The compelling case for returning to or continuing with negotiated contracts under the transition to a green fleet in Australia

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Abstract

Bus operators in the public and private sector are increasingly subject to competitive tendering and a requirement to operate under a gross cost contract. This contract sets out in detail the requirements of the operator including the levels of service as well as infrastructure required to deliver the contracted services. Buses acquired by operators in many jurisdictions in Australia have until very recently been essentially diesel fuelled and available from a panel approved set of buses compliant with Euro 6 standards. The predictability of the cost profiles of vehicles and associated costs of maintenance and repairs is well known and used in tendered offers. With the growing requirement of switching to a green fleet with varying timetabled transition rates, the future costs of providing bus services are going to be subject to significant unknowns. These unknowns are associated not only with the fast changing vehicle technology associated with a range of fuel sources (notably standard battery and fuel cell battery (i.e., hydrogen)), but also the impact this will have of the top-to-bottom change in the operations of bus fleets affecting operating and capital expenditure including depot infrastructure, timetabling, maintenance, labour skills and access to efficient electricity charging or hydrogen facilities. With such great uncertainty, the challenge of how to structure future contracts to allow for such volatility in cost commitments becomes of paramount importance to both the regulator and the bus operator. In this paper, I set out a preferred way forward to ensure that the transition to a totally green fleet is achieved without throwing the industry into chaotic uncertainty and potential financial ruin.

Keywords: Bus contracts, competitive tendering, negotiated contracts, buses, emissions, zero emission, electric, hydrogen, hybrids, infrastructure needs

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Introduction

The contracting of bus operators through either competitive tendering or negotiated contracts has been the standard procurement model for many years (Hensher 2020, Hensher and Wallis 2005). Although there was a period of debate as to whether the move to competitive tendering (preferred over economic deregulation in many jurisdictions) was value adding over negotiated contracts, this was often linked to jurisdictions where there was a history of family or publicly owned bus businesses (Hensher 2015). Operators have adjusted well to the competitive environment, mainly with gross cost contracts, although net cost contracts are also in place in some countries (for an update see van de Velde and Alexandersson 2020).

The bus fleets have historically been diesel with, more recently, a small number of hybrid vehicles, including diesel-CNG and diesel-electric. Diesel emits both CO_2, the main greenhouse gas[1], as well as a range of local air pollutants, in both the end use road environment and the maintenance cycle at the depot[2]. There is now a requirement in many countries to move to greener sources of fuel with a transition timetable. For example, in New South Wales (NSW), Australia, the Minister of Transport has recently announced that he wants all 8,000 buses under government contracts to be zero emission by 2030[3]. The candidate energy sources are standard battery and fuel cell battery (i.e., hydrogen)[4] with hybrids not seen as a long term solution. Such requirements are clearly challenging for the bus industry[5] and the regulator charged with implementing a plan to satisfy this aspirational goal. It has massive implications for how an entire bus business is run, impacting on not only the procurement of zero emission buses[6] but on infrastructure, maintenance, timetabling and training regimes.

It is an imperative for all stakeholders, assuming that it is even possible to replace 8,000 buses in nine years, to gain a better understanding of what will have to occur and the cost implications under existing contracts to achieve 100% replacement of a diesel fleet with a green fleet. The challenge is not only one contained within the operations of a bus business but also in how this new future might be costed[7] and

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[1] According to the Union of Concerned Scientists, an electric bus that is charged by the national electricity mix in the USA will produce 1,078 grams CO2e per mile, compared to 2,364 grams CO2e per mile for natural gas and 2,212 grams CO2e per mile for a diesel hybrid. (https://www.gregorypoole.com/electric-bus-guide/)

[2] All buses in Transport for London's (TfL) 9,000-strong bus fleet (similar in size to the 8,000 bus contract set in NSW) now meet or exceed the cleanest Euro VI emissions standards. This is a major milestone in tackling toxic air pollution in the capital and has significantly reduced the contribution from TfL buses to transport-related NOx emissions, with the proportion of transport nitrogen oxide (NOx) emissions coming from TfL's buses reducing from 15% to just four per cent. Since 2017, TfL has worked to phase out polluting diesel buses and to retrofit older buses with cleaner engines. Now completed, this will see harmful NOx emissions from buses fall by an average of 90%. For more details see https://tfl.gov.uk/info-for/media/press-releases/2021/january/london-s-buses-now-meet-ulez-emissions-standards-across-the-entire-city

[3] This may be seen as ambitious. For example, In the UK the big bus groups are working towards 2035 and they have had a significant head start on NSW.

[4] Hydrogen fuel cell vehicles that convert gas or liquid hydrogen into electricity to run an electric motor.

[5] The owner of Interline Buses in Sydney recently commented that "90 per cent of the operators wouldn't have a clue what they were buying, nor know what they are trying to buy". See https://www.busnews.com.au/product-news/2102/falling-into-line-interline-bci-e-bus

[6] The reference to zero emission is misleading since there are emissions associated with all so called green energy sources. For example, conventionally industrial hydrogen is manufactured from the methane in natural gas by using high-temperature steam in the presence of a catalyst. This produces hydrogen, but also carbon dioxide. This is called blue/grey hydrogen i.e., hydrogen created from fossil fuel. The problem here is that the process is not clean even if the subsequent use of the hydrogen is. Some processes lead to the carbon from the carbon dioxide being captured and stored in a stable form but this adds to the cost of producing hydrogen. Green hydrogen, in contrast, comes from a manufacturing process that is emission free through the electrolysis of water – sea water usually – into its constituent parts to give hydrogen with the power to instigate the electrolysis coming from renewable sources – solar/wind/water. Hence, the policy of zero emissions is unhelpful unless coupled to a zero emission form of production of the fuel in use. Ideally, transport decarbonisation strategies need to be accompanied by decarbonisation of the electricity generation network.

[7] A trial of individual buses in Australia suggests an addition 14c/km operating cost (excluding capital costs) for an electric bus over a diesel bus. For a fleet of 8,000 buses and an average km per bus of the entire NSW fleet of 729

financed by government, as well as the extent to which a major overhaul is required to obtain adequate access to energy sources required to charge the electric batteries or hydrogen production for fuel cell buses in a timely manner so that the bus fleet can maintain its on road obligations under current contracts.

We know, for example, from various trials of electric buses, that the amount of time required to charge a battery can impact significantly on the ability of the existing fleet to provide the timetabled and other contracted services, although in contrast, hydrogen can be used to fuel a bus in a similar time to diesel refuelling. There is currently a major constraint associated with the inability of many energy electricity suppliers to have enough capacity to serve an efficient charging regime at a bus depot and particularly as the number of zero emission buses is scaled up, even with upgrades on site. The result is likely to be a need to have more buses in the fleet to allow for the time that buses are out of service while their batteries are being re-energised[8]. This may not be an issue with hydrogen, although hydrogen has other challenges[9] including the continuation and price of hydrogen and how to make hydrogen. There is the real potential for sharing hydrogen production infrastructure amongst multiple fleets such as local authorities and freight operators[10].

With the growing requirement of switching to a green fleet with varying timetabled transition rates, the future costs of providing bus services are going to be subject to significant unknowns. These unknowns are associated not only with the vehicle technology associated with a range of fuel sources (notably standard battery and fuel cell battery (i.e., hydrogen)), which is fast changing, but also the impact this will have on the top-to-bottom change in the operations of bus fleets affecting operating and capital expenditure, including depot infrastructure, timetabling, maintenance, labour skills and access to efficient electricity charging facilities or volumetric hydrogen. With such great uncertainty, the challenge of how to structure future contracts to allow for such volatility in cost commitments[11] becomes of paramount importance to both the regulator and the bus operator. In this paper we propose a preferred way forward to ensure that the transition to a totally green fleet is achieved without throwing the industry in chaotic uncertainty and financial ruin.

A renewed interest in negotiated performance-based contracts

At the centre of the discussion on the best way to handle this transition to green is uncertainty and risk, value and the business ecosystem. The allocation of risk influences the choice of market arbitration and contract design. A Thredbo conference recommendation on appropriate risk sharing between the authority and operator is that risks should be allocated to the party that can best manage the risk (Leong et al. 2020). This is often difficult to determine, and inadequate risk allocation in the past may have triggered a revolving re-allocation of (arguably unmanageable) risks. This is akin to the idea of regulatory cycles initially proposed in Gwilliam (2008). Under a green transition, it is reasonable to assume that no one bus operator, let alone a regulator, can claim that they are the best agent to manage the risk, or indeed the experts advising each operator and government. Whereas operators often have greater experience in running a bus business (the operations level in the STO framework of strategic, tactical and operations), the regulator has tactical responsibility which is currently unclear, suggesting that both the operator and

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million, the additional cost per annum is around $100m per annum. Replacement of such a fleet today is estimated to cost around $5bn. at current vehicle purchase prices.

[8] We have been told that this could as much as 14% extra buses in a green fleet.

[9] The volume of hydrogen required to run a fleet of buses is significant due to the inefficiencies involved in creating usable hydrogen. Although hydrogen itself is the world's most abundant element, current access to sustainable green hydrogen and capability to store and distribute in a carbon-efficient way must be overcome to aid viability and further adoption.

[10] Aberdeen in Scotland has two publicly accessible H2 refuelling stations. https://www.aberdeencity.gov.uk/services/environment/h2-aberdeen#:~:text=Through%20the%20work%20of%20Aberdeen,road%20sweepers%20and%20waste%20trucks.

[11] Currently compounded by revenue uncertainty as we come out of the pandemic as passenger confidence hopefully grows. In NSW, contract renewal will not be an issue until at earliest next year but operators still face this uncertainty as the ex-STA regions are put out to tender.

the regulator are best to work together to share their skill sets and networks of advisors and agree on appropriate risk sharing in order to achieve the strategic intent of government.

This approach can be aligned with what is happening at present in many jurisdictions; namely the trend of de-risking on both sides of the operator in the value chain: on the manufacturer side with vehicles-as-a-service and the ever advancing (digital) capabilities of buses with many defects/maintenance requiring the expertise of the original equipment manufacturer (with links to new technologies like autonomous and electric); and on the government side with the government ownership of assets and management contracts. In some markets (e.g., Singapore, which modelled itself on Perth and London), government manages the hiring and training of bus captains (through the Ministry of Manpower and Singapore Bus Academy). In Darwin, the government even undertakes crew scheduling and development of rosters for their contracted bus operators. Bus operators can therefore become nothing more than an organiser of labour and are vulnerable to being squeezed out of the transport ecosystem (e.g., think a bus manufacturer putting drivers on their products and suddenly being able to take the role of a bus operator).

The rationale for such de-risking can be best be described as the need to be able to use best practice throughout the entire sector and to be able to draw on expertise from any source without barriers to entry or sharing. This will enable all parties to work together to share data and experience in sourcing the most appropriate technology for current and future digital platforms including vehicle technologies which will increasingly manage the supply chain of activities that the end use bus operator is becoming even more dependent on. Where operators are unwilling to share because of the tendered nature of their business future, there are major concerns.

The comments above have a pedigree in the literature on institutional maturity, and what we have through the green initiative is effectively a relatively immature market where we have much to learn about how best to transition into and delivery post-transition a cost efficient and cost effective bus service. This is a good argument for negotiation rather than tender.

Over the last thirty years there has been a global debate on the relative merits of competitive tendering versus negotiated contracts. Hensher and Stanley (2010) reviewed the evidence together with numerous studies reported in the Thredbo series (including Hensher 2015), suggesting that the case for tendering is no guarantee of achieving a cost efficient and service efficient outcome that is a significant gain over a well-designed negotiated contract model accompanied by a well-articulated performance regime with monitored key performance indicators. Despite the calls for careful comparison, competitive tendering in the main has won out on the argument of transparency. Hensher (2015) questioned this and provided evidence that many negotiated metropolitan contracts in Australia have been more cost efficient and hence give greater value for money than tendered contracts. The argument that competitive tendering is the best way to refresh the market has not been proven to be as effective as incumbent operators selling out to mainly multinational bus operators. Indeed the greatest quantum of businesses changing has occurred through purchase and not tendering.

Regardless of the relative merits of these two procurement models, the re-tendering model is premised on the (often implicit) assumption that we have a high level of knowledge of the expected levels of costs associated with the provision of bus services in the next contracted period, and with stable technology this of course was easier to predict. Both the regulator and operators (incumbent or otherwise) have always had access to information that allows the establishment of a cost efficient cost as a total cost/kilometre. With a stable technology this can be calculated by assuming that the bus fleet will continue to be diesel with a known depreciation profile (typically straight line) over an agreed life of the bus asset[12].

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[12] Some operators have reduced the period of write off in line with their revenue flows in order to reduce the tax impost in a particular year; however with a flat revenue stream there is little gain in so doing. In cases where operators continue to own buses, general requirements are for an average age of 12 years and no bus to be greater than 25 years. In NSW, the government specifies an approved panel from which operators may purchase their buses. Individual chassis and body manufacturers tender to be placed on that panel.

In addition, the maintenance program centred on diesel vehicles is well established as are the requirements for staffing to ensure that the timetabled and other bus services are delivered to the market without delay. This also has been achieved with a clear appreciation of the size of the fleet required to fulfil contracted services. Under competitive tendering, essentially of a Dutch auction format, the regulator has been able to receive bids and to compare them in such a way that they are strictly comparable in terms of what will be offered, essentially a well-designed level playing field (with known technology and associated costs). That is, the specification of all deliverables is very homogeneous, unambiguous and deemed to align with best practice. The difference between winning and losing is effectively linked to cost comparisons and offers of improved service quality. Hensher et al. (2016) investigated disruption costs in bus contract transitions and provided evidence that evaluators on tender evaluation committees do recognise the inherent risks in changing the service provider in bus contracts, and that it is possible to quantify the financial trade-off that evaluators make in balancing the risk associated with transition and disruption and the offer price. For example, if we take the median marginal rate of substitution between changeover cost and offer price reported by Hensher et al. (2016), the prices offered by a new provider might be adjusted upwards by the evaluation committee in their recognition of the impact of uncertainty due to expected risk of incurring transition costs from a change of incumbent, with the adjusted amount depending on the lowest offer price[13]. This is exactly the risk setting that will exist (and worse) under the transition to a green fleet.

With the advent of plans to transition to a green fleet, the context in which bus services will be provided is shrouded in extreme uncertainty, especially in respect of the underlying costs of providing services. Specifically, under a tendering regime, it may be virtually impossible to identify a comparable set of costs associated with a setting in which the infrastructure currently in place, especially at the depot as well as the appropriateness of the energy sources coming into the depot, is used to charge the batteries and/or replenish fuel cells. It is also unknown as to what green fleet fuel strategy will be adopted (electric battery, fuel cell battery hydrogen in particular), with access to various battery technologies improving at a fast rate, as well as the cost of redesigning the depot to accommodate charging bays that have enough ampere capability to charge in a reasonable time (noting that perceptions seem to vary widely) under an electric bus configuration, which is avoided with hydrogen tanks. There is also the added challenge of rolling out all of the required infrastructure at scale over a relatively short time frame. The current energy infrastructure in many depots is such that if electricity is used from the grid, charging times can be up to six hours[14], and depending on what time of day that can occur, there may be a need for additional buses to be able to comply with service requirements. The kilowatt hour (KwH) electricity charge is also something that is highly variable, and many electricity authorities currently do not have the capability through the grid to both vary the price and the intensity of energy, with this changing also as the pattern of demand changes. This is why why the transport policy and energy generation policy need to be considered hand in hand. With a highly variable KwH per kilometre, $/KwH and charging duration, there will inevitably be major issues in evaluating competitive bids. In contrast hydrogen can be set up in large tanks and used to refuel the buses along similar lines to diesel.

There is an issue here in terms of who is buying/owning the vehicles. It might be argued on the one hand that if the government owns the vehicles, one might expect a more consistent approach to be declared at some point in terms of the green fleet strategy. But that does not mean that the operator will have such good information on the relevant costs and indeed, what might be good for one operator may not be suitable for another, given the constraints and issues about infrastructure needs for the different green fuels. On the other hand, an operator who has the opportunity to devise their own strategy may well have a more informed view as a result of developing that strategy.

On the basis of the points raised above, the transition to a green fleet is best seen as a task that must not get confounded by the procurement of services model through uncertainties that are not the fault of the

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[13] For example, if we have a bid offer from a non-incumbent of say $6/km, then we might accept an equivalent offer of $6.50 from an incumbent.

[14] This is subject to the amps available and the time of day of charging since the latter is impacted by the overall demand on the grid.

operator or indeed the regulator. Until the large number of uncertainties have been ironed out, a more cautious approach needs to be considered. We would not want to see a very efficient incumbent operator missing out through the next rounds of tendering[15] as a consequence of the lack of reliable data and a tendering assessment process that is fraught with errors due to ambiguity and uncertainty in the way in which a green operations might evolve in the future.

What this situation suggests is the need for a trusting partnership between the regulator and *all* incumbent operators where sharing of knowledge and information will be essential (Stanley and Hensher 2008, Hensher 2020). This is the best way to proceed during such a rapid transition to green service provision which is surrounded by uncertainty. This can be achieved by a regime that is negotiated rather than tendered[16]. This will have the advantage of ensuring that all experiences gathered in transition and trials are shared amongst all operators and the regulator in an unencumbered way[17], and that the best outcomes are identified as a way in the future of developing an industry blueprint for any future tendered circumstance. In the remaining sections of the paper we take a look at some of the challenges that will face the bus industry in its transition to a fully green fleet.

Specific Challenges facing the Transition

In the process of investigating the best way forward to procure bus services from an operator in a green future with zero end use bus emissions, a large number of considerations have been identified that need to be commented on since they contribute to the support for a negotiated contract model with incumbent operators. Internal to the bus operation, there at least three major issues that need addressing.

The Diesel Bus

We begin with the existing bus fleets which have age profile obligations under the current contracts; for example, an average age in NSW of 12 years with a maximum age of 25. With a significant number of buses capable of operating for many more years, a timeline transition to a green fleet over the next 10 to 20 years in particular will mean that a large number of diesel buses will not have fully depreciated[18]. While the depreciation write off can be accelerated, this is a significant variation on the costs agreed to under existing contracts and could add as much as 25c/km to the existing gross cost agreement given the fleets currently in place in NSW. The equivalent annual capital costs of rigid standard and rigid long buses is approximately $50,000[19]. This is on average 7% of annual total costs, or 39c/km. Assuming that a diesel vehicle replaced early has an increased residual value, if it cannot be sold out of the contract then its value is effectively zero. Government however may not wish to sell these buses if the objective is to support a sustainable outcome regardless of whether the buses of interest are under a contract to government or otherwise[20]. It is likely that government would be severely criticised if they sold these buses to other parties, leaving the only option for government to fund the residual value, even if it were possible to sell off diesel vehicles to other jurisdictions which do not have such ambitious emissions

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[15] Contract cycles tend to be between 7 and 10 years, usually with a first option to extend for another 3 years.

[16] In NSW at present we have a number of procurement models: Sydney Metropolitan (SMBSC) is competitively tendered; Outer Metropolitan[16] (OSMBSC) is presently negotiated, with performance-based benchmarking; and Rural/Regional is going through an offer/acceptance process based on independent benchmarking.

[17] This will be crucial. Operators will not have the luxury of the learning experiences through (years of) trials that have occurred in Europe. Gaining familiarity with the green technologies will need to be built in somewhere. Operators owned by multinational groups may have some advantage here.

[18] Scania have suggested that if 650 buses were replaced with electric buses each year, it would take 25 years to replace the whole NSW fleet under government contract.

[19] Includes rehabilitation or mid-life refurbishment cost, typically at 12 years for buses and 20 years for trains, costing 10-15% of new vehicle cost. Calculations based on 7% discount rate per annum.

[20] The value will be affected by the way in which the second hand market for these vehicles will presumably flop as the world demands green vehicles?

reduction targets[21]. Strictly, the funding should be a net effect after accommodating the increased annualised capital cost of a zero-emission bus on present prices[22].

Available Energy sources

Electric Buses

Source/: https://www.gettyimages.com.au/detail/news-photo/electric-buses-stand-charging-at-a-yard-of-the-bvg-berlin-news-photo/1257428475?adppopup=true

The main focus here is on recharging the batteries in an electric bus, although we also comment below on hydrogen buses. The preferred model at present is recharging in the depot. The amount of charging space (and outlets) will depend on the charging cycle, which will itself depend on at least two considerations, the ampere (amps) available from the electricity supplier and the amount of energy remaining in the battery after completion of bus runs. Details of charging rates and experiences together with emission rates are given in Appendix A (especially Table A1).

The Leichhardt trial out of the Transit Systems depot in Sydney has shown that on route charging infrastructure may not be needed for bus routes in Sydney (Legislative Assembly of New South Wales 2020). Introducing electric buses in regional areas will require longer-term planning and consideration of what infrastructure is needed in each regional area.

Wiring and circuit breakers installed at existing depots may be inadequate for the load required, often insufficient to cope with 230 amps, which is a reasonable amount to reduce the battery charging time[23]. In one trial in NSW, even when the amps were reduced to 93 amps, some minor upgrades were required. In NSW, to draw in excess of 100 amps from the power grid, special approval has to be obtained from the power supply company. Electricians are generally concerned to install the charger at 230 amps due to what is believed to be insufficient coverage in AS /NZS 3000 for a charger of that amperage. Overall, the ability of the electricity supplier to ensure sufficient reliable amperage will be crucial to determining how many hours of charging are required, regardless of the operating condition of buses[24]. The greater the amount of time a bus is on charge, the greater the probability of requiring more buses to complete the

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[21] Furthermore, the chances of an Australian green fleet transition policy being explicitly linked with climate change emission reduction targets seems slim at present.

[22] From Australian trials, given the electric supply quality and tariff, the average operating cost per km for an electric bus is 0.28c compared to 0.42c for a diesel bus. For one trial, the total projected cost over the duration of the trial (97 days) for the operation of a diesel bus was $21,478; and an electric bus was $14,318, the difference being $7,159.

[23] Most electric buses are slow-charged overnight using 30-60kW chargers for three to four hours. So, creating a new depot for say 50 battery buses requires a 2.5MW connection – not easy to find in any city centre where the grid is already under pressure.

[24] The Interline CEO Joe Olivera in discussing his Sydney trial bus BCI Citirider E commented that for 10 buses "We estimated we'd be using about 300kW per day average on each bus and when we did this bus on full double shifts we actually pumped into it 279kW. And because I haven't got my electricity yet – my 2,000 amps – it took nine hours to charge because if I charged it any faster I would have blacked out the place." See https://www.busnews.com.au/product-news/2102/falling-into-line-interline-bci-e-bus

number of required bus runs, unless most of the charging can be undertaken outside of hours when most buses are at the depot. This would be mainly late evenings through to about 5am; however with increased demand for electricity supply from the grid for electric cars and other household items through the night, the capacity constraint on the grid may deny the ability of a bus operator to rely on off peak late at night and early morning charging, at competitive rates. Whilst these are issues likely to be repeated around the world there will also be local contextual issues; for example air conditioning in Australia versus heating needs in the UK/Europe that provide big draws on the power supply.

The appeal of Hydrogen

The alternative is hydrogen which may be more appealing since it bypasses the electricity grid and operates essentially the same as refuelling a diesel bus with the difference that the tank containing hydrogen is used to charge up the fuel cells in the bus. This process is very fast (just like refuelling a diesel bus) and hence may mean that the current depots can be more easily re-configured compared to re-charging stations for electric buses. For example, Transit Systems operate in the UK and maintain 10 hydrogen buses as part of the project 3Emotion (Environmentally Friendly, Efficient, Electric Motion). The hydrogen buses[25] are refuelled using a system that delivers gaseous hydrogen in a comparable time to the refuelling of diesel bus using the same refuelling process and procedures. Today the preferred form of hydrogen is liquid. However, the emission rates for hydrogen given current knowledge can vary significantly compared to plug-in charging for electricity (see Table A1), with gCO_2/km, gCH_4/km and gN_2O/km being approximately 7% lower or 42% higher (even when the end use emissions are zero) depending on the source of evidence, with the high end based on Taiwan evidence reported in Chang et al. (2019).

With a range of 400 kilometres from one fill, enough for a full day's work, hydrogen-powered fuel cell electric buses have great appeal. There are a number of ways to produce hydrogen (Table 1)[26]. For example, electrolysis, unlike battery charging, will place a relatively steady demand on the energy network throughout the day from a biomass power station consuming waste wood. Since it can be easily stored it can be produced at low electricity demand periods, in contrast to charging EVs on demand (which might occur with buses from time to time). And hydrogen buses will have a longer range than electric buses. To recoup the climate benefits of a greener vehicle fleet, we must look to a fuel supply that does not emit carbon i.e., we must look to renewable electricity or green hydrogen. Australia has vast resources in hydrogen production using both CCS and renewable methods to avoid high emission levels (Geoscience Australia 2020). Having clean production pathways is considered critical in determining whether hydrogen buses can help achieve emission reduction targets from the diesel bus fleet (Liu et al. 2018).

Correa et al. (2017) compare energy and environmental performances of five types of urban passenger buses powertrains using a multiphysic index on the basis of a well to wheel analysis. They conclude that

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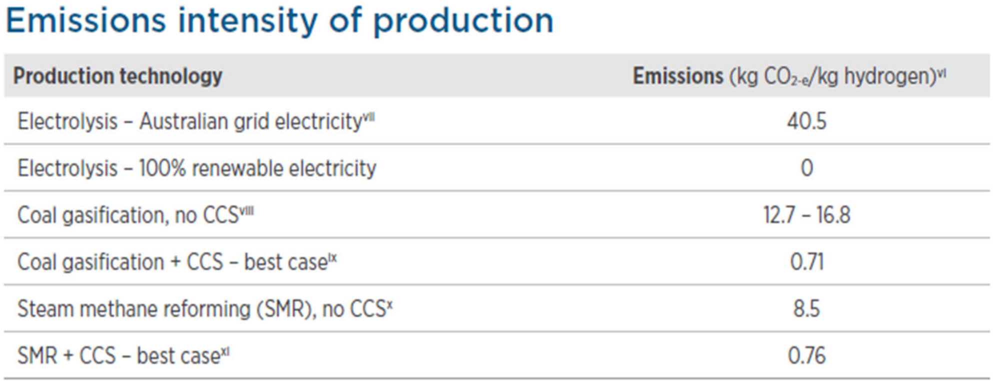
[25] The buses are ISE / Wrightbus hydrogen fuel cell BUS, Ballard FCvelocity HD-6 75kW fuel cell with a Dynetek hydrogen storage system, 30kg gaseous hydrogen at 350bar @ 15°C, Super Capacitor energy storage and VDL SB-200 chassis.

[26] For further detail see Logan et al (2020), section 1.2.

in the long term battery electric vehicles are convenient only for short driving range, while the fuel cell buses yield good performances for more extended driving ranges. For the cleaner powertrains to be competitive, hydrogen production must, however, be fed with clean and renewable energies and the renewable energy share in the electric energy matrix should be considerably high.

Table 1



Emissions intensity of production

Production technology	Emissions (kg $CO_{2\text{-}e}$/kg hydrogen)[vi]
Electrolysis – Australian grid electricity[vii]	40.5
Electrolysis – 100% renewable electricity	0
Coal gasification, no CCS[viii]	12.7 – 16.8
Coal gasification + CCS – best case[ix]	0.71
Steam methane reforming (SMR), no CCS[x]	8.5
SMR + CCS – best case[xi]	0.76

Source: https://www.ga.gov.au/scientific-topics/energy/resources/hydrogen

Infrastructure reconfiguration

Depots have historically been designed to cater for a range of maintenance tasks associated with all facets of a diesel bus. There are bays set up for oil and grease, general maintenance and tyre replacement etc. Electric buses cost less to maintain (in part due to less moving parts) and operate than diesel buses. Depot reconfiguration to accommodate electric buses will be substantial and costly. Additional funding will be required beyond the current contractual arrangements. Infrastructure costs will reach beyond the bus industry and depots. Clear guidelines and standards will have to be developed and agreed to by all parties in depot re-design and grid upgrades overall and access to depots. Nexport in tabling evidence to the NSW inquiry, has estimated that on site depot upgrades, allowing for 50 to 200 buses to be charged at any one time, would involve a new substation costing between $200,000 and $700,000. Hydrogen buses, by contrast, will require significant investment in secure tanks to store the hydrogen, similar in scale to diesel fuel, but it bypasses the electricity grid and requires less space for bus refuelling compared to electric re-charging.

Without adequate charging infrastructure, the wider uptake of electric buses will be severely curtailed. Private bus operators required to install such equipment would have to pass the cost on to government as part of their contract; however if this was subject to a competitive tender, it would create significant concern as to the availability of such facilities if an incumbent was unsuccessful in the bid process. More to the point, would a potential entrant be prepared to factor this uncertain upfront investment cost into their bid? While it is expected to be less of a risk for hydrogen buses, fuelled by liquid and gaseous hydrogen, changing technology will create great uncertainty on product selection. Building on the comments in a previous section it is important to know who will choose the nature of the fleet. If government insists on electric, then all the infrastructure costs need to be borne by an item line that is unambiguous in the gross cost contract. Individual companies may prefer hydrogen although it is far from guaranteed that the production of hydrogen is currently up to the demands that this would ensue.

All of these depot-related issues raise a more fundamental question as to whether the depot might become a totally separate business to the operation of a bus service on the road. Under a negotiated contract regime, it makes sense at this early juncture of great uncertainty and risk to work as a trusting partnership between the regulator and incumbent experienced operators to sort these matters out, even if subsequently a return to tendering takes place.

Although electric, in contrast to fuel cell, battery technology has had a head start and its lower cost reflects this, as the technology matures and production and distribution of hydrogen increases, hydrogen can become an increasingly viable option for heavy-duty uses such as buses. Hydrogen propulsion, although currently more expensive, is narrowing the gap with electric batteries, avoids upgrades to the local grid or the installation of on-street infrastructure, both of which are costly. It will however require other infrastructure such as electrical points at each parking bay to pre-heat the vehicles as well as installing roof sensors to map the levels of hydrogen in the atmosphere and modifications to workshops.

Conclusions

This paper has set out some of the challenges associated with transitioning a diesel-based bus fleet into a fully green fleet. The journey to 'greenness' will require significant changes in all aspects of operating a bus business and is shrouded in significant uncertainty and risk. The technology associated with alternative fuels is changing at a fast pace and it is far from clear as to what fuel sources will eventually win out as the preferred one for not only achieving zero emissions end use but also one that is cost efficient and effective within a business model that is workable for both a bus operator and the regulator[27]. The efficacy of electricity supply for recharging will also have a significant role to play in determining the amount of time required to recharge each battery and the need for additional buses over the diesel complement, unless the preference is for hydrogen. There may also be additional considerations related to the extent to which energy sources and bus supply can be sourced locally[28].

Whatever the likely technology landscape may look like, it is clear that the road to a green outcome will be best travelled through a trusting partnership between all the key stakeholders in the value chain, of which the regulator and the bus operator are the main participants, working closely with bus manufacturers, energy suppliers and depot reconfiguration specialists. To achieve this, we need to remove the competitive element of the procurement process, preferring coopetition through negotiated contracts with the incumbent bus operators until such time as the transition is complete and then to consider reviewing the market delivery options. That could be some time[29]. It is consequently very pleasing that the 2020 inquiry into electric buses in NSW (Legislative Assembly of New South Wales 2020) recommended that 'Transport for NSW includes the length of infrastructure upgrades and bus procurement in the transition plan.'

Appendix: Literature Review

There is a priority across the globe to shift diesel buses to electric buses (EBs) powered by Li-ion batteries or fuel cell hydrogen buses (FCHBs), or various forms of hybrid buses using both new and conventional fuels (e.g., Li 2016; Li et al. 2018; Pagliaro & Meneguzzo 2019). Li et al. (2018) examined the emerging trends and innovations for EB adoption in 22 countries across the Americas, Asia-Pacific and Europe. Their summary reveals that in most of these countries, the procurement of EBs is supported by governments' public grants. In several countries such as China, Singapore, South Korea, and Sweden, private grants are also given by large organisations. These grants come from local, national or international sources, in cash, in-kind or tax incentives. Availability of grants has sped up the process of shifting to EBs as well as uncertainty around these being maintained (e.g. due to COVID-19) will impact on the future roll-out of EBs.

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[27] I liken electric buses vs hydrogen buses as equivalent to the landline and mobile phone and there is a real risk that if we invest too heavily in electric buses (the outmoded landline) we may be missing out of the preferred technology of hydrogen buses (the mobile phone).

[28] Western Australia is committed to hydrogen as part of the alternative fuels strategy.

[29] The other elephant in the room is AVs and the extent to which these might also affect the cost structure – another big area of uncertainty.

In Asia, according to MarketWatch (2021), by May 2020, China had 420,000 EBs equal to close to 99% of the total global EB fleet. This represents 15% of China's bus fleet. Li (2016) provides several examples of how EBs have been rolled out in large Chinese cities such as Beijing and Shanghai through programs related to significant events such as the Beijing Olympics and the Shanghai World Expo. City governments are also the primary drivers to fund the shift to EBs in developed cities such as Shenzhen. Liu et al. (2018) also provide various incentive details for the national and local governments to roll out FCHBs in public transport. The other fast-growing country in Asia for EBs is India with a forecast by the year 2025, for India to account for 10% of the total annual demand globally (Sustainable Bus 2020a).

In Europe, EBs are gaining ground in many countries such as the Netherlands with over 10% of the total bus fleet and with the largest EB bus fleet in Europe. The EB rollout is also happening in the UK, France, Germany and other European countries. According to the UK government plan, by 2037 all 8,000 buses in London will be zero-emission buses (Sustainable Bus 2020a) with some private operators having set fleet-wide targets of 2035[30]. In the US as early as 2016, 55% of the public bus fleet were using alternative fuels, of which 15% were electric or hybrid-electric, the other 45% using natural gas or biodiesel (Lee et al. 2019). The current figures are higher with multiple emission plans being examined by national committees to shift heavy-duty vehicles, including buses, to a mixture of electricity, biofuel and hydrogen (National Academies of Sciences, Engineering, and Medicine 2020).

In Australia, State governments to varying degrees, have committed to an EV future and commenced the process of introducing EBs. In February 2021, the first 10 EBs begun operating on NSW roads and in total, 50 EBs will be rolled out during 2021. According to the NSW Minister for Transport, the goal is to convert the entire NSW bus fleet (8,000 buses) to electric by 2030 (Cotter 2021). This movement is expected to be followed by all States.

Both EBs and HBs have been tested in Australia (Li 2016). Although the general trend is to shift to EBs to achieve the zero-emissions target[31], state transport authorities are cautious in estimating the cost involved, with ongoing research to establish the feasibility of the fuel switch plan. For example, in Western Australia, the transit authority has tested buses using alternative energy, including diesel-electric hybrid and hydrogen buses. The data was used for Life Cycle Cost analysis to compare the total cost of these fuel types with the current diesel fleet. The results from 2015 suggest that the total cost of the hybrid bus is about 10% higher, and the hydrogen bus is much higher (Ally & Pryor 2016), although the gap is narrowing over time. How the findings are going to influence policymakers' decisions remains to be seen.

A report for the Victorian Department of Transport (Rare Consulting 2010) on how Australia might move to the new technologies and fuels, given the scale of the bus fleet, suggests that adopting new bus technology will be slower than in many overseas countries where technologies are more developed and implemented. In achieving the stated targets for emission reduction, four evaluation criteria are typically referred to, namely fleet suitability, fuel and emission benefits, cost implications, and the timeframe, all of which should the basis of an assessment of the merits of changes in alternative fuels (e.g., electric and hydrogen), alternative drivetrains (e.g., fully electric and hybrid), and vehicle technologies (e.g., vehicle aerodynamics, tyre technologies).

Fuel Consumption and Emissions of Current Diesel Buses

The fuel consumption of a bus depends on many factors such as the size and age of the bus, kilometres driven, road condition, patronage loading, and speed. Fuel consumption figures can vary from a typical low of 28 L/100km up to 65 L/100km from various sources (e.g., Ally & Pryor 2016; BudgetDirect 2020; Hydrogen Europe 2020). In the ITLS bus fleet data set for NSW, the average diesel consumption is around 41 L/100km (Balbontin et al. 2020). According to Ecoscore (2020), 1 litre of diesel generates 2.64 kg of CO_2 in the on-road environment. Suppose a bus uses 41 litres of diesel per 100km. For each kilometre, a bus would produce 1.08 kg of CO_2 emissions. In passenger per kilometre units, diesel buses in Australia result in 14 to 22 gCO2e/pkm (Climate Council 2017).

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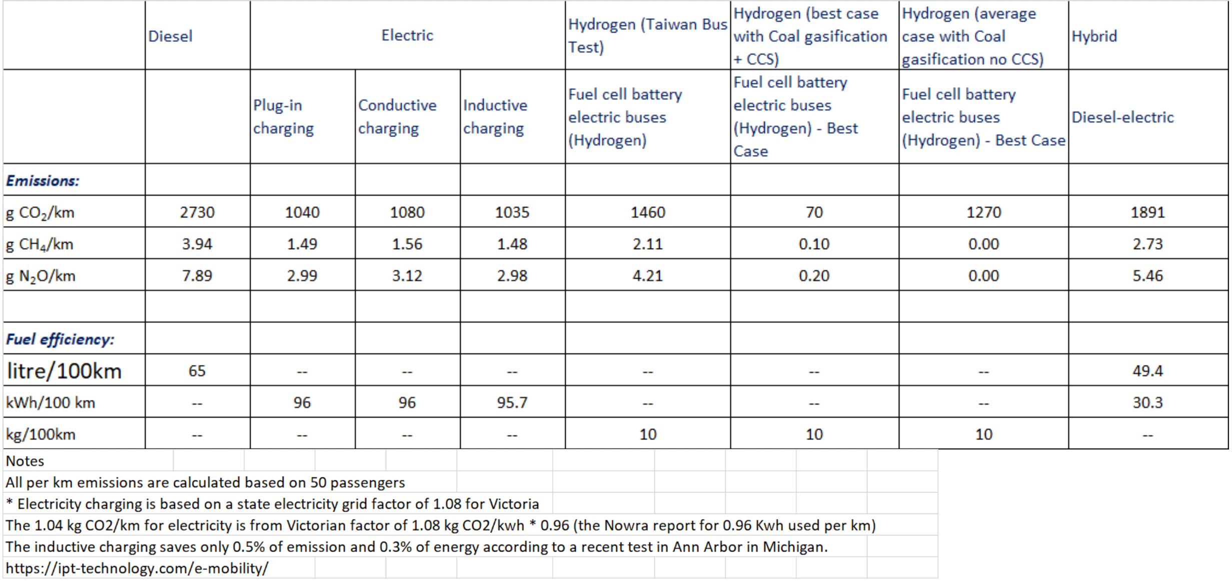
[30] See https://www.firstgroup.com/about-us/news/arrival-and-first-bus-confirm-start-zero-emission-bus-trials.

[31] Is it not a nonsense to have zero emission vehicles fuelled by dirty electricity? Even if it is only partly so?

The Australian Department of the Environment and Energy (2017) has provided detailed equations and factors for calculating transport fuel emission levels. For Euro buses using diesel (covering bus fleets in Australia), the energy content factor in GJ/kL unit is 38.6, and the emission factors are 69.9, 0.1 and 0.5 in kg CO_2-e/GJ unit for key GHG emission types of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) respectively. For example, if a bus fleet consumes 10000 kL of diesel, the relevant emissions are 26,981 tons of CO_2, 39 tons of CH_4, and 193 tons of N_2O. Table A1 summarises the assumption we have identified for a comparative assessment of the emissions of various energy-sourced buses.

Car passengers switching to bus travel can deliver noticeable environmental benefits. According to the Institute for Sensible Transport (2018), buses produce 17.7 gCO_2-e/pkm on-road emissions in the city of Melbourne, far better than 243.8 gCO_2-e/pkm for cars and also better than other public transport modes such as trains and trams. We question this estimate for buses, however, unless there is a very low average age of the fleet and favourable (low) load factors?[32] With a diesel bus producing end use gCO_2/km of 2730 (Table A1), and showing why hybrid has no part to play in a road to net zero, we would have to have an average passenger load of 154 passengers to obtain 17.7 gCO_2-e/pkm.

Table A1. Summary of Emission Factors for various Bus Configurations



	Diesel	Electric			Hydrogen (Taiwan Bus Test)	Hydrogen (best case with Coal gasification + CCS)	Hydrogen (average case with Coal gasification no CCS)	Hybrid
		Plug-in charging	Conductive charging	Inductive charging	Fuel cell battery electric buses (Hydrogen)	Fuel cell battery electric buses (Hydrogen) - Best Case	Fuel cell battery electric buses (Hydrogen) - Best Case	Diesel-electric
Emissions:								
g CO_2/km	2730	1040	1080	1035	1460	70	1270	1891
g CH_4/km	3.94	1.49	1.56	1.48	2.11	0.10	0.00	2.73
g N_2O/km	7.89	2.99	3.12	2.98	4.21	0.20	0.00	5.46
Fuel efficiency:								
litre/100km	65	--	--	--	--	--	--	49.4
kWh/100 km	--	96	96	95.7	--	--	--	30.3
kg/100km	--	--	--	--	10	10	10	--

Notes
All per km emissions are calculated based on 50 passengers
* Electricity charging is based on a state electricity grid factor of 1.08 for Victoria
The 1.04 kg CO2/km for electricity is from Victorian factor of 1.08 kg CO2/kwh * 0.96 (the Nowra report for 0.96 Kwh used per km)
The inductive charging saves only 0.5% of emission and 0.3% of energy according to a recent test in Ann Arbor in Michigan.
https://ipt-technology.com/e-mobility/

Energy Consumption and Emission Reductions by Electric and Other New Buses

Energy sources such as electricity and hydrogen, when consumed on the road, do not generate on-road emissions or only generate a negligible level of on-road emissions according to Climate Council (2017). However, the manufacturing, production, and disposal processes imposes non-zero emission outcomes resulting in positive overall life cycle emissions[33]. In comparing the full lifecycle emissions associated with alternative fuels to operate buses, these other emissions should not be ignored[34].

A comparison of life cycle environmental impacts of alternative energy types is summarised in Table A2 by Sharma and Strezov (2017). Interestingly they find that electricity linked sources create some of the greatest negative environment impacts than some other energy sources when the full life cycle is accounted for.

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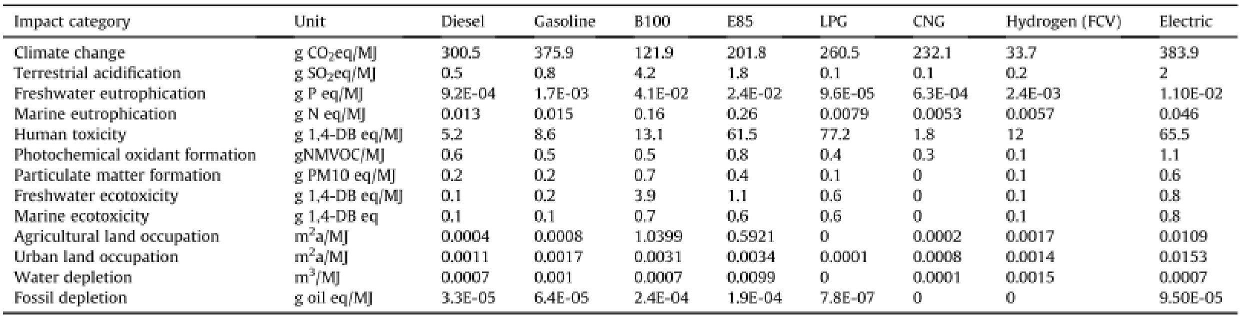
[32] See https://theicct.org/sites/default/files/publications/ICCT_Euro6-VI_briefing_jun2016.pdf

[33] For example, whilst green hydrogen has no emissions the cost of producing the plants to produce it is expensive?

[34] A useful a comparative paper for urban buses is Correa et al. (2017): https://www.sciencedirect.com/science/article/pii/S0360544217315876?via%3Dihub

Table A2. The emission intensity of production (Sharma and Strezov 2017)



Impact category	Unit	Diesel	Gasoline	B100	E85	LPG	CNG	Hydrogen (FCV)	Electric
Climate change	g CO_2eq/MJ	300.5	375.9	121.9	201.8	260.5	232.1	33.7	383.9
Terrestrial acidification	g SO_2eq/MJ	0.5	0.8	4.2	1.8	0.1	0.1	0.2	2
Freshwater eutrophication	g P eq/MJ	9.2E-04	1.7E-03	4.1E-02	2.4E-02	9.6E-05	6.3E-04	2.4E-03	1.10E-02
Marine eutrophication	g N eq/MJ	0.013	0.015	0.16	0.26	0.0079	0.0053	0.0057	0.046
Human toxicity	g 1,4-DB eq/MJ	5.2	8.6	13.1	61.5	77.2	1.8	12	65.5
Photochemical oxidant formation	gNMVOC/MJ	0.6	0.5	0.5	0.8	0.4	0.3	0.1	1.1
Particulate matter formation	g PM10 eq/MJ	0.2	0.2	0.7	0.4	0.1	0	0.1	0.6
Freshwater ecotoxicity	g 1,4-DB eq/MJ	0.1	0.2	3.9	1.1	0.6	0	0.1	0.8
Marine ecotoxicity	g 1,4-DB eq	0.1	0.1	0.7	0.6	0.6	0	0.1	0.8
Agricultural land occupation	m^2a/MJ	0.0004	0.0008	1.0399	0.5921	0	0.0002	0.0017	0.0109
Urban land occupation	m^2a/MJ	0.0011	0.0017	0.0031	0.0034	0.0001	0.0008	0.0014	0.0153
Water depletion	m^3/MJ	0.0007	0.001	0.0007	0.0099	0	0.0001	0.0015	0.0007
Fossil depletion	g oil eq/MJ	3.3E-05	6.4E-05	2.4E-04	1.9E-04	7.8E-07	0	0	9.50E-05

Chang et al. (2019) compared the emission levels associated with buses operated in the city of Tainan. They conclude that emission levels are 63.14 gCO2e/pkm (grams of carbon dioxide equivalent per passenger kilometre) for CNG buses, 54.6 gCO2e/pkm for diesel buses, 47.4 gCO2e/pkm for LPG buses, 37.82 gCO2e/pkm for plug-in EBs, and 29.17 gCO2e/pkm for FCHBs. These results suggest that reducing emission levels by moving from a fleet of diesel buses through to alternative fuels to a full electric bus does significantly reduce overall emissions, but when we consider the whole life cycle and not just end-use, we do cannot claim zero emissions and in general the debate of zero emission buses is misleading.

Generating electricity through the electricity grid creates emissions. The emission factors recommended by the Australian Department of the Environment and Energy suggest that the indirect emission factors for consumption of electricity or loss of the electricity from the grid vary by state. For example, in NSW and ACT, sourcing electricity from the grid would generate emissions at 0.83 kg CO2-e/kWh. In VIC, the factor is 1.08 kg CO2-e/kWh which is the highest in Australian states and territories (Department of the Environment and Energy 2017).

Logan et al. (2020) recently compared the emission levels of conventionally fuelled buses (CFBs) with electric buses (EBs) and hydrogen buses (HBs) in the UK. They found that CFB emissions were 36 times higher than EBs and 9 times higher than HBs, considering the various electricity and hydrogen generation process profiles. Some generation processes generate much higher emissions than other methods.

From tests run by electric bus makers such as Bozankaya Sileo, Solaris and VDL, the types of EBs and how much EBs consume in fuels largely depends on conditions associated with on-road operations, such as temperature, air conditioning, heating, driving behaviour and other factors. According to manufacturer's data, EBs with a 300 kWh charge may operate at 375 kms in the best case but may also only run as few as 130 kms in harsh weather with the heating turned on. This result also implies that the total emissions can vary significantly depending on electricity consumed for the same distance travelled. Some hybrid EBs with fossil fuel being used to run the air conditioning and heating may save electricity, but at the same will generate more on-road emissions due to the fossil fuel consumption (Sustainable Bus 2020b).

Similarly, emissions from hydrogen buses from a life cycle perspective can vary significantly due to various production technologies shown by the statistics provided in Table A3 by the COAG Energy Council (2019).

Table A3. The emission intensity of production (from COAG Energy Council 2019)

Production technology of hydrogen	**Emissions (kg CO2-e/kg hydrogen)**
Electrolysis – Australian grid electricity	40.5
Electrolysis – 100% renewable electricity	0
Coal gasification, no carbon capture and storage (CCS)	12.7 – 16.8
Coal gasification + CCS – best case	0.71
Steam methane reforming (SMR), no CCSx	8.5
SMR + CCS – best case	0.76

Several main hydrogen production processes include SMR, electrolysis, and solar, wind or biological driven processes (Energy.gov 2020; Rapier 2020). Some of these production processes can generate a large carbon footprint. With this said, Australia has vast resources in hydrogen production using both CCS and renewable methods to avoid high emission levels (Geoscience Australia 2020). Having clean production pathways is considered critical in determining whether hydrogen buses can help achieve emission reduction targets from the diesel bus fleet (Liu et al. 2018).

Without considering the production, emissions from hydrogen vehicles are negligible in fuel consumption. In a small hydrogen vehicle such as the Hyundai Nexo, 1 kg of hydrogen can travel up to 100 km. In heavy vehicles such as the transit bus, the fuel consumption level can be as low as 9 kg per 100 km in a new FCHB. FCHBs can run 300 to 450 kms without refuelling, offering a similar level of capacity (flexibility) as the diesel bus in operation (Hydrogen Europe 2020).

On-Road Factors Influencing Energy Consumptions and Costs of EBs

Without considering the production of electricity or hydrogen in the life cycle, what factors in bus fleet operation can influence the energy consumption levels of an EB or FCHB bus fleet? Higher energy consumption may not directly cause higher emissions on the road since both bus types generate negligible emissions but will certainly increase production-related emissions through higher demand.

Ally and Pryor (2016) show that distance, operating time, stops per distances, percent idle time, average operating time per day and average speed are closely related to energy consumption. This coincides with findings by Balbontin et al. (2020). Some other factors have also been discovered by researchers that are closely related to energy consumptions of EBs. For example, route characteristics and the amount of turning contribute to the energy consumed in electric buses (Beckers et al. 2020). Other factors that may impact electricity consumption include tyres, air conditioning, length and weight of the vehicle and fuel systems (National Academies of Sciences, Engineering, and Medicine 2020). Ritari et al. (2020) investigated the relationship of multispeed gearboxes of EBs and energy efficiency to energy consumption and costs.

Higher energy consumption on the road will also cause higher costs in operation to offset the benefits of EBs in using electricity compared to diesel. Mohamed et al. (2018) point out that cost is one of the top reasons that hinders Canadian bus service providers from adopting EBs. Besides capital costs for purchasing EBs and operating costs for human resources and infrastructure, fuel savings and electricity rates is a main consideration in cost. Lajunen (2018) simulated different operation conditions and scenarios of EBs concerning factors influencing energy efficiency, consumption and costs. The factors under investigation include bus configuration, charging method and operating routes. In particular, they looked at charging methods include overnight, end station and opportunity charging, and route conditions on different types of roads in Finland and California. The study reveals that the battery's energy capacity is crucial, while battery size has an insignificant impact on energy consumption and costs. The results also show in terms of life cycle costs that end station charges are more cost-effective than overnight charging and opportunity charging.

On FCHBs, according to Lee et al. (2019), the energy consumption of hydrogen buses is related to multilayer factors, and results can vary significantly, with examples of these factors related to each other such as geographic factors and regional electric grids. Energy efficiency for FCHBs is considered very important by the US government, so a benchmark was established to achieve 8 miles per diesel gallon equivalent. Besides technology development, the discussed factors and links to the bus fleet should be considered.

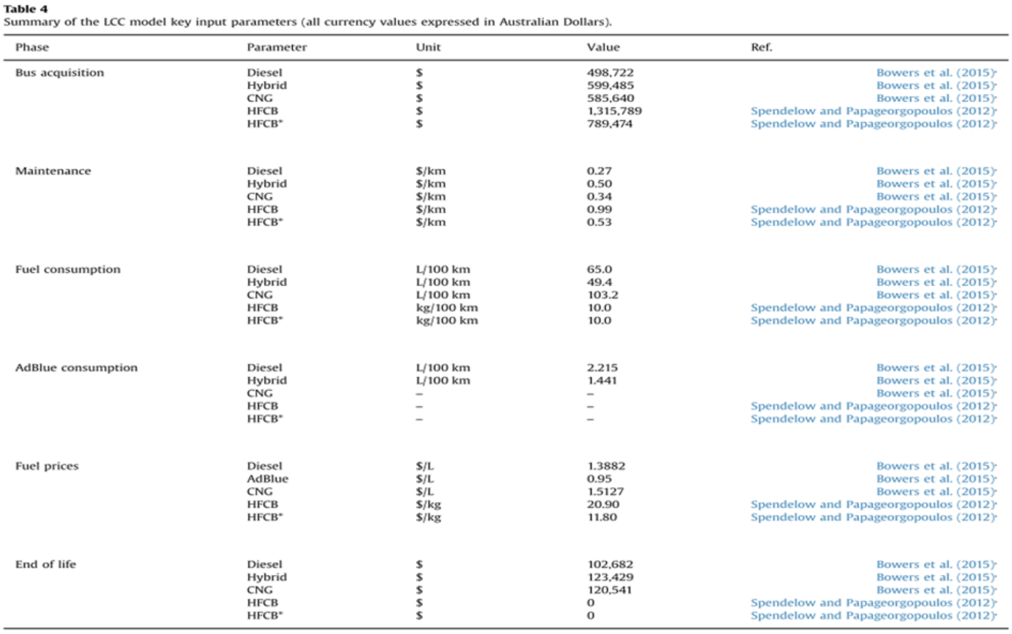


Table 4
Summary of the LCC model key input parameters (all currency values expressed in Australian Dollars).

Phase	Parameter	Unit	Value	Ref.
Bus acquisition	Diesel	$	498,722	Bowers et al. (2015)
	Hybrid	$	599,485	Bowers et al. (2015)
	CNG	$	585,640	Bowers et al. (2015)
	HFCB	$	1,315,789	Spendelow and Papageorgopoulos (2012)
	HFCB*	$	789,474	Spendelow and Papageorgopoulos (2012)
Maintenance	Diesel	$/km	0.27	Bowers et al. (2015)
	Hybrid	$/km	0.50	Bowers et al. (2015)
	CNG	$/km	0.34	Bowers et al. (2015)
	HFCB	$/km	0.99	Spendelow and Papageorgopoulos (2012)
	HFCB*	$/km	0.53	Spendelow and Papageorgopoulos (2012)
Fuel consumption	Diesel	L/100 km	65.0	Bowers et al. (2015)
	Hybrid	L/100 km	49.4	Bowers et al. (2015)
	CNG	L/100 km	103.2	Bowers et al. (2015)
	HFCB	kg/100 km	10.0	Spendelow and Papageorgopoulos (2012)
	HFCB*	kg/100 km	10.0	Spendelow and Papageorgopoulos (2012)
AdBlue consumption	Diesel	L/100 km	2.215	Bowers et al. (2015)
	Hybrid	L/100 km	1.441	Bowers et al. (2015)
	CNG	–	–	Bowers et al. (2015)
	HFCB	–	–	Spendelow and Papageorgopoulos (2012)
	HFCB*	–	–	Spendelow and Papageorgopoulos (2012)
Fuel prices	Diesel	$/L	1.3882	Bowers et al. (2015)
	AdBlue	$/L	0.95	Bowers et al. (2015)
	CNG	$/L	1.5127	Bowers et al. (2015)
	HFCB	$/kg	20.90	Spendelow and Papageorgopoulos (2012)
	HFCB*	$/kg	11.80	Spendelow and Papageorgopoulos (2012)
End of life	Diesel	$	102,682	Bowers et al. (2015)
	Hybrid	$	123,429	Bowers et al. (2015)
	CNG	$	120,541	Bowers et al. (2015)
	HFCB	$	0	Spendelow and Papageorgopoulos (2012)
	HFCB*	$	0	Spendelow and Papageorgopoulos (2012)

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