable. However, rapidly increasing knowledge about the health and environmental impact of diesel bus emissions is leading to more and more cities investing in ‘clean’ bus technologies. In Europe 10 cities are trialling electric bus technologies as part of the Zero Emission Urban Bus System (ZeEUS) programme. This programme, which was launched by the European Commission in 2013, aims to test electric bus technologies and facilitate their market uptake in Europe (ZeEUS, 2014). Twenty-six cities around the world have signed the C40 Clean Bus Declaration, which commits them to collectively roll out over 45,000 ultra-low emission buses by 2020. These cities (including Cape Town, Buenos Aires, London, San Francisco and Seoul) represent over 165 million urban dwellers across 20 countries. The C40 Clean Bus Declaration aims to give bus manufacturers clear signals about the market potential for low and zero emission bus technologies. It calls on bus manufacturers to support city ambitions to decarbonise public transport by providing sustainable and cost effective bus options (C40 Cities Climate Leadership Group, 2015). It is clear that clean bus technologies are being increasingly taken up as cities seek to reduce their emissions and improve air quality. The following cities are examples of world leaders when it comes to the adoption of clean bus technologies. These cities have been selected based on their high level of ambition and the availability of information regarding their bus strategies.

2.2. CITIES LEADING THE CLEAN BUS REVOLUTION

LONDON

London has set a target to reduce its CO₂ emissions by 60 percent of 1990 levels by 2025 (Mayor of London, 2015). Transport accounts for 21 percent of London’s CO₂ emissions. Buses and coaches make up 6 percent of London’s transport CO₂ emissions (Transport for London, 2014). Transport is the main contributor to air pollution in the city (Mayor of London, 2010). Nearly 9,500 people die prematurely in London each year due to air pollution (Walton et al., 2015). London breached the European Union annual legal limits for nitrogen dioxide (NO₂) just one week into 2016 (Vaughan, 2016). Transport for London (TfL) manages the approximately 8,500 buses that operate in the city. TfL have retrofitted many of the buses within the fleet with technology to reduce harmful emissions, and have accelerated the roll-out of Euro VI buses, retiring the oldest, most polluting buses in the fleet (Transport for London, 2014). The fleet includes 1,300 hybrid diesel-electric buses, which is set to increase to 1,700 by the end of 2016. These hybrid buses have faced some operational issues, in particular the new Routemaster-style hybrid buses which have been criticised for operating mostly on diesel due to battery malfunctions (Booth, 2015; Edwards, 2015). TfL is also trialling the use of biodiesel on some routes, and piloting hydrogen fuel cell buses, and single and double-decker electric battery buses. There are projected to be 70 all-electric buses operating in the fleet by the end of 2016 (Transport for London, 2014). TfL have stated that by

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2 ‘Clean’ refers to bus technologies that produce low and ultra-low emissions. This includes hybrid bus technologies, fully electric buses, and buses that operate using biofuels (C40 Cities Climate Leadership Group, 2015).
2020 all 300 single-decker buses operating in central London will be zero emission (either electric or hydrogen) and all 3,000 double-decker buses will be hybrid (Transport for London, 2014). These measures are expected to significantly reduce the tail-pipe emissions of London’s bus fleet.

PARIS

Paris has set a target to reduce its GHG emissions by 30 percent of 2004 levels by 2020, and by 75 percent by 2050 (Council of Paris, 2012). Transport is a major source of GHG emissions and air pollution in Paris (Council of Paris, 2012). The public transport operator for the Paris region is the Régie Autonome des Transports Parisiens (RATP). The RATP operate 4,500 buses in the Paris region, 97 percent of which are currently diesel buses. The RATP is aiming for its entire fleet of buses to be powered by electricity and biogas by 2025. This bus fleet will be made up of approximately 80 percent battery electric buses and 20 percent biogas buses (RATP, 2014). The RATP will purchase 550 hybrid buses by mid-2016 as a transition step to a fully electric and biogas fleet. They are also currently undertaking electric bus trials and preparing their bus depots for electric buses (RATP, 2014). The RATP is planning for a major deployment of electric and biogas buses between 2017 and 2025. This strategy is expected to reduce the RATP’s carbon footprint by 50 percent, and significantly reduce air pollution in the city (RATP, 2014).

COPENHAGEN

Copenhagen aims to be the first carbon neutral capital city in the world by 2025 (The City of Copenhagen, 2012). Transport is responsible for 22 percent of the city’s total CO₂ emissions. The city operates approximately 2,000 buses, most of which are currently diesel. Copenhagen is planning on making its public transport network carbon neutral by 2025 (The City of Copenhagen, 2012). In order to meet this goal Copenhagen is introducing new biogas buses on the city’s busiest bus route. The city aims for this route to be operated solely by biogas buses by 2017 (Marsh, 2015). The city is also investigating different battery electric bus technologies, and is currently undertaking two separate battery electric bus trials to establish the most appropriate technology for the city (Rychla, 2015).

STOCKHOLM

Stockholm’s climate target is to reduce GHG emissions by 100 percent by 2040 (Stockholm Stad, 2012). The transport sector is responsible for around 40 percent of the city’s GHG emissions. Buses account for around two percent of transport GHG emissions (Stockholm Stad, 2012). Stockholm operates just over 2000 buses on its network, many of which are powered by ethanol and biogas. The city is aiming to have 75 percent of all the buses in its fleet powered by renewable fuels by the end of 2016, and 90 percent by 2020. Stockholm wants the entire bus fleet to be free from fossil fuels by 2025 (Stockholm Stad, 2012). While the city is focusing on converting more of its buses to renewable fuels, it is also currently trialling eight hybrid electric buses with quick charging stations (Vattenfall, 2014).
VANCOUVER

Vancouver is aiming to be one of the greenest cities in the world (City of Vancouver, 2015a). It wants to derive 100 percent of the energy used in the city from renewable sources by 2050, and it is aiming to reduce GHG emissions by 80 percent below 2007 levels by 2050 (City of Vancouver, 2015a). Road transport accounts for approximately 37 percent of Vancouver’s total GHG emissions (City of Vancouver, 2015b). Vancouver operates approximately 1500 buses, 262 of which are electric trolley buses and 205 diesel-electric hybrid buses. Vancouver has operated trolley buses for 60 years and they continue to play a central role in the city’s urban transit network. It is the second largest and most modern trolley bus fleet in North America, with the overhead wires spanning 315 km through Vancouver (Translink, 2016). Vancouver plans on expanding the trolley bus network and converting the remainder non-electric bus routes to other renewable fuel sources. This will not only reduce carbon emissions but will significantly improve local air quality (City of Vancouver, 2015b).

SAN FRANCISCO

San Francisco’s climate change mitigation target is to reduce emissions by 25 percent below 1990 levels by 2017, 40 percent by 2025, and 80 percent by 2050 (San Francisco Department of the Environment, 2013). Transport accounts for approximately 43 percent of San Francisco’s GHG emissions (San Francisco Department of the Environment, 2013). San Francisco is aiming to have a GHG emission free bus fleet by 2020 (San Francisco Municipal Transportation, 2013). San Francisco operates the largest trolley bus fleet in North America, with over 300 trolley buses in service, including articulated models. The city is investing in new trolley buses to replace older models. San Francisco has also converted 100 percent of its 1500 diesel buses to run on biodiesel, which is sourced from the city’s waste cooking oil. The city is replacing diesel buses with hybrid biodiesel-electric buses as a transition step to a fully electric fleet (San Francisco Department of the Environment, 2013). The city currently operates approximately 170 hybrid biodiesel-electric buses (San Francisco Municipal Transportation, 2015).

2.3. CONCLUSION

Many cities around the world are implementing ambitious plans to clean up their bus fleets in response to increasingly stringent GHG emission reduction and air quality targets. The cities discussed above are all world leaders but they are certainly not alone in their efforts to decarbonise their public transport systems. It is clear that cities that are committed to cleaning up their bus fleets are already trialling or adopting clean bus technologies, and have plans in place to further adopt these technologies as soon as possible. These cities are driving the development of clean bus technologies, helping to lower their prices and improve their reliability. The cities discussed above offer a useful model for Wellington. They are already ahead of Wellington, with for example London and San Francisco already operating sizeable hybrid bus fleets. Their goals are more ambitious, often reflecting more ambitious state or national goals. These cities have explicit strategies and they are undertaking clean bus trials with the intention of fulfilling these strategies.
Learning opportunities for Wellington arise in particular from the following:

- San Francisco – already converted its entire diesel fleet of 1500 buses to biodiesel; already operates 170 hybrid biodiesel-electric buses; aims for its entire bus fleet to be GHG emission free by 2020
- Stockholm – aims for 75 percent of its buses to operate on renewable fuels by the end of 2016
- London – already operates 1,300 hybrid diesel-electric buses; that is set to increase to 1,700 by the end of 2016; aims to have 300 zero emission buses in the fleet by 2020
- Paris – aims to include 550 hybrid buses into its fleet by mid-2016; planning a major deployment of electric and biogas buses by 2025.

While every city has particular issues and goals, Wellington can learn from these cities if it wants to be an internationally competitive, progressive and sustainable city. In particular, Wellington can consider how its level of ambition in respect to the adoption of clean bus technology compares to these world-leading cities.
3. BUS TECHNOLOGY OPTIONS FOR UPGRADING WELLINGTON’S BUS FLEET

3.1. INTRODUCTION

The GWRC sets the direction for public transport in Wellington. The main benefits of public transport come from encouraging more people to leave their cars at home and take public transport. The GWRC is planning to increase public transport patronage through a number of improvements to Wellington’s public transport network. This includes introducing a new bus network and Bus Rapid Transit (BRT) in Wellington city, and upgrading Wellington’s bus fleet (GWRC, 2014b). The GWRC has been considering its replacement strategy for both trolley buses and diesel buses in Wellington’s bus fleet in recent years. The infrastructure associated with operating Wellington’s trolley buses requires further investment if they are to be maintained as part of Wellington’s bus fleet. Many of the diesel buses in the fleet will also need to be replaced within the next 5 to 10 years (GWRC, 2014b). At time of writing, the GWRC is set to release a tender for new bus operating contracts for the Wellington region in mid-2016 (GWRC, 2016c). There is a range of bus technologies that could be used to progressively improve Wellington’s existing bus fleet.

The following discussion provides a brief indication of the different factors that need to be taken into account in relation to the GWRC’s strategy for upgrading Wellington’s bus fleet. This includes how the GWRC’s wider transport strategies influence the options for Wellington’s bus fleet, and further considerations such as cost, environmental and health impacts, and noise pollution. Although these are the main factors to be taken into account, it is not an exhaustive list of issues associated with the different bus options. This report will then present a brief analysis of a range of bus technologies that could potentially be used to upgrade Wellington’s current bus fleet. This includes modern diesel buses, biofuel buses, hybrid technologies, hydrogen fuel cell buses, trolley buses and battery electric buses.

3.2. WELLINGTON’S WIDER PUBLIC TRANSPORT STRATEGIES

The GWRC has a number of wider public transport plans that influence the options for upgrading Wellington’s bus fleet. In particular, the Wellington Regional Public Transport Plan 2014 (PT Plan) includes two initiatives that directly affect Wellington’s bus fleet. The first is GWRC’s plan to implement a simpler bus network in Wellington city, and the second is the council’s plan to introduce BRT on the Wellington city public transport spine (GWRC, 2014b). The new bus network will have more frequent services than the current network, and will be available to more people. It will have less service duplication, with fewer buses operating on the Golden Mile. BRT should enable faster journey times through the Golden Mile and to the southern and eastern suburbs (GWRC, 2014b). These changes to the network directly affect the future of Wellington’s bus fleet.

WELLINGTON’S NEW BUS NETWORK

The GWRC reviewed Wellington city’s present bus network in 2012 and found that it was complicated and inefficient. Many services were duplicated and under- or over-supplied in some areas. The GWRC has developed a new more simplified network that will result in 75 percent of Wellington city residents being within 1 km of a high frequency bus route, compared to 45 percent currently. The GWRC plans on introducing the new bus
network in Wellington city by January 2018 (GWRC, 2014b). For the purpose of this report, it is assumed that the new network will indeed be more efficient than the current network, and will encourage more people to use public transport. It is therefore critical that Wellington’s future bus fleet can operate on the new network. This point is of particular concern when considering Wellington’s trolley buses, which are limited to routes on the current network which do not all align with the new design.

**BUS RAPID TRANSIT**

In 2012 the GWRC, Wellington City Council and the New Zealand Transport Agency (NZTA) commissioned the Public Transport Spine Study (Spine Study) with the aim of establishing the best option for a high-quality public transport spine through Wellington city. The Spine Study compared Bus Priority, Bus Rapid Transit and Light Rail and found that Bus Rapid Transit (BRT) offered the highest net benefits. The Regional Transport Committee decided after public consultation to adopt BRT as the public transport strategy for central Wellington. There has been significant debate about the Spine Study findings and the decision to adopt BRT. Many public transport advocates continue to push for Light Rail and the GWRC has so far decided that while Light Rail is too expensive for now it is still a possibility in the future (Forbes, 2015b). In the meantime, the actual BRT design is still being determined. The route depends on improvements at the Basin Reserve, a duplicated Mt Victoria tunnel and the widening of Wellington Road and Ruahine Street (GWRC, 2016b). It is unclear when BRT is likely to be implemented.

The ultimate objective of BRT is to create a flexible, efficient, and cost-effective public transport system. Wellington’s current bus services for the most part use general traffic lanes, which can be slow due to traffic congestion. The speed of bus services is further reduced by the time vehicles have to spend at bus stops for passengers to board and pay the fare, and pull back into traffic. The Golden Mile in particular has become a choke point for public transport in central Wellington. BRT typically involves a combination of dedicated bus lanes, bus priority at intersections, high-capacity buses, and streamlined ticketing systems. The GWRC has stated that BRT will be ‘tailored’ to Wellington conditions (GWRC, 2016a). Wellington’s narrow roads make it very difficult to implement a transformational, fully demarcated rapid transit system with dedicated bus lanes for the whole length of the transport spine. Instead, the GWRC have indicated that there will be targeted bus lanes with limited priority at some intersections. This has led to concern and debate about whether the new system will go far enough or can even be called BRT (Dominion Post, 2015).

The main impact BRT has on Wellington’s future bus options is that it necessitates the introduction of high-capacity buses into the fleet. In order for the BRT system designed for Wellington to be effective, it requires the core spine routes to operate high-capacity buses such as double-decker or articulated buses. This would reduce the number of vehicles in the central city, and on the Golden Mile in particular, enabling a faster, more frequent service. The GWRC plans to replace many of the trolley buses and older diesel buses in the fleet with high-capacity vehicles. The requirement for high-capacity buses to operate on the core routes in Wellington has implications for which bus technologies could be used to upgrade the fleet.
3.3. FURTHER CONSIDERATIONS

The options for Wellington’s future bus fleet are not only limited by wider transport strategies but also by cost, health and environmental impacts, and noise pollution.

COST

The GWRC has to take into account the cost of each different bus technology. The GWRC contracts services to providers, such as NZ Bus, who directly bear the capital costs of bus purchases and (some) infrastructure. The contracted services also cover operating costs – for maintenance, drivers and fuel. There are also indirect (‘external’) costs which the council needs to take into account, and which are not easily quantified such as those associated with the health and environmental impact of emissions, and noise pollution. While this report will provide a brief indication of the costs of each option, an in-depth investigation into the costs is outside the scope of this study. It is worth noting that the costs associated with upgrading Wellington’s bus fleet could vary significantly depending on whether current buses in the fleet are converted to clean technology or replaced with new vehicles.

HEALTH AND ENVIRONMENTAL IMPACTS

It is vital to take into account the health and environmental implications of each bus technology. The main health and environmental benefits of public transport come from encouraging people to leave their cars at home in favour of taking public transport. This will reduce emissions as well as traffic congestion. In this regard, it is important for Wellington to have an efficient bus network, regardless of which type of bus operates on that network. However, the type of bus used to upgrade Wellington’s bus fleet will have an impact on Wellington’s level of GHG emissions and air pollution.

Reducing GHG emissions is vital for mitigating climate change. The Wellington City Council (WCC) has set a climate mitigation target that is likely to be affected by Wellington’s future bus fleet. The WCC aims to reduce Wellington city’s GHG emissions by 30 percent from 2001 levels by 2020, and by 80 percent by 2050 (WCC, 2013). The former target is likely to be relaxed as 30 percent is now unattainable by 2020, but the 2050 target is likely to be retained. The GWRC has not set a climate mitigation target, but has stated that it will act to reduce GHG emissions across all its areas of influence, including its own operations (GWRC, 2015a). The GWRC is currently developing an emission reduction target for its own operations, but we understand the bus fleet will not come under that target. This is particularly concerning given the impact the bus fleet will have on emissions and Wellington’s image as a sustainable city. Wellington can reduce its GHG emissions through incorporating low and zero emission buses into its bus fleet.

The type of buses used in Wellington’s bus fleet will influence air pollution in the city. Some bus technologies produce local harmful emissions, such as particulate matter (PM), nitrogen oxides (NOx), hydrocarbons (HC) and carbon monoxide (CO). These air pollutants are a major health issue, increasing the risk of stroke, heart disease, lung cancer and both chronic and acute respiratory diseases (World Health Organization, 2014). Uhrner and colleagues have undertaken research that suggests that while air quality in Wellington is generally good, there
are problematic areas. Air quality simulations indicate that air quality standards for nitrogen dioxide ($\text{NO}_2$) are violated in wind sheltered road sections or street canyons, which have high traffic densities and steep road gradients (Uhrner et al., 2013). Uhrner and colleagues argue that because trolley buses have a positive impact on air quality, they should only be replaced with comparably low emissions vehicles. Further, they suggest that in order to improve air quality within central Wellington, existing diesel buses that are Euro IV standard and below should be replaced with better performing vehicles (Uhrner et al., 2013).

The strategy that the GWRC adopts for upgrading Wellington’s bus fleet will also send an important message regarding the council’s commitment to climate change mitigation, and its concern for the health and wellbeing of Wellington’s citizens. It will affect Wellington’s image – helping to define whether the city is considered a progressive and sustainable place to live and work.

**NOISE POLLUTION**

The GWRC has to take into account the impact different bus technologies will have on noise pollution in Wellington. Noise levels are measured in decibels, which is based on a logarithmic scale. This means that a small increase in the number of decibels can correspond to a large increase in total noise. Exposure to high levels of noise can lead to hearing loss and a range of non-auditory health effects such as annoyance, sleep disturbance, cardiovascular disease, and impairment of cognitive performance in children (Basner et al., 2014). Noise pollution can also have an adverse effect on amenity and property values (Nunns, Varghese, & Adli, 2015). Noise pollution can be difficult to evaluate as it varies significantly in different locations. Buses can be a major source of noise pollution, particularly in relatively dense urban areas where buses operate in higher concentrations (Nunns et al., 2015). Buses can therefore affect public health, and have a considerable impact on amenity and property values. They can also deter visitors to the city centre. This may be an increasingly important issue as Wellington’s CBD continues to intensify. Electric bus technologies are significantly quieter than diesel buses. The GWRC can reduce noise pollution and its impact on CBD residents through incorporating electric bus technologies into its bus fleet.

### 3.4. BUS REPLACEMENT OPTIONS

In light of the above, a range of different bus technology options is briefly set out below and summarised in Table 1 (section 3.5), for upgrading Wellington’s current bus fleet. Each bus option is considered with respect to its ability to operate the new bus network and BRT, cost, emissions profile, and impact on noise pollution.

**DIESEL**

Diesel buses are a proven, reliable technology that is already used extensively in Wellington. Diesel buses can be used flexibly within the existing road network, and will be able to operate the new Wellington city bus network. High-capacity diesel double-decker or articulated buses are used extensively overseas, and could be used to operate the new BRT network.
Diesel buses cost between NZ$300,000 and $450,000 per vehicle depending on the model and capacity (Nunns et al., 2015; PwC, 2014). This is significantly cheaper than other bus technologies. However, diesel buses cost more to maintain than other technologies due to the complex engine components of diesel engines (PwC, 2014). Diesel is more expensive than other fuel sources, and raises issues around energy security and oil price volatility (Nunns et al., 2015). The introduction of a carbon tax, or the strengthening of the existing emissions trading scheme, is likely following the Paris Agreement and this will raise the effective cost of diesel significantly in the future. Standard diesel buses will not require any new infrastructural investment to operate in Wellington (PwC, 2014). It is unclear whether high-capacity double-decker or articulated buses would require infrastructural investment to operate on the core routes of the new network. In order for double-deckers to operate with flexibility on all of the new network, significant investment would likely be required for road strengthening and tunnel enlargements (Forbes, 2015a; Hunt, 2016).

Diesel buses have far greater adverse environmental and health impacts than other cleaner bus technologies, contributing to both GHG emissions and air pollution. Stricter European guidelines have meant that modern diesel engines are considered significantly cleaner than older engines. However, there has been increasing concern on the part of health authorities such as the WHO about fine particulate emissions from diesel, and even modern diesel buses cannot be considered ‘clean’ in comparison to bus technologies that have no tail-pipe emissions. The continued use of diesel buses in Wellington will adversely affect air quality in the city and Wellington’s total GHG emissions. The GWRC’s strategy for reducing CO₂ emissions does cover more than just emissions from the bus fleet. However, bus emissions are a significant area that the GWRC can directly influence. A continued use of diesel buses would suggest that the GWRC was not taking its commitment to climate change mitigation seriously, and could negatively affect Wellington’s image as a liveable, sustainable city.

The noise level of modern diesel buses is between approximately 65 and 77 decibels, which is significantly noisier than other bus technologies such as hybrid and electric buses (Nunns et al., 2015; PwC, 2014). Diesel buses are particularly noisy when accelerating, which is especially problematic in urban areas where buses are frequently stopping and subsequently accelerating (PwC, 2014). The continued use of diesel buses could have an adverse effect on local amenity and property values in Wellington, affecting an increasing number of residents as the population of central Wellington grows.

BIOFUELS

Biofuels are liquid or gaseous fuels that are produced from biomass – matter derived from plants or animals. There is a range of biofuels that can be used to operate buses including biodiesel, biogas, ethanol and renewable synthetic diesel (RSD). These are all established reliable public transport fuels with the exception of RSD which is an emerging technology (Donovan, 2012).

Biodiesel is produced from non-mineral oil sources, such as tallow and waste vegetable oil and is usually blended with mineral diesel. Lower blends such as B5 – B20 (5 – 20 percent biodiesel blended with mineral diesel) can be used in most heavy duty diesel engines whereas B100 (100 percent biodiesel) requires specialised engines (Donovan, 2012). Biogas is gas made from renewable resources and landfill gas. In order to operate using biogas,
buses require specialised engines (Donovan, 2012). Ethanol is a pure alcohol made from various biomass sources. Ethanol sourced from a renewable feedstock is sometimes distinguished as bioethanol. Like biogas, ethanol requires buses to have specialised engines (Donovan, 2012). RSD is produced from various biomass sources such as woody waste and is fully substitutable for fossil diesel (Donovan, 2012).

The advantage of lower blends of biodiesel and RSD is that they can be used in standard diesel buses. This means they offer the same flexibility as diesel, and can be used to operate the new network and BRT. Standard capacity biogas and ethanol buses offer similar flexibility to diesel buses and could be used to operate the new network. It is not clear whether high-capacity buses that operate using these fuels are available, and therefore whether they could be used to implement BRT.

The cost of biofuel buses differs depending on the price of fuel and the requirement for specialised engines. As lower blends of biodiesel can be used in standard diesel buses, the costs are the same as for diesels with the exception of fuel. Lower blends of biodiesel are currently slightly more expensive than mineral diesel per litre (Donovan, 2012). Biogas buses are likely to have higher overall maintenance costs than diesels due to their specialised engines. The fuel can be significantly cheaper than diesel depending on the availability of surplus landfill gas or a specific biogas project (Donovan, 2012). Ethanol buses also have higher maintenance costs than diesel and the fuel costs slightly more than diesel. As RSD can be used in standard diesel buses, the costs are the same for diesel with the exception of fuel. RSD is currently much more expensive to produce than diesel; however this may change as the technology develops further.

The availability of biofuels is a significant constraint on their adoption in Wellington. Biodiesel is currently only produced in New Zealand on a small scale. Z Energy is currently constructing New Zealand’s first large-scale biodiesel production facility, which should be completed in 2016. The biodiesel will be produced from animal fat and used cooking oil, and will be available as 5 percent biodiesel blended with ordinary diesel (Z Energy, 2015a). In the short term Z will only be supplying biodiesel to the Auckland, Waikato and the Bay of Plenty regions; however depending on demand, the company would like to supply biodiesel to the whole of New Zealand (Z Energy, 2015b). This may result in biodiesel being a more viable option for Wellington’s bus fleet in the medium term. Biogas is produced at Wellington’s Happy Valley and Silverstream landfills; however this is already used to generate electricity (Bioenergy Association of New Zealand, 2015). It is not clear whether there are any unexploited sources of biogas in the Wellington region. Ethanol is also only produced in New Zealand on a small scale by Fonterra from whey, a by-product of the dairy industry (Donovan, 2012). Research is currently being undertaken on the potential to produce RSD from renewable sources of wood in New Zealand; however it will not be available in New Zealand in the short term (Donovan, 2012).

Biofuels are generally considered a renewable alternative to fossil fuels. They can help reduce GHG emissions and improve energy security. The overall performance of different biofuels in reducing GHG emissions can vary significantly. It depends on the type of crop and land that is used, as well as how feedstock production and fuel processing are carried out. When forest or grassland is converted to farmland for the production of biofuels, it can result in a net increase of GHG emissions rather than a decrease. The whole life cycle of a biofuel needs to
be evaluated to establish whether it leads to a net decrease in emissions. As with GHG emissions, the overall performance of different biofuels in reducing local harmful emissions can also vary significantly. For example, biodiesel can produce 10 to 50 percent less particulate matter than standard diesel, depending on the biodiesel to diesel blend (Paulson, 2010). There is very little difference between biofuel and diesel buses in terms of their impact on noise pollution.

It is apparent from the above discussion that converting Wellington’s bus fleet to biofuels would require overcoming a number of constraints, particularly concerning supply. In the long term, the GHG emission reductions offered by biofuels may be considered insufficient in comparison to cleaner technologies. Further, biofuels offer little in the way of reduced noise pollution.

**HYBRID TECHNOLOGIES**

Hybrid buses are being trialled in many cities around the world, and larger fleets already operate in a number of cities such as London and San Francisco. Hybrid buses have faced a number of operational issues; however their technology has matured significantly in recent years and they are becoming increasingly reliable (Donovan, 2012). Hybrid buses generally combine an electric motor (and battery or capacitor) with an internal combustion engine. Hybrid buses also typically use regenerative braking, which transforms kinetic energy from braking into electrical energy.

Hybrid buses would have similar flexibility on Wellington’s current road network as diesel buses. High-capacity hybrid buses are being trialled overseas, with larger fleets operating in a small number of cities. It is therefore likely that hybrid buses could be used to operate both the new Wellington city bus network and BRT.

Hybrid diesel-electric buses cost approximately NZ$600,000 to NZ$800,000 per vehicle depending on model and capacity (GWRC, 2014a; Nunns et al., 2015). There may be further costs if buses require battery replacements. Hybrid buses do not require the development of supporting infrastructure. The fuel efficiency of hybrid buses varies significantly but most are considerably more efficient than standard diesel buses (Donovan, 2012). Hybrid buses cost slightly more than diesel buses to maintain (Nunns et al., 2015).

Conventional hybrid diesel-electric buses typically produce up to 25 percent less emissions than diesel buses (Nunns et al., 2015). However, other hybrid technologies offer significantly greater emission reductions. NZ Bus have recently announced that they will be converting a number of their buses to use Wrightspeed Range-Extended Electric Powertrain technology (NZ Bus, 2016). The Wrightspeed powertrain uses an electric motor to drive the wheels, powered by a small bank of batteries (with a range of 40km). The batteries can be charged from the grid or by using the on-board turbine engine, which can operate using diesel, compressed natural gas (CNG), liquid natural gas (LNG), liquid propane (LPG), or biogas. NZ Bus have estimated that their converted buses will only need to operate using hydrocarbon fuel between 0 and 17 percent of the time (Fulljames, 2016). This could result in an 83 to 100 percent reduction in emissions in comparison to standard diesel buses. If achieved, this would be a considerable improvement on conventional hybrid buses.
The impact hybrid buses have on air pollution and noise pollution can be significantly improved if the buses can operate on their electric battery alone whilst travelling through denser areas. This could reduce the public’s exposure to local harmful emissions and noise. Many cities are treating hybrid buses as a transition step to converting their fleets to fully electric buses. It is likely that they will not be a long-term solution because their emission reduction margin is insufficient in the long term.

**HYDROGEN FUEL CELL**

Hydrogen fuel cell (HFC) buses are an emerging technology that operate using hydrogen. HFC technology is being trialled in a number of locations around the world; however, they still face a number of cost and performance barriers. The advantage of HFC buses is that they can be operated like diesel buses – they have a range of 300-450 kilometres and can be refuelled in less than 10 minutes (Donovan, 2012). HFC buses can be completely flexible within an existing road network provided refuelling stations are accessible. They could be used to operate Wellington’s new network and potentially BRT.

The current cost of HFC buses is prohibitive. They are estimated to cost approximately NZ$2.7 million per vehicle, in addition to the capital cost of hydrogen fuel stations (PwC, 2014). This bus purchase cost is far more expensive than other bus technologies. In the long term, as the technology develops and the prices come down, HFC buses have significant potential. Nevertheless, they face intense competition from battery electric buses.

HFC buses produce no harmful emissions during operation, and if the hydrogen is produced from renewable electricity then their GHG emissions are very low (PwC, 2014). In terms of noise pollution, HFC buses produce approximately 60 to 70 decibels, which is far quieter than diesel buses (PwC, 2014).

**ELECTRIC TROLLEY**

Trolley buses are already used in Wellington and are a proven technology. San Francisco and Vancouver are upgrading their existing trolley bus fleets, and a number of other cities in the world are investing in new trolley bus networks. Trolley buses are powered by electricity delivered by overhead cables. The reliance of trolley buses on an overhead network of cables limits their flexibility. Wellington’s new bus network was not planned to include the existing trolley bus network. In order to maintain trolley buses as part of the new network there would have to be a significant extension to the trolley bus power supply and overhead network (GWRC, 2014b). The new network could be revised to incorporate the existing overhead cables; however this could reduce its efficiency. High-capacity articulated trolley buses are used overseas. Provided there was the necessary infrastructural investment, they could potentially be used in Wellington on the BRT network.

The trolley bus fleet was refreshed from 2007 to 2009, and the buses have an estimated remaining life of between 5 and 10 years. A modern trolley bus is estimated to cost NZ$700,000 per vehicle (comparable to hybrid diesel-electric buses). Hybrid trolley buses that are equipped with a battery or diesel motor could help overcome their flexibility limitation. A trolley bus with an added diesel engine is estimated to cost approximately $800,000 per vehicle (PwC, 2014). The work to upgrade the current network and required electricity infrastructure is estimated to cost approximately NZ$52 million (PWC, 2014). This is particularly costly when
taking into account that there are only 60 trolley buses out of a fleet of 515 buses operating in the Wellington region. There has been some debate around the accuracy of the costs presented by the council for upgrading the current network (Neilson, 2015). Upgrading and extending the trolley bus network to match the new network and fulfil the requirements of BRT would require significant investment that is likely to be cost prohibitive. It is not clear how much it would cost to maintain only part of the current trolley bus network as part of a revised new network. There are also costs associated with maintaining the trolley overhead network. Over the period 2008/9-2012/13 the annual cost of maintenance and renewals for the overhead network ranged from $3.4 million to $5.6 million (GWRC, 2014b). In terms of fuel, trolleys are significantly cheaper to run than diesel buses due to the lower price of electricity compared to diesel.

The GHG emissions profile of trolley buses depends on the proportion of the electricity that is generated from renewable sources. In New Zealand, around 75 to 80 percent of electricity is generated by renewable sources, and the government has set a target for 90 percent of New Zealand's electricity to be generated from renewable sources by 2025 (Ministry of Economic Development, 2011). Trolley buses do not produce any harmful tail-pipe emissions.

The noise level of trolley buses is approximately between 60 and 70 decibel (PwC, 2014). This is far quieter than diesel buses. The overhead wires required for trolley buses do have an adverse visual impact on the streetscape.

**BATTERY ELECTRIC**

Electric battery powered buses are an emerging technology that is being trialled extensively overseas, although their reliability is unproven in the long term. They generally require their batteries to be charged overnight or for short intervals along bus routes which have dedicated charging infrastructure. The main area of concern regarding battery electric buses are the time it takes for their batteries to recharge and battery life – both of which can limit bus flexibility and range. Battery technology is improving quickly and significant progress has already been made in relation to charging times and battery life.

Battery electric buses that are charged overnight are designed to operate all day without needing to be recharged. This gives them flexibility on the existing road network and means they could be used to implement the new Wellington city bus network. High-capacity battery electric buses are only beginning to be trialled overseas and are unlikely to be available in the short term. However, in the long term they could be used to operate the BRT network. The passenger capacity of battery electric buses is slightly less than their diesel counterparts due to the additional weight of the battery (PwC, 2014).

Battery electric buses are estimated to cost approximately NZ$0.9 to $1.1 million per vehicle, and they may also require a battery replacement during their lifetime (Nunns et al., 2015; PwC, 2014). This is significantly more expensive than diesel buses. Battery electric buses also require some capital investment in recharging stations. Recharging stations along bus routes would require more investment than recharging stations at bus depots (PwC, 2014). Battery electric buses are less expensive to maintain than diesel buses due to fewer moving parts,
and cost less to operate, as electricity is cheaper than diesel. If they are re-charged overnight when electricity demand is lower, their running costs are even lower.

Like trolley buses, the GHG emission profile of electric buses depends on the proportion of the electricity that is generated from renewable sources. They do not produce tail-pipe emissions. The noise level of battery electric buses is approximately between 60 and 70 decibels (PwC, 2014). This is far quieter than diesel buses.

### 3.5. SUMMARY OF BUS REPLACEMENT OPTIONS

Table 1 below provides a simplified summary of the advantages and disadvantages of each bus technology.

<table>
<thead>
<tr>
<th>Bus type</th>
<th>Capital costs</th>
<th>Operational costs</th>
<th>GHG emissions</th>
<th>Local harmful emissions</th>
<th>Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel (Euro VI)</td>
<td>✓ ✓ ✓</td>
<td>✓</td>
<td>X X</td>
<td>X X</td>
<td>X X</td>
</tr>
<tr>
<td>Biodiesel*</td>
<td>✓ ✓ ✓</td>
<td>X</td>
<td>X X</td>
<td>X X</td>
<td>X X</td>
</tr>
<tr>
<td>Hybrid**</td>
<td>✓ ✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hydrogen fuel cell</td>
<td>X X</td>
<td>✓</td>
<td>✓ ✓ ✓</td>
<td>✓ ✓ ✓</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>Electric trolley</td>
<td>X X</td>
<td>✓</td>
<td>✓ ✓ ✓</td>
<td>✓ ✓ ✓</td>
<td>✓ ✓ ✓</td>
</tr>
<tr>
<td>Battery electric</td>
<td>X X***</td>
<td>✓</td>
<td>✓ ✓ ✓</td>
<td>✓ ✓ ✓</td>
<td>✓ ✓ ✓</td>
</tr>
</tbody>
</table>

**Table 1 Summary of main advantages and disadvantages of each bus technology**

* Biodiesel was selected out of the range of biofuels as it appears to have the most potential to be adopted by Wellington’s bus fleet. It is assumed that it is a lower biodiesel-diesel blend such as B5 – B20

** Hybrid technologies differ significantly. For the purpose of this table, it is assumed that they offer a considerable reduction in GHG emissions, and that their adverse impact in terms of local harmful emissions and noise is reduced by their ability to operate solely on electricity in built up locations

*** This assumes investment in charging stations at bus depots rather than along bus routes, reducing infrastructural costs

### 3.6. CONCLUSION

The discussion above demonstrates that there is a range of bus technologies that could potentially be used to upgrade Wellington’s bus fleet.

The advantage of modern diesel buses is they have the lowest capital cost and are the most reliable technology. They could be used to operate both the new Wellington city bus network and BRT. However, they also produce the highest emissions, which would have considerable health and environmental implications for Wellington.
The carbon emission implications are of particular concern, given the urgency of carbon emissions reductions, WCC’s emission reduction targets and the GWRC’s commitment to reduce emissions across its areas of influence. Diesel buses also have the highest level of noise pollution, which affects local amenity and may affect property values.

Biofuels face significant constraints on their adoption in Wellington, particularly concerning securing fuel supply. Biofuels produce less GHG emissions and local harmful emissions than diesel, with the level of reduction depending on the biofuel. In the long term, biofuels may not offer sufficient reductions in emissions in comparison to electric technologies. Further, biofuels offer very little improvement in regard to noise pollution. Biodiesel could be used to improve the emission profile of diesel and hybrid diesel-electric buses in the fleet; however this is not a long term solution.

The advantage of hybrid technologies is that they have as much flexibility as diesel buses but are more efficient. The emission reductions offered by hybrid technologies differs significantly but all are a considerable improvement on standard diesel buses. In particular, hybrid technologies that can operate solely on electricity in built up areas can significantly reduce their impact in terms of air pollution and noise. However, as hybrid buses still produce emissions, many cities are treating them only as a transition step towards a fully electric fleet, rather than as a long-term solution.

The principal obstacle facing fully electric bus technologies is their high capital costs. HFC buses are still very much an emerging technology and are currently prohibitively expensive. In the long term they have significant potential as they offer complete flexibility on the road network, and unlike battery electric buses, they are not limited by battery life and recharge times. Trolley buses already operate in Wellington; however, their lack of flexibility means they could not be used to operate the new bus network and BRT without significant investment. Battery electric buses are also an emerging technology, and are currently significantly more expensive than diesel and hybrid technologies. While they are far more flexible than trolley buses, they are still limited by battery life and recharge times. The advantage of all of these fully electric bus technologies is that they offer the most environmental and health benefits as they produce no local harmful emissions, and very little GHG emissions due to New Zealand’s high share of renewable electricity. Electric bus technologies are also far quieter than diesel buses, which would have positive benefits for local amenity and property values.

It is clear that from an environmental and health perspective Wellington should aim to have a fully electric bus fleet in the future. This would reduce Wellington’s GHG emissions and send an important message regarding Wellington’s commitment to mitigating climate change. It would also improve air quality and reduce noise pollution, positively affecting the liveability of the city and the health and wellbeing of Wellington’s citizens. However, cost considerations need to be taken into account as an immediate shift to a fully electric bus fleet would be very costly. The next section of this report addresses transition options.
4. WELLINGTON BUS REPLACEMENT PLAN

4.1. INTRODUCTION

The GWRC has been considering its replacement strategy for both trolley buses and diesel buses in Wellington’s bus fleet for a number of years. It is clear from the previous section of this report that there is a range of bus technologies that could be used to upgrade Wellington’s bus fleet.

In 2014 the GWRC commissioned PwC to undertake a cost-benefit analysis evaluating a range of different bus options for upgrading Wellington’s bus fleet (PwC, 2014). Subsequently the GWRC decided that it would not renew the trolley bus contracts in 2017. The GWRC stated that this was due to the magnitude of current and future costs required to operate the trolley bus network, and because it would not allow the introduction of the new network (GWRC, 2014b). Instead, the GWRC decided it would replace trolley buses, as well as older diesel buses in the fleet, with hybrid diesel-electric buses. This would be a transition step to getting a fully electric bus fleet in the future (GWRC, 2014b). Hybrid buses would allow the GWRC to implement the new network and reduce emissions from the fleet (GWRC, 2014b).

In 2015 the GWRC updated this plan, deciding instead to replace the trolley and older diesel buses with modern diesel buses, with the exception of ten hybrid double-decker buses (GWRC, 2015b). It is unclear why the GWRC has decided to replace the majority of the older diesels and trolleys with modern diesel buses, as opposed to hybrids as originally planned. The GWRC has set an aspirational goal for Wellington to be the first region in New Zealand with an all-electric bus fleet when the technology is more mature and affordable (GWRC, 2015b). However, when this occurs will be a matter of judgement.

This section of the report first gives a breakdown of Wellington region’s current bus fleet. This is followed by an outline of the GWRC’s bus replacement plan as well a range of other scenarios for upgrading Wellington’s bus fleet. The implications of each replacement strategy are then discussed in relation to implementing the new network and BRT, and from the viewpoint of cost, emissions and noise pollution.

4.2. WELLINGTON REGION’S CURRENT BUS FLEET

Wellington region’s bus fleet currently comprises 515 buses in total. The majority of the fleet is made up of diesel buses of mixed age and mixed European (Euro) emission standards. Euro emission standards for vehicles define the acceptable levels of exhaust emissions for vehicles sold within the EU. These standards range from Euro I standard to Euro VI standard. Euro I standard buses are the oldest and most polluting of the Euro standard buses. Euro VI standard buses are the newest and cleanest of the Euro standard buses. The fleet also contains 41 pre-Euro emission standard buses, and 60 trolley buses; 278 of the 515 buses operate in Wellington city, including all of the trolley buses.

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3 For a summary of the PwC report’s findings, and a discussion of some of its main limitations, see Appendix 1.
The graph below provides a breakdown of Wellington (Wgtn) region’s bus fleet by bus type.  

4.3. WELLINGTON REGION BUS FLEET REPLACEMENT SCENARIOS

The GWRC has provided two indicative replacement scenarios for Wellington region’s bus fleet. The first scenario provided by the GWRC (Scenario 1) is clearly a ‘business as usual’ replacement plan as it assumes that the new Wellington city bus network and BRT are not introduced and that there are no changes to bus emission standards. The second scenario provided by the GWRC (Scenario 2) involves replacing the trolley buses and older diesel buses in the fleet with modern diesel buses, with the exception of ten hybrid diesel-electric buses.

Scenario 2 is in line with the strategy that the GWRC announced in December 2015 for upgrading Wellington’s bus fleet (GWRC, 2015b). This report provides three further strategies for replacing Wellington’s current bus fleet (Scenario 3, Scenario 4 and Scenario 5). Scenario 3 replicates the GWRC’s initial plan to replace all of the trolley buses and older diesel buses with conventional hybrid diesel-electric buses. Scenario 4 is the same as Scenario 3 except that it assumes the adoption of Wrightspeed hybrid technology rather than conventional hybrid diesel-electric buses, as this technology offers far greater reductions in emissions. Scenario 5 is a ‘best case’ scenario in which the current bus fleet is replaced with fully electric battery powered buses, bypassing hybrid technology altogether. Scenarios 3, 4 and 5 are far more ambitious than the GWRC’s indicative scenarios, adopting low emission and zero emission buses far more quickly.

All five scenarios are outlined below.

4 The figures for Wellington region’s bus fleet were provided by the GWRC via personal communication. For a breakdown of Wellington City’s bus fleet, please see Appendix 2.

5 These scenarios were provided by the GWRC via personal communication.

6 This scenario has been included in light of NZ Bus’s recent announcement regarding their intention to convert a significant proportion of their fleet to operate using Wrightspeed electric powertrains (NZ Bus, 2016). However, Scenario 4 cannot be equated with NZ Bus’s plan. So far, NZ Bus have stated that they plan to convert the trolley buses to Wrightspeed technology, but their intention regarding diesels is unclear. Scenario 4 involves replacing all of the trolley buses, plus pre-Euro, Euro I and Euro II diesel buses in the fleet with Wrightspeed hybrid technology.
**SCENARIO 1**

Scenario 1 (provided by the GWRC) assumes that:
- the new Wellington city bus network and BRT are not implemented
- there are no changes to the maximum age of buses or bus emission standards
- trolley buses are retired from the fleet by 2018 and replaced with modern diesel buses
- older diesel buses are progressively replaced with modern diesel buses.

**SCENARIO 2**

Scenario 2 (provided by the GWRC and in line with the December 2015 announcement) assumes that:
- the new Wellington city bus network and BRT are implemented
- there will be a new maximum age for buses and new stricter bus emission standards
- trolley buses and Pre-Euro, Euro I and Euro II standard diesel buses are retired from the fleet by 2018 and replaced with modern diesel buses, with the exception of 10 conventional hybrid double-decker buses
- Euro III to Euro VI buses are phased out from 2023 and replaced with battery electric buses
- there are fewer total buses in the fleet than Scenario 1 due to the incorporation of high-capacity vehicles into the fleet.  

**SCENARIO 3**

Scenario 3 assumes that:
- the new bus network and BRT are implemented
- there will be a new maximum age for buses and new stricter bus emission standards
- trolley buses and Pre-Euro, Euro I and Euro II standard diesel buses are retired from the fleet by 2018 and replaced with conventional hybrid diesel-electric buses
- Euro III to Euro VI buses are phased out from 2020 and replaced with battery electric buses
- there is the same total number of buses as Scenario 2 due to the incorporation of high-capacity vehicles into the fleet.

**SCENARIO 4**

Scenario 4 has the same assumptions as Scenario 3, with the exception that Wrightspeed hybrid buses, rather than conventional hybrid diesel-electric buses, replace trolley buses and Pre-Euro, Euro I and Euro II standard diesel buses.

**SCENARIO 5**

Scenario 5 assumes that:
- the new bus network and BRT are implemented
- there will be a new maximum age for buses and new stricter bus emission standards
- trolley buses and Pre-Euro, Euro I and Euro II standard diesel buses are retired from the fleet by 2018 and replaced with battery electric buses
- Euro III to Euro VI buses are phased out from 2020 and replaced with battery electric buses
- there is the same total number of buses as Scenario 2 due to the incorporation of high-capacity vehicles into the fleet.

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7 The GWRC have indicated that in this scenario the Wellington region bus fleet will incorporate 215 high-capacity vehicles (168 single-deckers and 47 double-deckers); including 10 hybrid double-decker buses.
The following graphs indicate the bus fleet configurations for each of the scenarios described above for the Wellington region until 2032.8 The graphs do not distinguish between standard and high-capacity buses; however, each of Scenarios 2 - 5 has the same number of high-capacity vehicles.9

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8 The bus fleet configurations for each scenario for Wellington City can be found in Appendix 2.

9 While it is known how many total high-capacity vehicles will operate in the fleet for both scenarios, it could not be established for the purposes of this report how many high-capacity buses are already operating in the fleet and their retirement profile.
4.4. IMPLICATIONS OF THE REPLACEMENT SCENARIOS

The bus replacement scenarios outlined above – the GWRC’s two scenarios and the three alternative and more ambitious scenarios – have different implications for Wellington. The following discussion reviews the five scenarios in relation to their impact on implementing Wellington’s new bus network and BRT, as well as cost, emissions and noise pollution.

IMPLEMENTING WELLINGTON’S NEW BUS NETWORK AND BUS RAPID TRANSIT

The main benefits of public transport come from encouraging more people to leave their cars at home and take public transport. In order to increase public transport patronage, the GWRC is implementing the new Wellington city bus network and BRT. It is therefore vital that the buses used to upgrade Wellington’s bus fleet enable the implementation of the new network and BRT. Scenario 1 assumes that the new network and BRT are not implemented. Scenarios 2 to 5 assume that the new network and BRT are implemented. Modern diesel buses, hybrid technologies, and battery electric buses all have the flexibility to operate on the new network. In terms of high-capacity vehicles for the BRT routes, diesel and conventional hybrid high-capacity vehicles are already available. High-capacity vehicles that operate fully on electric batteries or use advanced hybrid technology, such as offered by Wrightspeed, may not be available in the short term.

COST

The costs associated with each bus technology differ significantly. They include bus purchase costs, infrastructure costs, maintenance costs, driver costs and fuel costs. They also involve not easily quantified indirect costs – those associated with the health and environmental impact of emissions, and noise pollution. The scenarios above all assume that new buses are purchased to replace the current fleet; however, significant savings could be made if current buses in the fleet can be converted to operate using clean technologies.

Scenario 1 assumes that the new network and BRT are not implemented. This would result in a range of costs for Wellington due to the continuation of the current inefficient network. Scenario 1 is the most affordable in terms of capital costs as it requires no infrastructural investment, and modern diesel buses have the lowest purchase price. However, this scenario has higher operational costs than the other scenarios. The operation of a full fleet of diesel buses would impose significant health and environmental costs because of emissions. Diesel buses also have the highest level of noise pollution, adversely affecting local amenity and property values.

Scenario 2 requires more capital investment than Scenario 1 due to its investment in 10 hybrid vehicles in 2018, and battery electric buses and their associated infrastructure from 2023. This scenario would be more affordable operationally than Scenario 1, particularly once battery electric buses are incorporated into the fleet. In the short term, Scenario 2 is only marginally better than Scenario 1 in regard to health, environmental and noise related costs. In the long term, once more of the fleet is operated from electricity, these costs will significantly reduce.
Scenarios 3 and 4 require more capital investment than Scenario 2 due to the replacement of all older diesel buses and trolley buses with hybrids in 2018, and the phase-in of battery electric buses and their associated infrastructure from 2020. Scenario 3 is more affordable operationally than Scenario 2 and offers a moderate reduction in emissions. Scenario 4 is far better than Scenario 3 in this regard, offering substantial operational savings and a significant reduction in emission and noise related costs.

Scenario 5 requires even more capital investment than Scenario 3 and 4 due to the replacement of all older diesel buses and trolley buses with fully electric battery powered buses from 2018. This scenario is operationally cheaper than the other scenarios, and has the least emission and noise related costs.

EMISSIONS

The type of bus used to upgrade Wellington’s bus fleet will influence Wellington’s level of GHG emissions and air pollution. Reducing GHG emissions is vital for mitigating climate change. Reducing local harmful emissions improves air quality and public health. The following series of graphs indicate the tail-pipe emissions profile for each of the bus replacement scenarios for Wellington region. The emissions shown include particulate matter (PM$_{10}$), nitrogen oxides (NO$_X$) and carbon dioxide (CO$_2$). It is important that these graphs should be considered indicative only as they have a number of limitations. The values used to calculate the emissions were taken from the PwC (2014) report; PwC made a number of assumptions to calculate these figures. The graphs only indicate the tail-pipe emissions of each bus technology. Electric trolley buses and battery buses do not produce tail-pipe emissions. However, it is important to acknowledge that the GHG emission profile of electric bus technologies depends on the proportion of electricity that is produced from renewable sources. In New Zealand, around 75 to 80 percent of electricity is generated by renewable sources, and the government has set a target for 90 percent of New Zealand’s electricity to be generated from renewable sources by 2025. The renewable proportion could reach higher levels, possibly even around 100 percent, by 2030 with appropriate central government incentives. The graphs use emission values (in g/km or kg/km) for each bus technology and multiply this by the number of each type of bus in the fleet. This means that the graphs assume that all vehicles travel an equal distance. The graphs are also based on all the buses in the fleet being standard capacity. The emissions profile of high-capacity buses could not be established for this analysis. However, it is expected that high-capacity diesel and hybrid buses have slightly higher emissions than standard capacity buses, but would perform significantly better per passenger.

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10 Scenario 4 is based on the purchase of new hybrid vehicles, which operate using Wrightspeed powertrain technology. If current buses in the fleet are converted to using this technology, this could significantly reduce the capital costs associated with this option. NZ Bus has stated that they plan on converting a significant proportion of their current bus fleet to operate using Wrightspeed hybrid technology (NZ Bus, 2016).

11 The emissions for Wellington City’s bus fleet have also been calculated and can be found in Appendix 4.

12 Hydrocarbon (HC) and carbon monoxide (CO) emissions have also been calculated. The graphs for Wellington Region can be found in Appendix 3 and for Wellington City in Appendix 4.

13 The values taken from the PwC report can be found in Appendix 5, as well as a brief summary of some of the assumptions used by PwC in their calculations.
Scenario 1 Wgtn Region bus fleet PM$_{10}$ emissions g/km

- Battery electric
- Conventional hybrid
- Euro V/VI
- Euro IV
- Euro III
- Euro II
- Euro I
- Pre-Euro
- Trolley

Year:
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022
- 2023
- 2024
- 2025
- 2026
- 2027
- 2028
- 2029
- 2030
- 2031
- 2032

Scenario 2 Wgtn Region bus fleet PM$_{10}$ emissions g/km

- Battery electric
- Conventional hybrid
- Euro V/VI
- Euro IV
- Euro III
- Euro II
- Euro I
- Pre-Euro
- Trolley

Year:
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022
- 2023
- 2024
- 2025
- 2026
- 2027
- 2028
- 2029
- 2030
- 2031
- 2032
It is clear from the graphs above that the retirement of the oldest diesel buses in the fleet has the most significant impact on PM$_{10}$ and NOx emission levels, regardless of which bus technology replaces them. Scenarios 2 to 5 are therefore considerably better than Scenario 1, as they remove the oldest diesel buses from the fleet by 2018 rather than phasing them out more gradually. Scenario 3 offers a moderate improvement on Scenario 2, with Scenario 4 and 5 better still.

Scenario 1 results in a slight increase of CO$_2$ emissions in Wellington region in 2018 due to the removal of the trolley buses. CO$_2$ emissions decrease slightly until 2025 while older diesel buses are removed from the fleet and replaced with more efficient modern diesel buses. CO$_2$ emission levels remain approximately the same from 2025 as the fleet continues to operate solely from diesel. Scenario 2 is an improvement on Scenario 1 as CO$_2$ emissions decrease slightly from 2018, and more significantly from 2023 with the introduction of fully electric buses. Scenario 3 is a significant improvement on Scenario 2. CO$_2$ emissions drop more quickly in Scenario 3 than in Scenario 2 due to the inclusion of a higher number of hybrid buses in the fleet from 2018 and the faster incorporation of battery electric buses into the fleet. Scenarios 4 and 5 are considerably better again. In particular, Scenario 5 offers an emission free bus fleet by 2030.

NOISE POLLUTION

Noise pollution from buses can have a significant effect on amenity and property values. This is particularly a problem in areas with high bus movements. Diesel buses have a high level of noise pollution. Hybrid technologies are quieter than diesel buses, and could significantly reduce their impact on noise pollution if they can operate solely on electricity in built up areas. Electric bus technologies are significantly quieter than diesel buses.

Scenario 1 will result in the highest level of noise pollution due to the entire fleet comprising of diesel buses. Scenario 2 offers only a slight improvement on Scenario 1 in the short term. In the long term, Scenario 2 reduces noise pollution as it incorporates battery electric buses into the fleet. Scenario 3 is an improvement on Scenario 2 as it includes a higher proportion of hybrid diesel-electric buses, and incorporates battery electric buses more quickly into the fleet. Scenario 4 is even better due to the ability of Wrightspeed hybrid buses to operate solely on electricity in built up areas. Scenario 5 is better again.

4.5. DISCUSSION

The GWRC has been considering its strategy for upgrading Wellington’s bus fleet for a number of years. They have provided two indicative scenarios for replacing the current bus fleet, which have been compared in this report with three alternative, more ambitious, scenarios.

Scenario 1 is a ‘business as usual’ scenario which can be set aside as an unrealistic strategy for the GWRC to adopt, given the GWRC’s own public transport aspirations to implement the new Wellington city bus network and BRT, as well as reduce emissions. Scenario 2 is a far more realistic strategy for the GWRC to adopt. The combination of bus technologies can be used to operate the new network and BRT. It requires more capital investment than Scenario 1 but it is more affordable operationally, especially in the long term. In terms of
emissions, Scenario 2 represents an improvement on Scenario 1 due to the earlier retirement of older diesel buses in the fleet, the inclusion of 10 hybrid buses into the fleet, and the phase-in of electric battery buses from 2023. Scenario 2 will reduce noise pollution, especially in the long term. The main problem with Scenario 2 is that it will not considerably reduce CO₂ emissions until the late 2020s.

Scenario 3 offers a more ambitious strategy for upgrading Wellington’s bus fleet. Like Scenario 2, the combination of bus technologies can be used to operate the new network and BRT. Scenario 3 requires more capital investment than Scenario 2 but is more affordable operationally. Scenario 3 performs better than Scenario 2 in terms of emissions due to the earlier retirement of diesel buses, the higher proportion of hybrid buses in the fleet, and the earlier and quicker phase-in of battery electric buses. It is considerably better than Scenario 2 in terms of CO₂ emissions as it makes substantial reductions from 2018. Scenario 3 will reduce noise pollution more quickly than Scenario 2.

Scenario 4 is very similar to Scenario 3. However, the incorporation of Wrightspeed hybrid buses into the fleet instead of conventional hybrid buses results in greater benefits in terms of operational costs, emissions and noise pollution. If buses in the current fleet are converted to Wrightspeed hybrid technology, this could significantly reduce the capital costs associated with this option.

Scenario 5 is the most ambitious of all the strategies, as it adopts fully electric battery powered buses from 2018, bypassing hybrid technologies altogether. It would require significantly more capital investment than the other options but would be the most affordable operationally, and result in the greatest reduction in emissions and noise pollution. Scenario 5 offers an emission free bus fleet by 2030.

The GWRC’s strategy, as represented by Scenario 2, is not ambitious. The retirement of the oldest diesel buses in 2018 has the most impact in terms of local harmful emissions. However, the gradual phase-in of battery electric buses means that it is a long time before air quality is improved further and significant CO₂ emission reductions are made. Scenarios 3, 4 and 5 are all far more ambitious. They all require more capital investment but offer substantial benefits in relation to operation, health and the environment, and noise levels.
5. CONCLUSION AND RECOMMENDATIONS

Wellington’s bus fleet is both a source of GHG emissions and air pollution. The reduction of GHG emissions is vital for mitigating climate change, an urgent matter. Air pollution is a significant health issue, increasing the risk of stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases. Many cities around the world are implementing ambitious plans to clean up their bus fleets in response to increasingly stringent GHG emission reduction and air quality targets. Wellington can learn from these cities if it wants to be an internationally competitive, progressive and sustainable city. In particular, Wellington should consider how its level of ambition compares to these world-leading cities in respect to the adoption of clean bus technology.

This report has outlined a range of bus technologies that could be used to progressively upgrade Wellington’s bus fleet. It is clear that, from an environmental and health perspective, Wellington should aim to have a fully electric bus fleet in the future. This would reduce Wellington’s GHG emissions and send an important message regarding Wellington’s commitment to mitigating climate change. It would also improve air quality and reduce noise pollution, positively affecting the liveability of the city and the health and wellbeing of Wellington’s citizens. The principal obstacle facing fully electric bus technologies is their high capital cost – shifting immediately to a fully electric bus fleet could be very costly. Even though the GWRC does not directly bear the capital costs of fleet upgrades, its strategy for transitioning to a fully electric bus fleet has to be economical while still reducing emissions as quickly as possible.

The GWRC has been considering its replacement plan for Wellington’s bus fleet for a number of years. In 2015, the GWRC decided that it would replace the trolley buses and older diesel buses in the fleet with modern diesel buses, with the exception of ten hybrid double-decker buses. In the long term, the GWRC aims for Wellington to have the first fully electric bus fleet in the country. Their decision not to renew the trolley bus contract has been very controversial. In part, this may be because it seems counterintuitive to aim to have a fully electric bus fleet in the future, whilst removing the only fully electric buses that currently operate in the fleet. However, in the scheme of the Wellington region, the trolley buses are only a small proportion of the fleet. It is therefore understandable that the GWRC may wish to focus on improving the region’s entire bus fleet rather than spending a significant amount of money on upgrading only 60 buses and their associated infrastructure.

The main health and environmental benefits of the GWRC’s strategy come from its removal of the oldest, most polluting diesel buses from the fleet by 2018. This will have the most impact on improving air quality in the city. It is concerning that the GWRC plans to replace all of the trolley buses and older diesel buses with diesel reliant bus options, as this could lock in emissions for a considerable period of time. The GWRC has not given a specific date for when the fleet will become fully electric. The GWRC’s indicative scenario (Scenario 2) suggests that in 2032 over half the fleet will still be made up of diesel buses. This strategy cannot be considered ambitious and is far behind the goals being set by leading international cities.

If the GWRC does wish to be ambitious then it should consider afresh its earlier plan to replace all the trolley buses and older diesel buses with hybrid buses. From a health and environmental perspective, this would be a considerable improvement on its current strategy. In particular, hybrid technologies that can operate for the
majority of the time without using their diesel combustion or turbine engine offer substantial benefits. Hybrid buses require more capital investment than modern diesel buses but offer a range of savings over the long term. The cost of replacing all the buses in the current fleet with battery electric buses may be seen as too costly in the shorter term. However, the GWRC could be trialling battery electric buses now with the intention of adopting them as soon as possible.

An environmentally sustainable upgrade of the Wellington bus fleet is only part of the changes that need to be made to deliver an effective and environmentally sound transportation strategy for the Wellington region. Nonetheless, it is an important part. The GWRC could have a far more ambitious and explicit strategy for upgrading the bus fleet, one that is more in line with the strategies of leading international cities and the urgent need for rapid climate action. The GWRC’s strategy needs to be economical, but also give proper weight to the impact which the bus fleet has on public health, the environment, and Wellington’s liveability and image as a progressive, sustainable city.
REFERENCES


APPENDICES

APPENDIX 1. THE PWC 2014 REPORT

The GWRC commissioned PwC to undertake a cost-benefit analysis evaluating a range of different bus options for upgrading’s Wellington’s bus fleet (PwC, 2014). PwC’s cost-benefit analysis included evaluation of bus purchase costs, infrastructure costs, maintenance costs, driver costs, fuel costs, time savings and emissions for each of the bus options. The report also included a wider economic evaluation of non-quantifiable considerations such as how the bus fleet contributes to national and local transport initiatives, wider environmental impacts, noise and visual pollution and cost risks. The report found that most options provided positive net benefits relative to the baseline option of maintaining Wellington’s current mix of trolley and diesel buses. The baseline option had the highest cost of the options due the current and future costs of upgrading and maintaining the power supply required to operate the trolley bus network. The report found that the greatest environmental benefits come from replacing the oldest diesel buses in the fleet, regardless of which bus option replaces them. The options that do not involve investment in supporting infrastructure (full diesel and hybrid buses) provide large, positive net benefits as they are cheaper, and have significant environmental benefits due to the replacement of the older diesels. The cheapest option would be to introduce modern diesel buses but this was the worst performing option in regards to reducing emissions.

PwC’s cost-benefit analysis has a number of limitations, particularly in regard to its calculation of the health, environmental and noise impacts of each bus option. For example, the PwC report has attempted to take into account the impact of PM_{10} and NO_{x} emissions on public health. However, it is not clear to what extent the monetised values applied to these emissions capture their health impact on society. The report does not include consideration of CO and HC emissions in its cost-benefit analysis. If the full health costs to society of diesel exhaust were realised in the evaluation this could have altered the benefit to cost ratio of the diesel reliant bus options. PwC also set the price of carbon at $40 per tonne in their evaluation. While $40 per tonne is significantly higher than the market price of carbon as currently charged in New Zealand, it does not truly represent the full impacts of emissions to society. The carbon price should realistically be set around $100 per tonne and placed on a rising trajectory (Chapman, 2015). The report also does not take into consideration a number of wider costs related to the continued use of fossil fuels, such as how it will affect the WCC and the GWRC’s climate mitigation targets, Wellington’s image, and whether it is considered a sustainable progressive city. Noise pollution is only factored into PwC’s wider evaluation and not in the cost-benefit analysis. The report itself acknowledges the shortcomings of its own evaluation into noise pollution, and suggests further more detailed modelling is required to fully understand the noise impacts of each bus option. PwC’s cost-benefit analysis has a number of other limitations; however, the issues discussed above highlight how the report underestimates the health, environmental, and noise impact of diesel reliant bus technologies.
APPENDIX 2. WELLINGTON CITY BUS FLEET

WELLINGTON CITY’S CURRENT BUS FLEET

The figures used in the graph below for Wellington City’s current bus fleet (as opposed to the Region’s fleet) were sourced from the PwC (2014) report.

![Bus Fleet Graph]

- **Total**: 278 buses
- **Euro V/VI**: 89 buses
- **Euro IV**: 11 buses
- **Euro III**: 51 buses
- **Euro II**: 4 buses
- **Euro I**: 63 buses
- **Pre-Euro**: 0 buses
- **Trolley**: 60 buses

(Wgtn City's current bus fleet)
The Wellington City replacement scenarios were interpolated from the regional data and the information available in the PwC (2014) report.
WELLINGTON REGION HC EMISSIONS

Scenario 1 Wgtn Region bus fleet HC emissions g/km

Scenario 2 Wgtn Region bus fleet HC emissions g/km
APPENDIX 4. WELLINGTON CITY BUS FLEET EMISSIONS

WELLINGTON CITY PM$_{10}$ EMISSIONS

**Scenario 1 Wgtn City bus fleet PM$_{10}$ emissions g/km**

**Scenario 2 Wgtn City bus fleet PM$_{10}$ emissions g/km**
WELLINGTON CITY CO₂ EMISSIONS

Scenario 1 Wgtn City bus fleet CO₂ emissions kg/km

Year

CO₂ emissions kg/km


Battery electric
Conventional hybrid
Euro V/VI
Euro IV
Euro III
Euro II
Euro I
Pre-Euro
Trolley

Scenario 2 Wgtn City bus fleet CO₂ emission kg/km

Year

CO₂ emissions kg/km


Battery electric
Conventional hybrid
Euro V/VI
Euro IV
Euro III
Euro II
Euro I
Pre-Euro
Trolley
Scenario 1 Wellington City bus fleet HC emissions g/km

Scenario 2 Wellington City bus fleet HC emissions g/km

Battery electric
Conventional hybrid
Euro V/VI
Euro IV
Euro III
Euro II
Euro I
Pre-Euro
Trolley
Scenario 3 Wgtn City bus fleet HC emissions g/km

Scenario 4 Wgtn City bus fleet HC emissions g/km

Scenario 5 Wgtn City bus fleet HC emissions g/km
APPENDIX 5. EMISSION CALCULATIONS

The tail-pipe emissions of the fleet replacement scenarios were calculated using figures from the PwC, 2014 report. The figures used by PwC are based on a number of assumptions, and are therefore indicative only.

The Euro emission standards for diesel buses cover CO, HC, NO\textsubscript{x}, and PM emissions. They are provided in g/kWh. In order to convert these values into a more easily comparable format of g/km, PwC used efficiency values (in MJ/100km) sourced from S. Donovan’s 2012 report: Powering Public Transport in New Zealand: Opportunities for alternative technologies and the standard energy conversion rate of 3.6MJ in 1kWh.

CO\textsubscript{2} emissions are not specified in the Euro standard for large vehicles. PwC have assumed that diesel emissions (kg/CO\textsubscript{2}) per MJ are 0.07325. This figure was sourced from the European Commission’s 2007 report: Well-To-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context. PwC used Donovan’s efficiency values (in MJ/100km) and the European Commission kg/CO\textsubscript{2} per MJ value (0.07325) to convert to kg CO\textsubscript{2} per km. PwC assumed, based on the year of Donovan’s report, that this value applied to Euro V standard vehicles. They therefore adjusted each Euro generation prior to Euro V to be 5% worse and for Euro VI to be 5% better. Hybrid emissions were calculated using the same method. PwC assumes, based on Donovan’s efficiency values, that conventional hybrid diesel-electric buses as 30 percent more efficient than Euro V diesels. The Wrightspeed hybrid buses are assumed to be 83 percent more efficient than Euro VI diesel buses. This is based on the conservative end of NZ Bus’s estimate that their converted buses will only need to operate using hydrocarbon fuel 0 to 17 percent of the time. It has not been possible to independently confirm NZ Bus’s figures.

PwC calculated the emissions from electricity generation but for the purpose of this report, only tail-pipe emissions were analysed.

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Table 2. Tail-pipe emissions by bus and emission type