Zero (Tailpipe) Emission Buses, Transition Challenges, and Opportunities for New Partnership Contracting Models

Professor David A. Hensher, PhD, FASSA
Founder and Director
Dr Edward Wei, Senior Research Analyst
Institute of Transport and Logistics Studies (ITLS)
The University of Sydney Business School
The University of Sydney NSW 2006 Australia
http://sydney.edu.au/business/itls

Hensher, D.A., Wei, E. and Balbontin, C. (2021) *Comparative Assessment of Zero Emission Electric and Hydrogen Buses, report (including DSS),* 15 July report, 70pp.

Hensher, D.A. (2021) The compelling case for returning to or continuing with negotiated contracts under the transition to a green fleet, *Transportation Research Part A*, 154, 255-269.

Hensher, D.A., Wei, E. and Balbontin, C. (2022) Comparative Assessment of zero emission electric and hydrogen buses in Australia, *submitted to Transportation Research Part D, online Dec 1 2021.*

BEB Trials and 'almost' Current (I thank Dr Yale Wong for this update: yale.wong@sydney.edu.au) https://www.busnews.com.au/bus-sales-data/data, October 2021

Operator	Operating Area	Currently in Use (inc trial)	Trialled (finished)
NSW			
Total Busways Electric	All	7	
Total Transit Systems Electric	All	17	
Total Punchbowl Bus Co Electric	All	5	
Total Interline Bus Services Electric	All	10	
Total Transdev NSW Electric	All	3	
Total State Transit Electric			2
Total Premier Nowra Coaches			1
VIC			
Total Transdev VIC Electric		1	
Total Ventura Electric		1	
QLD			
Total Transdev QLD Electric		1	
Total CavBus Logan Coaches Electric		2	1
Total Brisbane City Council Electric		4	
TransLink	South-East Queensland		1
ACT			
Total ACTION			3
Non-government public services			
Sydney Airport Carbridge	Airport shuttle	6	
Brisbane Airport Carbridge	Airport shuttle	12	

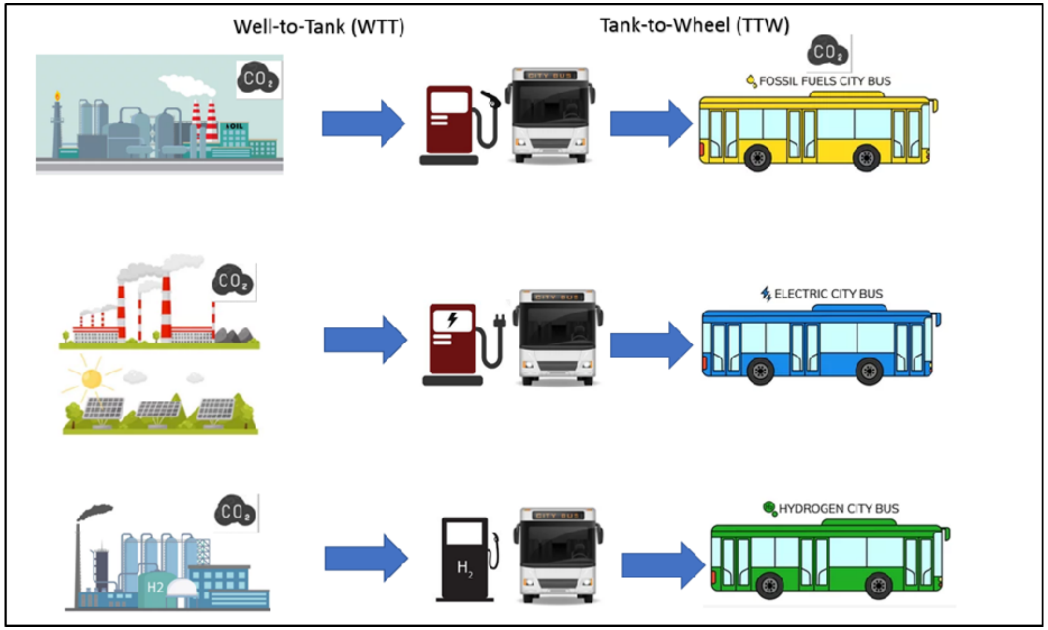
Future Plans (Ordered and/or Committed)

Operator	Operating Area	Type	Number Ordered and Committed	Notes
Ordered				
New South Wales				
Transdev John Holland Buses (NSW) from April 2022	Sydney Region 9	Custom Element	136	Transdev/John Holland
NSW Govt Contract Operators	Unknown	Bustech ZDi	60	Unknown exact operator
Queensland				
Clarks Logan City Bus Service	Logan City, Brisbane Region	Bustech ZDi	10	Due late 2022
Hornibrook Bus Lines (Keolis Downer)	Redcliffe City, Brisbane Region	Bustech ZDi	16	Due late 2022
Brisbane City Council	Brisbane City Council	HESS-Volgren-ABB Bi-Articulated	60	For Brisbane Metro
Sunbus (Kinetic)	Sunshine Coast	Yutong E12	5	Due 2022
Sunbus (Kinetic)	Cairns	Yutong E12	5	Due 2022
Western Australia				
Swan Transit (Transit Systems)	Perth	Volvo BZL Volgren Optimus	4	Due early 2022
Committed				
NSW				
NSW Govt Contract Operators	All Regions	Unknown	~8000	Replace diesel fleet by 2030
Keolis Downer	Sydney Region 8	Unknown	125	Takeover State Transit
Busways	Sydney Region 7	Unknown	35	Takeover State Transit
Total NSW	Franchise Contractual Commitment		160	
Total NSW	Policy Commitment		~8000	
Australian Capital Territory				
ACTION	Canberra	Unknown - sounding underway	90	
Victoria				
Kinetic	Melbourne Metro Bus Franchise	Unknown chassis Volgren bodied	36	Takeover Transdev

Comparison of the typical CO_2 emissions from different buses in the fleet (some non-zero emissions prior to tail pipe) Note: No local air pollution considered

Urban Bus Technology	gCO_2/km (WTT= Well-to-tank)	gCO_2/km (TTW = Tank-to wheel)	gCO_2/km (WTW or total)
Diesel Bus	162	1326	1488
Hybrid Bus	154	796	949
CNG Bus	187	1014	1201
Electric Bus	**292**	**0 (ZEB)**	292 (20% of Diesel WTW)

Conceptual illustration of WTW (WTT & TTW) emissions for diesel, BEB and FCEB



Well-to-Wheel' (WTW) includes all the emissions involved in the process of extraction/creation, processing and use of fuel in a vehicle to gauge the total carbon impact of that vehicle in operation. **'Well-to-Tank' (WTT)** only includes all the emissions associated with fuel up to the point that it enters a vehicle's fuel tank or energy storage device. **'Tank to Wheel' (TTW)** covers the emissions associated with fuel combustion in the vehicle, i.e. from the tailpipe.

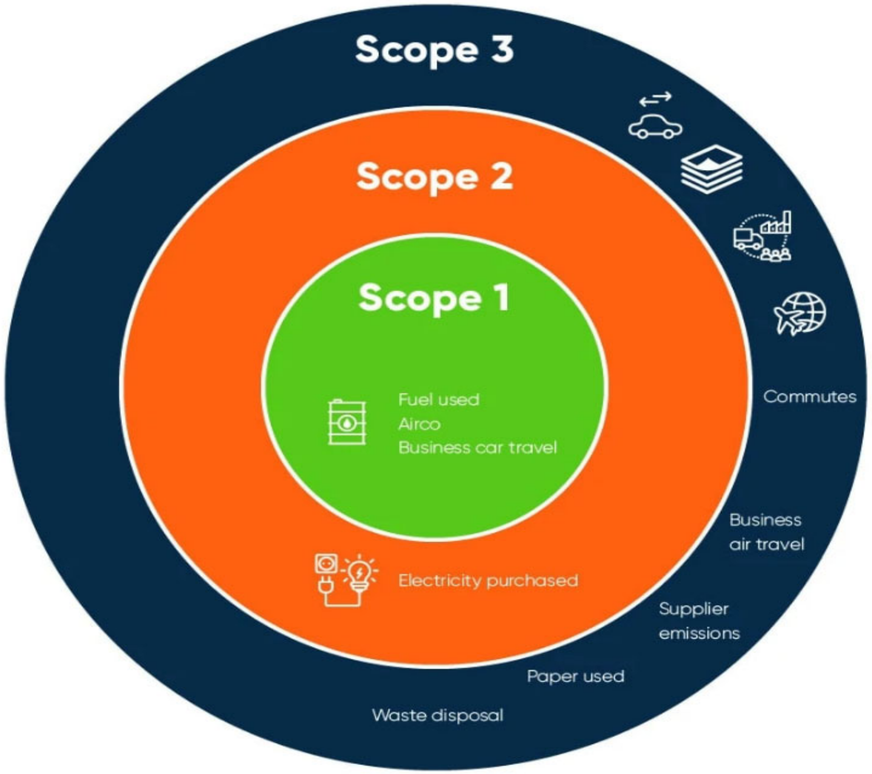
Renewable energy penetration by state (Source: Clean Energy Council 2021)

Gigawatt hours (GWh), is a **unit of energy representing one billion (1 000 000 000) watt hours,** equivalent to one million kilowatt hours

State	Total Generation (GWh)	Fossil Fuel Generation (GWh)	Total Renewable Generation (GWh)	Renewable Proportion of Generation	Renewables as Proportion of Consumption
Tasmania	10,956	90	10,866	99.2%	100.0%
South Australia	14,285	5,763	8,523	59.7%	60.1%
Victoria	49,390	35,705	13,685	27.7%	28.4%
Western Australia	19,171	14,528	4,643	24.2%	24.2%
New South Wales	**68,158**	**53,846**	**14,312**	**21.0%**	**19.1%**
Queensland	65,426	54,537	10,888	16.6%	18.0%
National	227,386	164,469	62,917	27.7%	27.7%

Clarifying Definitions : Direct and Indirect Emissions in the Supply Chain

– Emissions can also be categorised as direct and indirect.
– **Direct emissions** are emissions from sources that are owned or controlled by the reporting entity.
– **Indirect emissions** are emissions resulting from the activities occurring at sources owned or controlled by other entities.
– In defining the direct and indirect emissions, a definition of three scopes of emissions are often mentioned.



'The Grid – gorilla in the room' Neil Smith

Indirect emission factors for consumption of purchased electricity or loss of electricity from the grid (Source: Department of Environment and Energy 2017)

(Victoria is worse in Australia, but look at Europe, Poland excluded!)

State or Territory	Emission factor kg CO_{2-e}/kWh
New South Wales	**0.83**
Australian Capital Territory	0.83
Victoria	1.08
Queensland	0.79
South Australia	0.49
Western Australia	0.70
Tasmania	0.14
Northern Territory	0.64

State or Territory	Emission factor kg CO_{2-e}/kWh
Norway	0.019
Sweden	0.012
Denmark	0.209
Nordic countries	0.075
Italy	0.327
Poland	**0.846**
EU	0.294
US-avg.	0.432
China	0.555
Japan	0.506

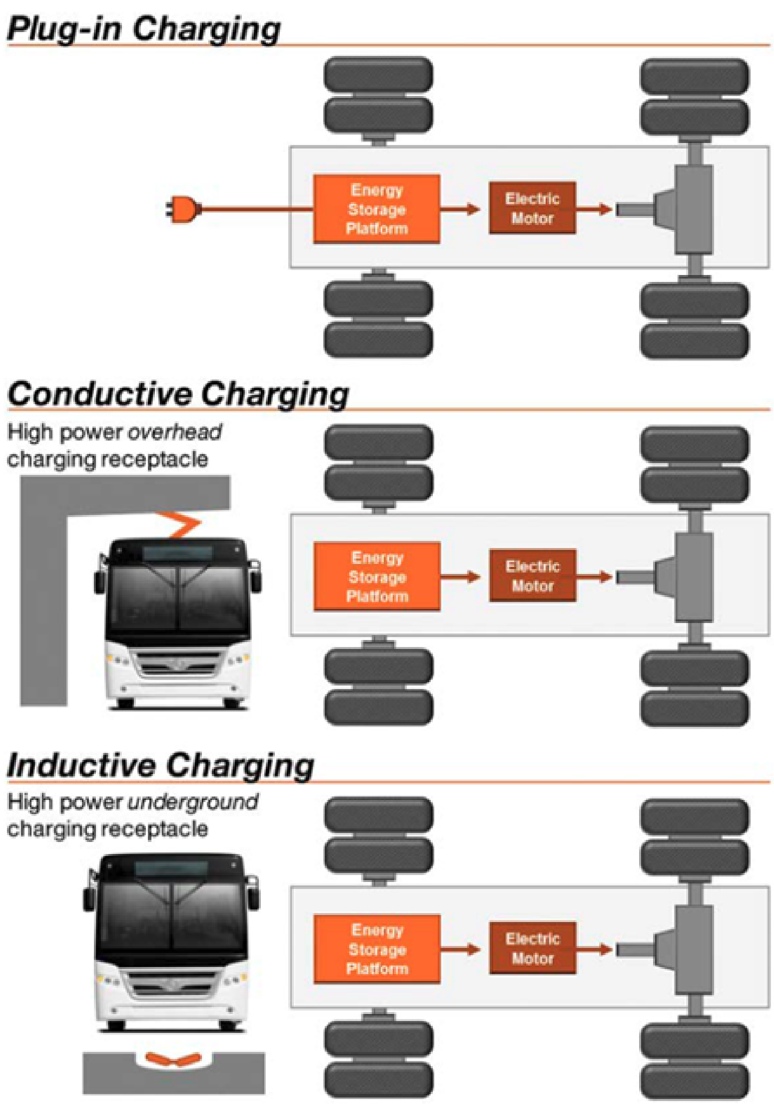
Source: Lie, K.W., Synnevåg, T.A., Lamb, J.J., & Lien, K.M. (2021). The Carbon Footprint of Electrified City Buses: A Case Study in Trondheim, Norway. *Energies*, 14,770, 1-21.

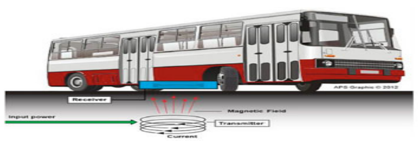
Comments on Various Fuel sources in terms of emissions

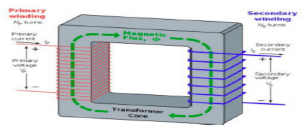
- The emissions that BEBs cause, when charged from the grid are indirect emissions.
- **A diesel bus** will generate on average 1.3 kg/km CO_2 emissions.
- If a bus is **an electric bus**, then to run 1km, 1 to 1.4 kWh electricity is required from the grid.
- An Example: Let us make it simple with 1km for 1kWh:
  - **Electric Bus:**
    - The actual level of CO_2 emissions from an electric bus running 1km is about
      - 1kg CO_2 if charged from a coal-powered station **(~70% of current energy)**, and
      - 0.5kg CO_2 from a gas-powered station;
    - The **actual life cycle emission reduction (cf diesel) can be as low as 26% if electricity is produced from coal** and **63% if electricity is produced from gas**.
  - If **Hydrogen** is produced with carbon capture and storage (CCS), the emission rate is about
    - 0.28 kg/kWh, plus some extra for compressing and transport;
    - hence the emission reduction will be less than either coal or gas generated electricity charged electric buses, calculated as a **75% reduction (cf diesel) in the life cycle emissions.**
  - However, if electricity or hydrogen are produced from **renewables** (e.g., solar, wind) and then used to power BEBs and FCEBs,
    - the life cycle CO_2 emissions will be close to zero or very low.
  - For example, in the above case, if BEBs are adopted in Tasmania, where electricity has a very low carbon density, **BEBs can truly be called ZEBs.**

A Note: Re zero emissions, "it all depends on the emissions intensity of the input source. If current grid energy, then electrolytic hydrogen would have emissions 2-3 times higher than the BEB. If using renewable energy, then both the BEB and green FCEB could be at zero. Thus BEB can also be zero; and conversely, it is not as simple as just plugging an electrolyser into the electricity grid, as emissions reductions will only be delivered if paired directly with renewable energy."

The charging methods: it matches fast charging with conductive charging, and wireless charging with inductive charging







The three leading charging technologies are:

1) lower power charging through cable and plug-in (e.g., AC or DC charging using charging system (CCS) or CHAdeMO systems);

2) higher power charging through conductive charging with physical connections (e.g., using fast charging equipment like a pantograph); and

3) fast charging through inductive/wireless charging using a magnetic field for fast charging (UITP 2019).

Besides these three methods, BEBs also include an **on-board regenerative braking process that may recharge up to 40% of the electricity back to the battery during operation**, especially in a metropolitan bus with many stops and starts.

A note: In the Australian market, there is early preference for depot charging with great emphasis on battery capacity and longevity per route, per day. But should this always be the case and will cities re-structure so as to enable route charging points?

Theme: charge fast and often - to minimise costs and maintain schedules via charging while passengers embark and disembark. (Implications on whether need more BEBs (15%?) cf Diesel buses for the given task?)

Key differences between the main battery types

	LFP Battery	NMC Battery
Configuration	Lithium, iron and phosphorous	Lithium, nickel, manganese and cobalt
Countries batteries mostly made in	Almost all bus batteries made and used in China are LFP	Japan, Korea, the US
Manufacturers	BYD, Yutong and other Chinese BEBs	Proterra
Market Share in 2018	88%	1.35%
Market Share predicted for 2028	58%	42%
Energy density	100 to 110 Wh/kg, or at most 60 to 70% of NMC	200 Wh/kg
Space occupation	bigger battery	smaller battery (40 to 50% smaller)
Mostly used in	**Buses**/Trucks	Cars (e.g., Tesla)
Safety	Safe against fire; less chance to have flames in a crash; high-temperature resistant	Less safe; overheating; fire incidence
Temperature	Better performance for high temperature	Better performance for low temperature (e.g., at -20 degree still can release 70% of capacity vs 55% from LFP batteries)
Charging efficiency	**Slow due to low energy density**	**Fast due to high energy density**
Cycle life	Longer. It can remain at 80% capacity after 3000 cycles of charge/discharge	Shorter. The theoretical life of NMC is 2000 cycles. Capacity fades to 60% after 1000 cycles.
Price difference	20% to 40% cheaper than NMC, can be as low as US$80/kWh after 2021	20% to 40% more than LFP battery
EU Bus Choice	Most	Less often

Overview of Emissions, Energy and Cost Savings

	Diesel	Battery Electric			Fuel Cell Electric (Hydrogen)		
		Plug-in charging	Conductive charging	WPT/IPT* (Inductive charging)	Grey Hydrogen (best case)	Blue Hydrogen (best case)	Green Hydrogen
Life cycle emission ($g\ CO_2/km$)	1350 (0.5 ltr/km)	656 (1 kWh/km)	682 (1 kWh/km)	650 (1 kWh/km)	850 (0.1kg/km)	71 (0.1kg/km)	0 (0.1kg/km)
Emission percentage relative to diesel (per km)	100.00%	48.59%	50.50%	48.15%	62.70%	5.26%	0.00%
Fuel efficiency per 100 kms	40 to 60 litres	90 to 150 kWh			9 to 10 kgs	9 to 10 kgs	9 to 10 kgs
Unit cost ($AUD2021)	1.50/litre	0.25/kWh			6.60/kg	9.06/kg	11.64/kg*
Energy/Fuel cost per 100 kms (low end) $AUD2021	**60.00**	**22.50**			59.40	81.54	104.76
Energy/Fuel cost per 100 kms (high end) $AUD2021	**90.00**	**37.50**			66.00	90.60	116.40
Cost saving relative to diesel (best case) (high end)	0	75.00%			26.67%	-0.67%	-29.33%
Cost saving relative to diesel (low end) (per km)	0	37.50%			1.00%	-35.90%	-74.60%

Grey H_2: Hydrogen formed through the processing of hydrocarbons, such as via SMR, where there is an unmanaged by-product of carbon dioxide.
Blue H_2: Hydrogen formed through the same processes as grey, black and brown hydrogen but where the carbon dioxide by-product is captured and secured via an appropriate Carbon Capture Utilisation and Storage (CCS) technology.
Green H_2: Hydrogen is formed via electrolysis of water using renewable electricity source(s) with no process-related carbon emissions.

Steam methane reformer

Black H_2: Hydrogen formed through coal gasification, where there is an unmanaged by-product of carbon dioxide.
Brown H_2: Hydrogen formed through lignite gasification, where there is an unmanaged by-product of carbon dioxide.

"It is imminently achievable that we will reach that magic $2 per kilogram for green hydrogen production well before the 2030 target," the director of the Energy Futures Network at the University of Wollongong Ty Christopher.

* A production cost at $2/kg seems possible, but then need to add in the distribution, infrastructure costs and profit margin, which I still believe will be closer to that $10/kg mark at the pump." Jake Whitehead UQ.

An Illustrative Scenario in Transition to 2030 (40 buses p.a. Using ITLS DSS discussed in later session) Savings compared to diesel buses

Scenario A: Replaced a bus fleet with 400 diesel buses in 2020 with 400 BEBs by 2030, with 40 BEBs replaced each year from 2021 to 2030. Electricity price at $AUD0.124 per kWh.

Scenario B: The case that all ZEBs are FCEBs, with 40 FCEBs purchased per annum from 2021 to 2030, will reach 100% ZEBs by 2030. $AUD2.00/kg with 90% green hydrogen

Scenario C: A mixed ZEB scenario group with 50% BEBs and 50% FCEBs in the 400 ZEBs fleet, incrementing equally over ten years. Next, we set the best conditions for both types with the electricity price at $AUD0.124 per kWh for BEB and $AUD2.00/kg with 90% green hydrogen for FCEB.

	Scenario 1b Electricity Price at $0.124/kWh	**Scenario 2c Green hydrogen 90% & $2.00/kg**	**Scenario 3b BEB and FCEB best scenario**
Average Annual Emission Reduction %	32.63%	53.44%	43.03%
Average Annual Fuel/Energy Cost Saving %	46.74%	41.19%	43.97%
Average Annual Maintenance Cost Saving %	16.80%	4.80%	10.80%
Total Emission Reduction (in tonne)	**98,281**	**160,951**	**129,616**
Total Fuel/Energy Cost Saving from 2020 to 2030 ($AUD for the year)	$69,350,530	$61,107,143	$65,258,837
Total Capital Investment for Purchasing ZEBs ($AUD for the year)	$278,000,000	$398,000,000	$338,000,000
Total Maintenance Costs Saving from 2021 to 2030 ($AUD for the year)	$30,800,000	$8,800,000	$19,800,000
Total Costs Savings Including Fuel and Maintenance 2021 to 2030 ($AUD for the year)	$89,036,442	$69,907,143	$85,028,837

Hensher, D.A., Wei, E. and Balbontin, C. Comparative Assessment of zero emission electric and hydrogen buses in Australia, ***Transportation Research Part D,*** accepted 24 November 2021**.**

Key factors to consider when purchasing and operating electric buses

Operation	Charging Infrastructure	Maintenance
• Route length, topography & electric range Passenger capacity • Operation day length of the bus • Flexibility of operational base/term of contract • Depot space to facilitate charging at night • Driver training to optimise efficiency and range • Fuel cost savings • Integration of e-buses across the whole organisation • Requirement for additional buses to cover e-bus downtime	• Number, type of charger & locations • Peak vehicle requirement • Availability of power • Power capacity at charging site • Managing peak demand • Optimising route scheduling with bus charging • Maintenance contract for infrastructure	• Lower frequency in brake pad replacement • No requirement for engine oil filter changes • Components likely to require replacement lithium battery, traction motor and power electrics • Manufacturers typically offer five-year warranty periods • Extra cost for extension beyond warranty periods • Tailored packages to support the vehicle life are available

1. Vehicles – weight, range, capacity
2. Infrastructure – fueling, equipment
3. Depot size
4. The Grid – gorilla in the room
5. Mixed fleets
6. Supplier concentration

Contract Risks:

1. Daily experience!
2. Grid – unmanageable for an operator
3. Time frame – contract length, long life assets
4. Depots: Design and Location
5. Finance: Availability, second-hand values
6. "Energy price" – predictable?

1. An inevitable upheaval of the industry
2. A decade of uncertainty ahead – technology, costs, contracts, capital
3. Conflicts between jurisdictions – energy regulation, land-use planning, depot location
4. 'Bias to big (operator)' may kill innovation

Procurement Considerations

"What is required is not a myopic, blind pursuit of a *process* goal [of a contract specification] often driven by dogma and ideologism, but a better appreciation of nuance in ensuring that context-specific institutional structures are put in place, guided by clear *end* goals."

Source: Wong, Y. (2020) Thredbo 16: Continuing the competition and ownership story, Working Paper number ITLS-WP-20-11, Institute of Transport and Logistic Studies, The University of Sydney Business School.

An important note: This talk promotes a procurement model that is not being targeted at a specific geographical jurisdiction, since we know that it may not be applicable to all situations, but in general appears to have appeal in many locations.

THE UNIVERSITY OF SYDNEY
Business School

Is it time for a revised bus contracting procurement model under a zero tailpipe emissions bus setting? The journey may have already begun!

Looking beyond Transition

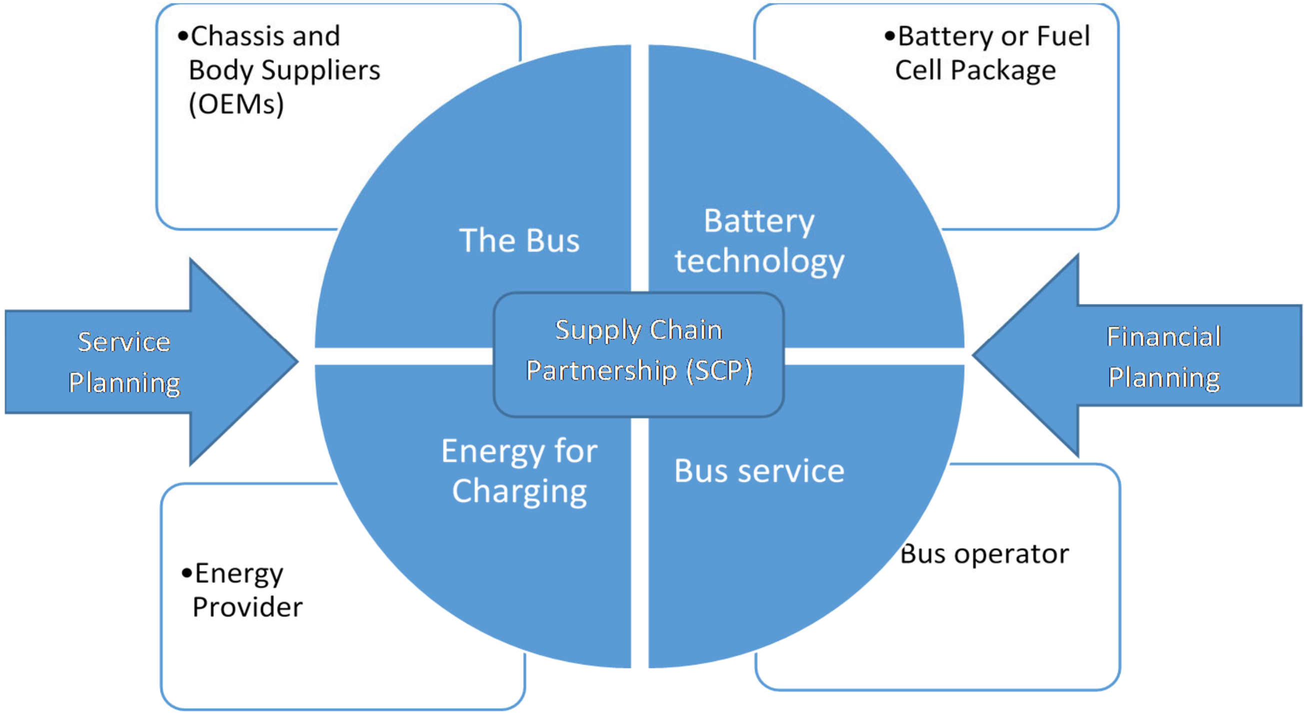
- Under a green transition, and more generally even over the past, it might not be unreasonable to assume that no one bus operator, let alone a regulator, can claim that they are necessarily the single agent best able to manage all sources of risk, or indeed have all the expertise required to best ensure a smooth ZEB transition.
  - This matter is even more relevant today.
- Whatever the likely technology landscape, the road to a green outcome is likely to be best travelled through
  - A "trusting" partnership between all (many of) the key stakeholders in the supply chain,
  - of which the regulator and a committed bus operator are the main participants, BUT working closely with electric/hydrogen bus manufacturers, energy suppliers and depot infrastructure reconfiguration specialists etc.
  - **With all sharing the risk given they are likely to obtain significant benefit as a consequence of the transition in recognition of shared value and its role in building corporate social responsibility.**

- **It is this heightened risk that suggests to me a new way, indeed an opportunity, to think about procurement**

- **We propose what I call, a *Supply Chain Partnership Contract (SCPC)***
  - Collaborative Contracting ***– see next slide***
  - Sound Familiar? – like a PPP for infrastructure projects. (e.g., Leichardt Depot: Transit systems West with Transgrid and Zenobi)
    - **Collaborative contracting is an alliance style delivery model.**
  - This recognises the real reason for contracting – to get the best value for the tax payers dollar.
  - It also reinforces the history of close working between OEMs, fuel suppliers, financial and technical advisers, and bus operators etc. (in contrast to working only or directly through government).
  - Applies to both metropolitan and rural/regional service contracts.

A Supply Chain representation of the Procurement model for Bus Contracts: Collaborative Contracting

Supply Chain Partnership (SCP)



A way forward: likely paradigm shift from traditional contracting i.e., contracts between government and operator, to contracts or management agreements between government and consortiums that account for the entire supply chain i.e., energy, OEM, asset owners, and operators, to give the government certainty of service continuance in a ZEB era.

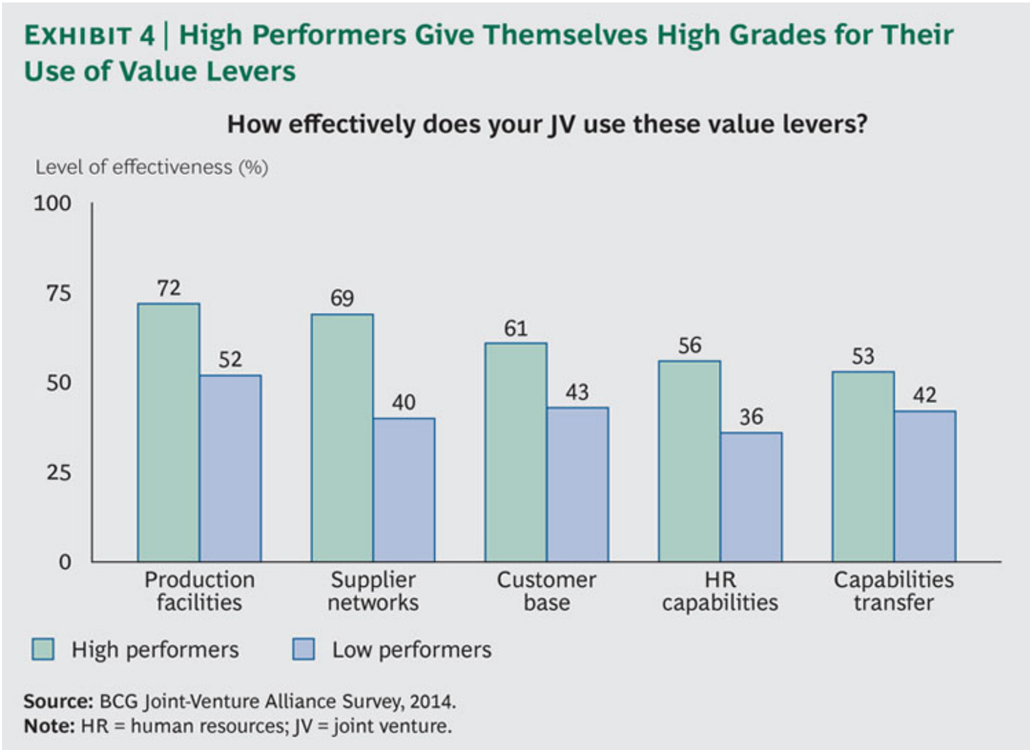
Encouraging: The very recent (Nov 28, 2021) Region 9 (Sydney) contract awarded to Transdev-John Holland partnership (called 'Transdev John Holland Buses (NSW)') is a good example of elements of an SCPC. (Advice: Robert Macey, Managing Director NSW, Transdev, ITLS Alumni) (Note: Macquarie Bank research says: "we believe this appointment reflects price, corroborating XXX discipline in bidding to avoid running contracts at a loss." Maybe it fails to recognise JV pricing advantage?

Joint Ventures – an SCPC model

Some advantages:

- Provides bus operators with the opportunity to gain new capacity and expertise.
- Enables bus operators to enter related businesses or new geographic markets or gain access to modern technology.
- Provides access to greater resources - including specialised staff and technology.
- Delivers competitive advantage compared to going it alone and subcontracting in other services and expertise.
- Can reduce cost of offer and hence improve success in winning contracts (on cost, service, risk….)
    - Including access to internal cross-subsidy capability

- Note: Bus operators who do not start to think this way may be more exposed to a limited (uncompetitive) future?



What might this all mean? Summary and the Proposed SCPC Approach

– We begin with a Q: Who will pay for the costs associated with achieving a smooth transition to ZEBs regardless of whether it involves battery electric buses (BEBs) or fuel cell electric buses (FCEBS)?
  – and in particular how can we provide a protective overlay to enable all bus operators, who to date have been cost and service efficient service providers, to continue in the industry with confidence that the burden of greater risk and uncertainty is shared amongst all parties who stand to gain by the transition to ZEBs?
  – This needs to be formalised in way that ensures that this new risk spectrum is reflected in the benefits on offer.
– Many approaches have been proposed, with the dominant plan in many countries being the transfer of most of the risk to government
  – through capital grants or government taking control in purchasing and paying for buses, the redesign of the depots and labour training, and subsequent ownership of most, if not all, infrastructure.
  – Leaving little risk to the operator and indeed is seen as reducing the obligations and responsibilities of operators and opportunities for operators to make a more positive contribution that simply be the servant in the master-servant model.

In Summary and the Proposed SCPC Approach

- As a consequence of a redistribution of risk, in large measure linked to the great uncertainty faced by bus operators in costing their future services under the ZEB transition, either through negotiation or competitive tendering,
  - the idea that the current contracting model (1 regulator, 1 bus operator) between government and the operator is sustainable in attracting enough bidders (if CT) is open for review.
- With an increased role for energy suppliers, bus manufacturers and infrastructure specialists in particular, who stand to benefit significantly,
  - a paradigm shift from traditional contracting i.e., contracts between government and operator,
  - to contracts or management agreements between government and competitive consortiums (or JVs) that account for the entire supply chain i.e., energy, OEM, asset owners, asset developers and operators,
  - to give the government greater certainty of service continuance in a ZEB era,
  - *might be more appropriate.*
  - Seems that Transdev has got the idea already to some extent.

In Summary and the Proposed SCPC Approach

- The binary agent tendering process between the bus operator and government throws everything up in the air and places an unnecessary degree of uncertainty, in my view, on government for the 'service continuance' imperative (see Hensher 2021).
- Time to spread the risk and reduce the uncertainty? Region 9 has started the journey.
- And to take greater advantage of all the expertise in the supply chain
  - For all of the expertise does not, and neither should it, reside with the regulator
    - Robb Sharp, The Secretary of TfNSW has stated on a number of occasions that TfNSW's role is to facilitate partnerships to add value.
- With benefits accruing to energy, infrastructure and bus providers in particular, there is a case that should be made for sharing the risks with all parties who stand to benefit from the ZEB transition.
- This also aligns well with the real reason for contracting – to get the best value for the tax payers dollar, and

- should be achieved in the way that inputs to the ZEB supply future are competitively determined during the phase where input risks are identified in contrast to just output risks that are common to the traditional tendered model.

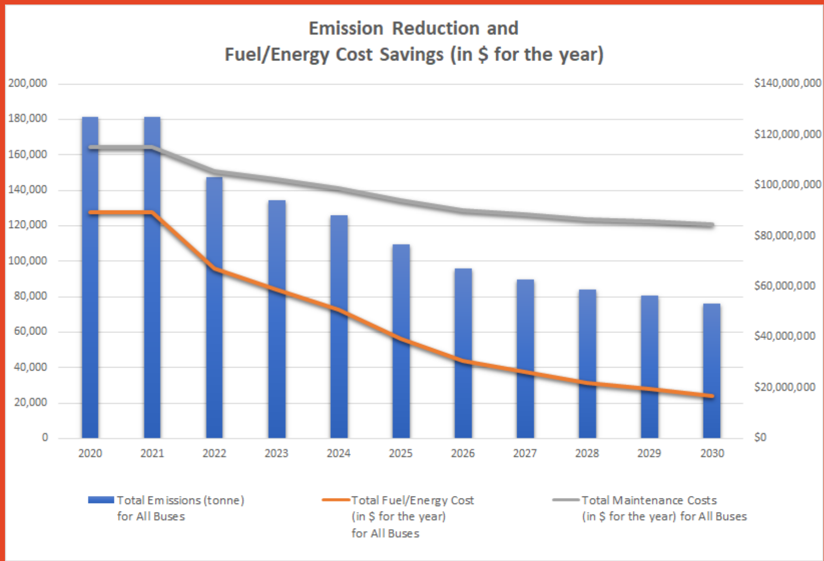
Finally, it is important to acknowledge that ‘the market cannot “just provide” without help from government, as the market does not exist as such. It needs commitments from government to coalesce and formulate viable business models.

Conversely, government cannot move forward without assurances as to what the market can reliably deliver, and at what price.’ (Dr David Ashmore, TSA Mgt, Linkedin 30 Nov 2021)

Catch 22;

A clear case for an SCPC as set out in this presentation is appealing.

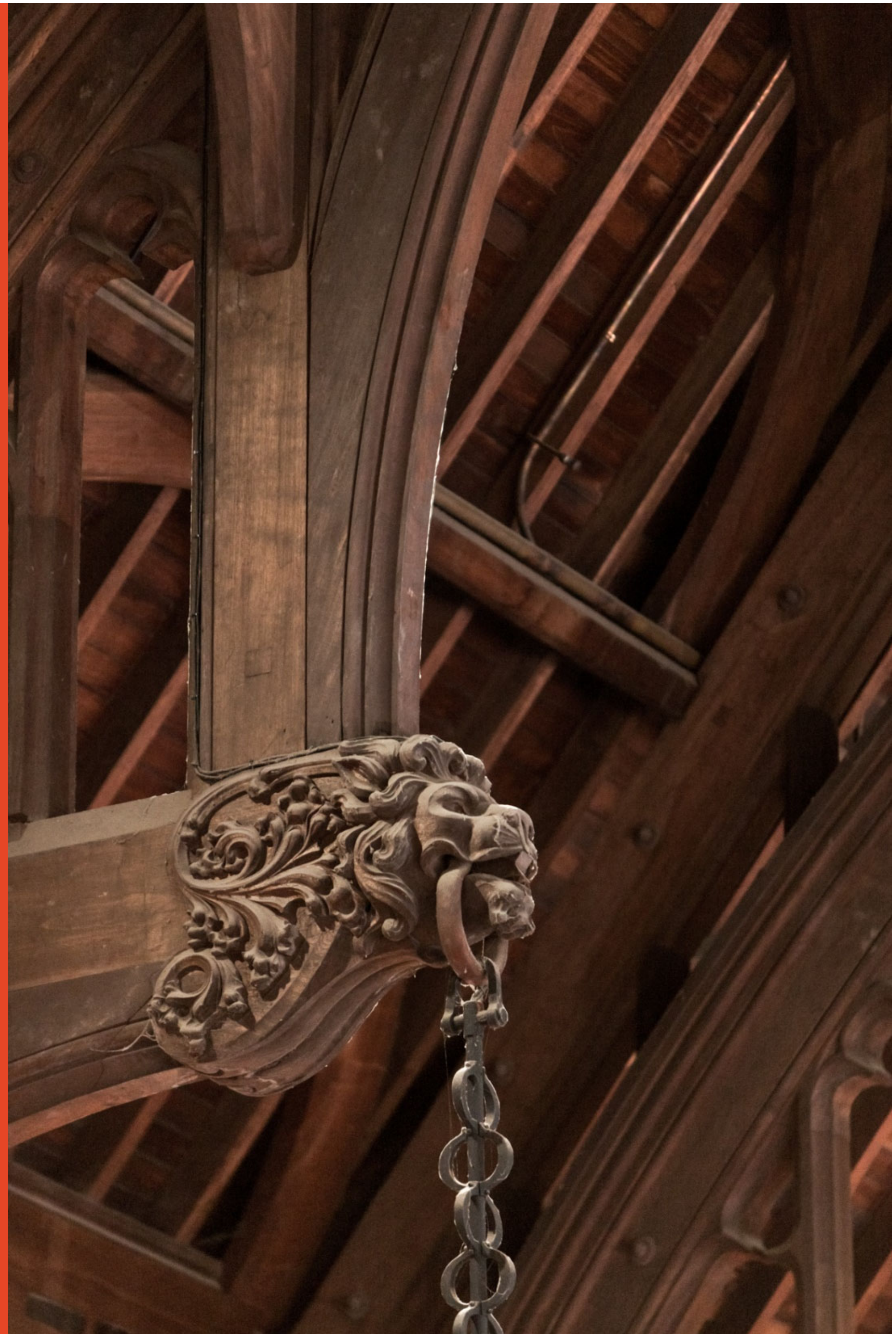
Decision-Support System (DSS):*Training and AdvisoryTool*



Copyright 2021 by ITLS, University of Sydney Business School

THE UNIVERSITY OF SYDNEY

Business School



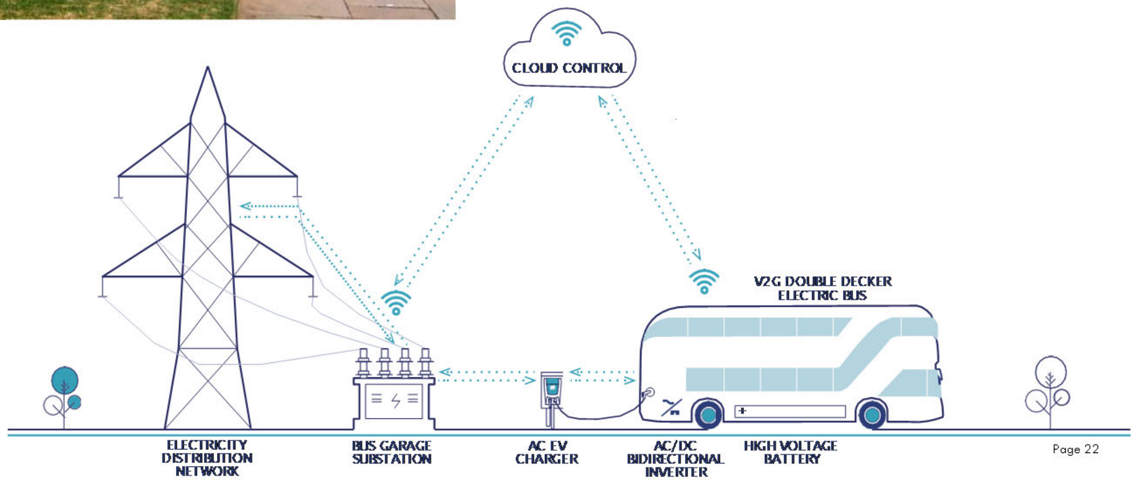
THANK YOU

David Hensher PhD FASSA
Institute of Transport and Logistics Studies (ITLS)
The University of Sydney Business School

THE UNIVERSITY OF SYDNEY
E david.hensher@sydney.edu.au | **W**
http://sydney.edu.au/business/itls

THE UNIVERSITY OF SYDNEY

ITLS



In Summary and the Proposed SCPC Approach

– Although the SCPC model is conceptually appealing to both competitive tendering and negotiation, once the competitively obtained SCPC product offer is ready to deliver to government, with full disclosure of the competitive process used to select participants in the SCPC,
  – we would support an initial negotiation between the regulator and the incumbent bus operator or another agent (representing the SCPC), as an appealing method for ushering in such transformational change,
  – based on the premise that there are at present a lot of unknown risks associated with transitioning fleets, large or small, from diesel to ZEB (Hensher 2021).
  – This is aligned with the adage 'give the efficient incumbent operator a chance'.
  – However, even if government wishes to use CT, the SCPC model will still work with a double dose of a competitive test at both the input and output stages of *efficiency determination.*

– Importantly, the SCPC model is a way of building in an incentive structure to move forward to a negotiated performance-based or CT contract with the regulator that has already been subject to a rigorous transparent competitive process.

– **The Transdev-John Holland Buses (NSW) joint venture (JV)** for Region 9 in Sydney is a first in Australia to recognise the value, in a partial sense, of a SCPC as a contract with government in providing bus services, with a commitment to provide a minimum of 136 electric buses up to 2030.
  – This may well signal the value of partnerships or joint ventures as a way of sharing risk and expertise, resulting in benefit creation under ZEB transition and beyond transition.

– More details in a paper available on request:

Hensher, D.A. Is it time for a new bus contract procurement model under a zero emissions bus setting? Full draft 29 November 2021.

Australia is not alone and others are working towards the SCPC

We can learn a great deal from the Canadian Urban Transit Research and Innovation Consortium (CUTRIC).

Within CUTRIC, federal and state government, infrastructure financiers, transport operators, bus and truck manufacturers, energy companies, and charging infrastructure firms come together to develop standards, and workable transition paths. Industry and academia can help facilitate these groups:
“Doing Science and Management with everyone at the table” (NAS, USA)

Developing whole-of-life cycle analytical models will assist the parties in the contract, supply and operational chain, to design a commercially, technically, and politically viable transition that manages risk, and allows for different rollout scenarios to be tested.

These need to work across both the transport and energy sectors.

https://lens-monash-edu.cdn.ampproject.org/c/s/lens.monash.edu/@climate-change-rising-to-the-real-urgent-and-globa/2021/11/11/1384045/wheels-in-motion-battery-powered-buses-and-the-road-to-zero-transport-emissions?amp=1

Finally, it is important to acknowledge that the market cannot “just provide” without help from government, as the market does not exist as such. It needs commitments from government to coalesce and formulate viable business models. Conversely, government cannot move forward without assurances as to what the market can reliably deliver, and at what price. Catch 22; but a case for an SCPC as set out in this presentation is appealing.

Importantly, this is very different to a bus operator negotiating or tendering with government since we now have a supply chain procurement team doing this within a setting where many of the transition risks have already been resolved prior to dealing with government, and most if not all risks are then internalised through the sharing model between the consortium partners, enabling government to have a clear contractual pathway in terms of its obligations to covering residual risk.

This should deliver a more cost efficient outcome than the current procurement model.

Like any reform, however, there are always caveats with one potential risk with the SPC consortium approach being the possible inclusions of financial buffers, margins and risk, although the competitive context proposed is designed to avoid or minimise this, but it needs to be compared to the inefficiencies of direct government engagement.

The question is: can a model be developed to achieve the desired outcome without paying more than the sum of the sub-elements?

The government model is essentially an ownership position that allows Government to ‘solve’ the infrastructure/ownership piece and simply tender or negotiate services.

That is where we will see an industry divided in many countries with large multinational, national and progressive operators in particular looking to Government to take the ownership and others resisting.

Institute of Transport and Logistics Studies (ITLS), The University of Sydney Business School

Decision Support System

The purpose of this Decision Support System is to provide an evidence-based forecasting tool for bus operators to forecast outcomes of emission reductions and fuel and energy cost savings when transitioning from a diesel bus fleet to a zero-emission bus (ZEB) fleet.

The DSS allows different numbers of buses in the bus fleet and includes both battery electric buses (BEBs) and fuel cell electric buses (FCEBs) using hydrogen. Treating 2021 as the starting base year with your chosen number of buses in a bus fleet, the DSS allows users to explore the financial and emission implications of a selected electrification plan over a ten year period from 2022 to 2031. Users can assign different numbers of BEBs and FCEBs for each year, and make a selection related to fuel consumption, charging strategy, battery type, and other choices relating to BEBs and FCEBs. The DSS also allows users to change the price for diesel, electricity and hydrogen to reflect market prices.

The summary worksheet provides the overall yearly and accumulated total CO2 emission reduction, fuel/energy cost saving and capital investment associated with a ZEB procurement plan.

Copyright 2021 by ITLS, University of Sydney Business School

Years	Total Numbers of Diesel Buses/BEBs/FCEBs Number of Battery Electric Buses (BEBs)	Number of Fuel Cell Electric Buses (FCEBs)	Number of Diesel Buses	Extra Diesel Buses
2020	0	0	2000	
2021	119	0	2181	0
2022	238	0	2062	0
2023	473	0	1827	0
2024	735	0	1565	0
2025	1001	0	1299	0
2026	1351	0	949	0
2027	1576	0	724	0
2028	1815	0	485	0
2029	1967	0	333	0
2030	2122	0	178	0

Reset Defaults and 0s for BEBs and FCEBs

Starting Number of Buses

2300

	Annual Shift to BEBs
0	0
0	119
0	119
0	235
0	262
0	266
0	350
0	225
0	239
0	152
0	155
Total	**2122**

	Annual Shift to FCEBs
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
Total	**0**

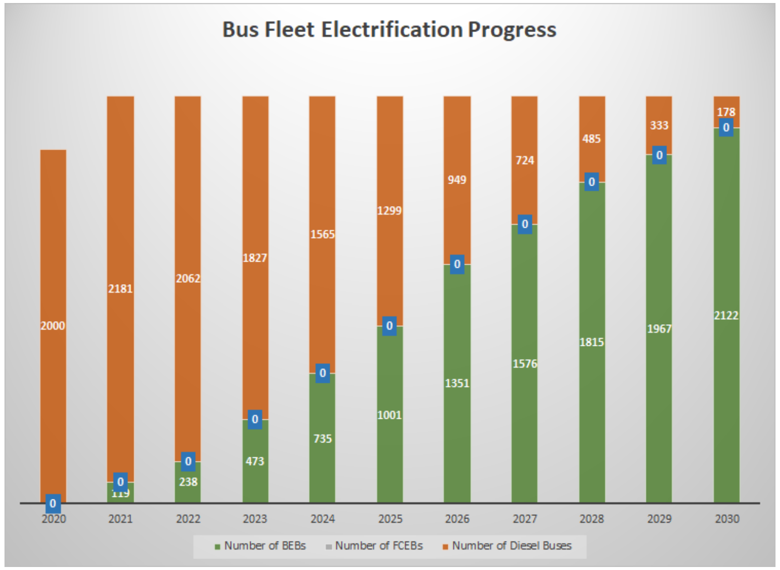
Now that you have entered your transition plan, you can either go straight to the summary tab where we provide estimates of costs and emissions based on assumptions we have made, or you can go to the year tabs and change the various items associated with our assumptions

The assumptions relate to

Annual bus kms
Passenger occupancy percentage
Diesel fuel efficiency (litres/100km)
Cost of diesel ($/litre)
Fuel consumption of BEBs in KwH/100kms and FCEBs in Kg/100km
Percentage of charging at the depot
Braking charge energy saving percentage
Percentage of charging time that is off-peak
Battery type mix (percentage)
Price per KwHr for LFP battery (all other prices are relative to this)
Price of NMC battery over LFP battery (higher in %)
$/kWh (electricity)
$/kg (hydrogen base price)
BEB Bus Value / BEB Battery Pack Value (Times)
Prices for Diesel bus and FCEB
Maintenance costs for BEB, FCEB and diesel buses

Reset to Base Defaults	BEBs	FCEBs	Diesel
Number of Buses	119	0	2181
Annual Kms Per Bus	66,400	66,400	66,400
Annual average occupancy rate per bus (%)	50%	50%	50%
Fuel Consumption (100 kms)			
Diesel (litre/100kms)			42
BEB (kWh/100kms)	97		
FCEB (kg/100kms)		10	
Annual Consumption (diesel in litre)			60,823,728
Annual Consumption (kWh of electricity)	5,365,186		
Annual Consumption (kg in hydrogen)		0	
Charging (BEB only)			
Depot charging %	100%		
Opportunity charging (Fast) %	0%		
Braking charge energy saved			
Braking charging save energy up to %	30%	30%	
Charging Time (BEB only)			
Off-peak hour charging (e.g., 11pm to 4am)	50%		
Battery Type and Price (BEB only)			
LFP Battery (e.g., in BYD, Yutong BEBs) %	88%		
NMC (e.g., in Proterra BEBs) %	12%		
LFP Battery Size (kWh per bus)	345		
NMC Battery Size (kWh per bus)	425		
Price per kWh for LFP battery	$200		
Price of NMC battery over LFP battery (higher in %)	40%		
Electricity mix (BEB only)			
% renewables & others	17%		
% of Coal	60%		
% of CNG	23%		
Hydrogen Type			
Grey Hydrogen %		40%	
Blue Hydrogen %		30%	
Green Hydrogen %		30%	
Cost for fuel/energy			
$/litre (diesel)			$1.33
$/kWh (electricity)	$0.124		
$/kg (hydrogen base price)		$8.85	
Price for New Diesel and Hydrogen Bus		$1,000,000	$450,000
Distance-Based Charge (cents/km)	0	0	0
Total Emissions (CO_2 in tonne)	3,644	0	164,224
Total Energy/Fuel Costs	$662,601	$0	$80,895,558
Total Battery Costs for BEB	$8,925,000		
Total Capital Costs to Purchase New Buses	$71,400,000	$0	-$595,000
The numbers of diesel and ZEBs changes for 2021	119	0	-119
Resale Value of Diesel Bus (per bus)			$5,000
BEB Bus Value / BEB Battery Pack Value (Times)	8		
Distance-Based Charge ($)	$0	$0	$0
Maintenance Costs Per Bus	$36,000	$46,000	$50,000
Average depot infrastructure cost per ZEB	$100,000		
	Total Emissions (CO_2 in tonne of Three Types)	167,868	
	Total Energy/Fuel Costs of Three Types	$81,558,159	
	Total Capital Investment for 2021	$82,705,000	
	Total Distance Based Charge	$0	
	Total Maintenance Costs	$113,334,000	
	Total Depot Infrastructure Costs	$11,900,000	

	Number of Diesel Buses	Number of BEBs	Number of FCEBs	Annual Increased New ZEBs	Total Emissions (tonne) for All Buses	Total Fuel/Energy Cost (in $ for the year) for All Buses	Capital Investment ZEBs (in $ for the year)	Distance-Based Charge (in $ for the year)	Total Maintenance Costs (in $ for the year) for All Buses	Total Fuel/Energy Cost (in PV$2021)	Capital Investment ZEBs (in PV$2021)	Distance-Based Charge (in PV$2021)	Maintenance Costs (in PV$2021)	Emission Reduction Over Base %	Fuel Cost Saving Over Base % (in $ for the year)	Maintenance Cost Saving Over Base % (in $ for the year)
2020	2000	0	0	0	150,595	$74,182,080	--	--	$100,000,000	$75,665,722	--	--	$102,000,000	--	--	--
2021	2181	119	0	119	167,868	$81,558,159	$82,705,000	$0	$113,334,000	$81,558,159	$82,705,000	$0	$113,334,000	-11.47%	-9.94%	-13.33%
2022	2062	238	0	119	162,552	$77,806,926	$82,705,000	$0	$111,668,000	$76,281,300	$81,083,333	$0	$109,478,431	-7.94%	-4.89%	-11.67%
2023	1827	473	0	235	152,054	$70,399,028	$163,325,000	$0	$108,378,000	$67,665,348	$156,982,891	$0	$104,169,550	-0.97%	5.10%	-8.38%
2024	1565	735	0	262	140,350	$62,140,010	$182,090,000	$0	$104,710,000	$58,555,920	$171,587,474	$0	$98,670,572	6.80%	16.23%	-4.71%
2025	1299	1001	0	266	128,467	$53,754,901	$184,870,000	$0	$100,986,000	$49,661,219	$170,791,304	$0	$93,295,454	14.69%	27.54%	-0.99%
2026	949	1351	0	350	112,831	$42,721,862	$243,250,000	$0	$96,086,000	$38,694,506	$220,319,019	$0	$87,028,051	25.08%	42.41%	3.91%
2027	724	1576	0	225	102,780	$35,629,194	$156,375,000	$0	$92,936,000	$31,637,704	$138,856,525	$0	$82,524,508	31.75%	51.97%	7.06%
2028	485	1815	0	239	92,103	$28,095,204	$166,105,000	$0	$89,590,000	$24,458,566	$144,604,398	$0	$77,993,486	38.84%	62.13%	10.41%
2029	333	1967	0	152	85,312	$23,303,713	$105,640,000	$0	$87,462,000	$19,889,495	$90,162,723	$0	$74,647,975	43.35%	68.59%	12.54%
2030	178	2122	0	155	78,388	$18,417,653	$107,725,000	$0	$85,292,000	$15,411,068	$90,139,461	$0	$71,368,530	47.95%	75.17%	14.71%



Summary	
Average Annual Emission Reduction %	18.81%
Average Annual Fuel/Energy Cost Saving %	33.43%
Average Annual Maintenance Cost Saving %	2.54%
Total Emission Reduction (in tonne)	283,248
Total Fuel/Energy Cost Saving from 2020 to 2030 ($ for the year)	$247,994,151
Total Capital Investment for Purchasing ZEBs and Changing Depot ($ for the year)	$1,474,790,000
Total Fuel/Energy Cost Saving from 2021 to 2030 (PV$2021)	$215,860,492
Total Capital Investmentfor Purchasing ZEBs (PV$2021)	$1,347,232,129
Total Distance-Based Charge (PV$2021)	$0
Total Maintenance Costs Saving from 2021 to 2030 ($ for the year)	$9,558,000
Total Maintenance Costs Saving from 2021 to 2030 (PV$2021)	$3,713,113
Total Costs Savings Including Fuel and Maintenance 2021 to 2030 ($ for the year)	$257,552,151
Total Costs Savings Including Fuel and Maintenance 2021 to 2030 (PV$2021)	$219,573,605