Electric Buses in Cities

Driving Towards Cleaner Air and Lower CO_2

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On behalf of:

Financing Sustainable Cities Initiative

C40 Cities

World Resources Institute Ross Center

Citi Foundation

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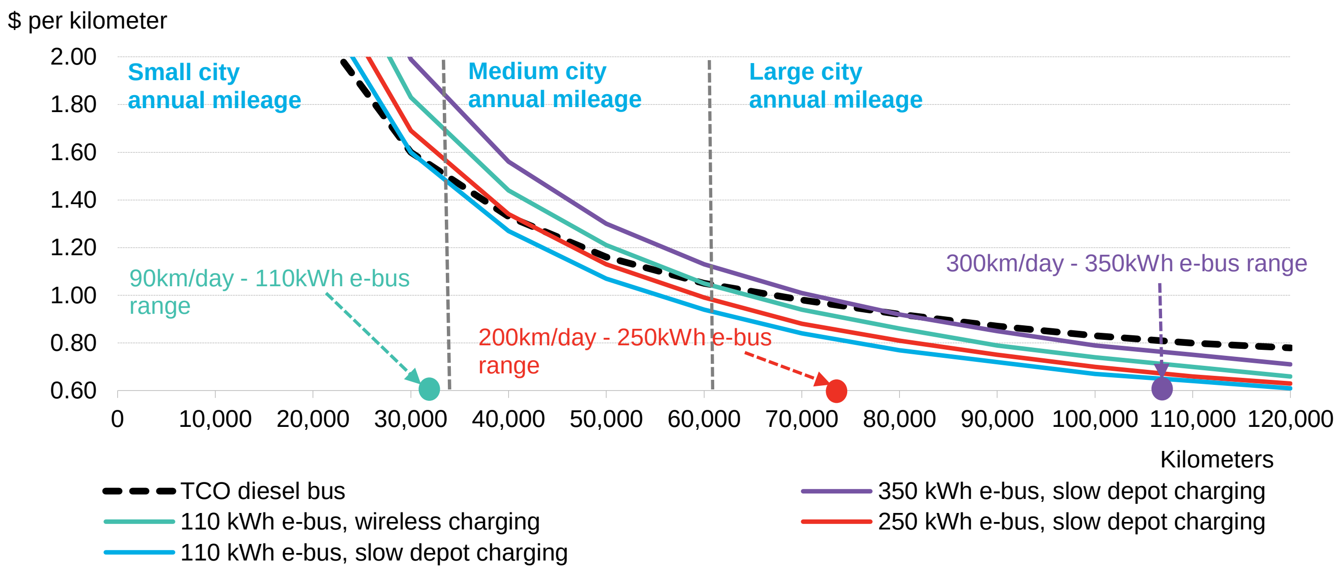
Section 1. Executive summary

Cities around the world are introducing electric buses, driven by growing concerns over urban air quality, carbon emissions and potential operational cost savings. The timing is now right for cities to start shifting to electrified transport but there are still several barriers to widespread adoption. This report, authored by Bloomberg New Energy Finance on behalf of the C40 Cities Climate Leadership Group, provides an overview of the e-bus sector, including a description of business models, an overview of existing e-bus manufacturers and a detailed analysis of the costs associated with running e-buses. The report also discusses how different types of cities can best deploy electric buses.

- Air quality is a growing concern in many urban environments and has direct health impacts for residents. Tailpipe emissions from internal combustion engines are one of the major sources of harmful pollutants, such as nitrogen oxides and particulates. Diesel engines in particular have very high nitrogen oxide emissions and yet these make up the majority of the global bus fleet. As the world's urban population continues to grow, identifying sustainable, cost effective transport options is becoming more critical. Electric vehicles – including electric buses – are one of the most promising ways of reducing harmful emissions and improving overall air quality in cities.
- The biggest challenge for electric buses is still their high upfront cost compared to equivalent diesel buses. To help with the upfront cost issue, new business models are emerging, involving battery leasing, joint procurement and bus sharing. Most of these are being implemented in North America and Europe, where e-bus purchase prices are typically much higher than in China.
- Another challenge shared by different cities considering e-buses is the uncertainty around the residual value of the bus, which in turn is driven by uncertainty around the lifetime of the battery and end-of-life options. One solution to help address this issue is to introduce policies that regulate the end-of-life requirements for batteries, and provide clear responsibilities to the different parties involved. As the market for e-buses and lithium-ion batteries matures, some of these concerns will be reduced.
- Our analysis of battery cost curves indicates that electric buses will reach unsubsidized upfront cost parity with diesel buses by around 2030. By then, the battery pack in the average e-bus should only account for around 8% of the total e-bus price – down from around 26% in 2016. However, increasing demand for e-buses could bring e-bus battery prices down faster. In this case, electric buses would reach cost parity with diesel buses by the mid-2020s.
- E-buses have much lower operating costs and can already be cheaper on a total cost of ownership basis than conventional buses today. A typical bus with a 250kWh battery charging slowly once per day at the depot and operating around 166km/day has a lower total cost of ownership (TCO) than diesel ($1.05/km) or CNG ($1.19/km) buses at $0.99/km. However, a bus with a 350kWh battery using the same charging configuration would not yet be competitive. Its competitiveness improves significantly in large cities, where buses travel above 220km/day.

- The TCO of all selected electric bus configurations improves significantly in comparison to diesel buses as the annual number of kilometers increases. An 110kWh e-bus coupled with the most expensive wireless charging reaches TCO parity with a diesel bus at around 60,000 kilometers travelled per year (37,000 miles). Many city bus in large cities already travel more than this in a given year, indicating that e-bus adoption in these areas could go quite quickly once more suitable models become available.
- In a large city, with electricity prices at $0.10/kWh, for the most expensive 350kWh e-bus, using slow, overnight charging at the depot, diesel prices would need to be around $2.5/gallon ($0.66/liter) for the e-bus to have a competitive total cost of ownership. Diesel prices are already above this level in several countries.
- Falling battery prices will make e-buses fully cost competitive on a TCO basis in almost all configurations within 2-3 years. The more expensive e-bus configurations, the 350kWh bus using slow depot charging and the 110kWh e-bus coupled with wireless charging, will become TCO competitive with diesel, even with lower annual mileage this year (2018).
- Despite the emergence of new models, most of the e-buses on the road in the U.S. and Europe were still paid for up-front, either by the municipality or the bus operator. The most popular method of financing e-bus projects in Europe is a combination of self-funding and various levels of grants, including EU, national, regional or municipal grants. The grant funding covers much of the cost with the rest coming from state and local governments and the bus operator itself.
- Underdeveloped supply chains were another issue shared by the majority of the cities interviewed for this report. Cities believe the number of e-bus models offered is still very limited, and does not sufficiently cover all of their needs. Cities need to work closely with e-bus manufacturers to show demand for specific types of e-buses. We believe that with the right signals in place, e-bus manufacturers will expand their offerings. Setting annual fleet-electrification targets and commitments can help with this goal.

Figure 1: Total cost of bus ownership comparison with different annual distance



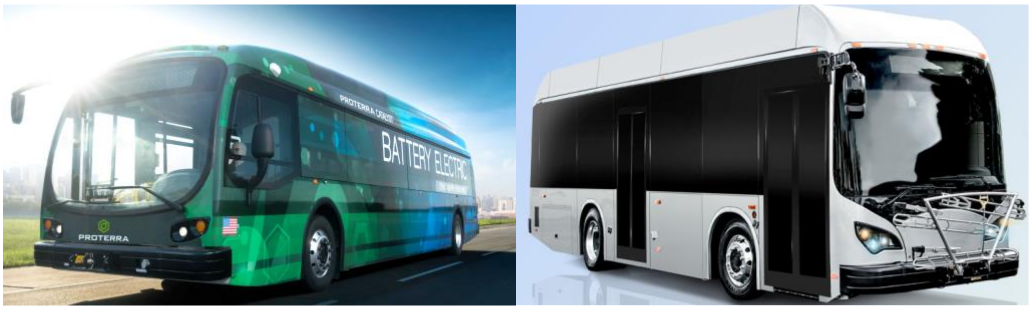
Source: Bloomberg New Energy Finance, AFLEET, Advanced Clean Transit Notes: Diesel price at $0.66/liter ($2.5/gallon), electricity price at $0.10/kWh, annual kilometers traveled – variable. Bus route length will not always correspond with city size.

Section 2. Overview of the e-bus market

Momentum is building globally for electric buses in municipal public transport fleets. The e-bus market is largely focused around metropolitan areas, where major cities are under pressure to find ways to improve air quality and cut CO_2 emissions. China has been pushing in this area for several years, while in Europe, public awareness of urban air quality issues has increased as a result of the Volkswagen diesel emissions scandal. This in turn gives more freedom to cities and local governments to step up their efforts in changing over their municipal bus fleets. At the same time, falling battery prices are making electric buses more economically attractive.

Figure 2: Selected electric buses

Proterra Catalyst E2 | BYD K9



Source: Bloomberg New Energy Finance, respective e-bus manufacturers

2.1. The global bus and e-bus fleet

> *The global e-bus market is changing quickly as cities make increasingly ambitious fleet electrification commitments. In October 2017, 13 cities signed the C40 Fossil-Fuel-Free Streets Declaration, pledging to procure only zero-emission buses from 2025 onwards.*

We estimate the global fleet of municipal buses totaled around 3 million units in 2017. The number of municipal buses has been on a decline or at best stayed relatively flat for several years now in major markets like China, U.S. or Europe.

The global bus fleet is still mostly powered by diesel and CNG, but in China around 18% of the bus fleet is already electric.

The global bus fleet is still predominantly powered by diesel and CNG, and, with the exception of China, the share of electric buses in the total fleet is minimal. In 2017 there were around 385,000 electric buses on the roads globally, with 99% of the total located in China. Around 13% of the total global municipal bus fleet was electric in 2017. The global e-bus market is changing quickly as cities make increasingly ambitious fleet electrification commitments. In October 2017, 13 cities signed the C40 Fossil-Fuel-Free Streets Declaration, pledging to procure only zero-emission buses from 2025 onwards.

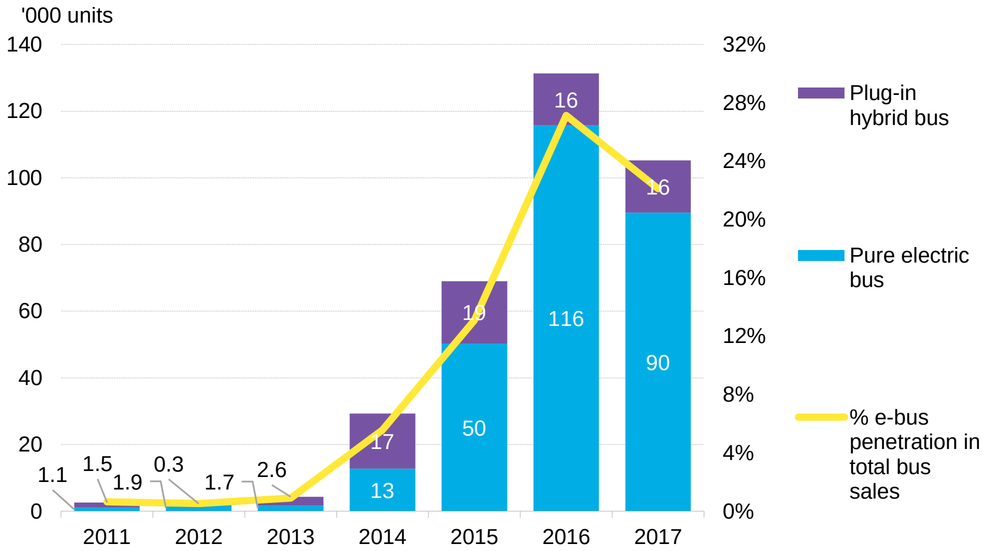
China

China was 99% of the cumulative e-bus market at the end of 2017

China is the largest producer and user of electric buses. Domestic demand in China is strongly driven by national sales targets, supportive subsidies and municipal air quality targets. Major cities like Shanghai and Shenzhen have stopped purchasing new internal combustion engine (ICE) municipal buses and are only buying electric. As a result, 99% of the cumulative number of e-buses sold globally at the end of 2017 were in China.

Sales of electric buses in China jumped to 69,000 units in 2015 and 132,000 units in 2016. In 2017, e-bus sales in China were slightly lower than in the previous year as a result of the cut to purchase subsidies. The share of e-buses in total bus sales in China increased to 22% in 2017, up from just 0.6% in 2011. E-buses now make up around 17% of the total Chinese bus fleet and pure electric buses clearly dominate over plug-in hybrid buses.

Figure 3: China electric bus sales and share of total bus sales

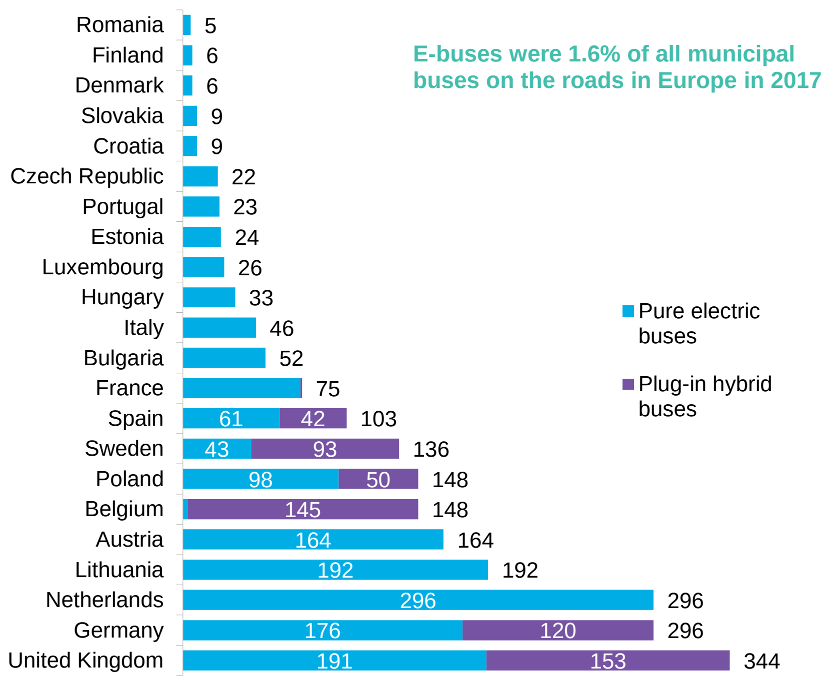


Source: Bloomberg New Energy Finance, OFweek. Note: Total e-bus sales in China in 2015 were reported at roughly 107,000 units, however, an estimated 43% of the total – 38,000 units – were fraudulent and never made it to the roads. We have excluded them from the chart.

Europe and the U.S.

The cumulative number of e-buses in Europe reached just over 2,100 units in 2017. Pure electric buses made up the majority of the total at 1,560 units. The U.K. has the largest e-bus fleet in Europe in absolute terms, but the share of e-buses in the total municipal bus fleet in the country was still below 1% in 2017. In total, share of e-buses in the municipal bus fleet in the whole region was around 1.6% in 2017.

Figure 4: E-bus fleets in Europe, 2017



Source: Bloomberg New Energy Finance, EAFO

Until the end of 2016, combined national and regional subsidies in China were able to bring the initial capital cost of an e-bus below that of a diesel bus.

We estimate that in 2017 in the U.S. there were a little over 360 electric buses[1] deployed in various transit agencies throughout the country, contributing roughly 0.5% to the total municipal fleet of 70,000 buses.

Why is China leading the e-bus race?

Funding: In China, until the end of 2016, national and regional subsidies combined were able to bring the initial capital cost of an e-bus below that of a similar diesel bus, removing the main barrier to e-bus adoption: high upfront costs.

Urban pollution and reduced oil imports. China has the biggest urban population in the world and local air pollution issues from growing transport demand have quickly become a major political issue. China is also aiming to reduce its dependence on imported oil.

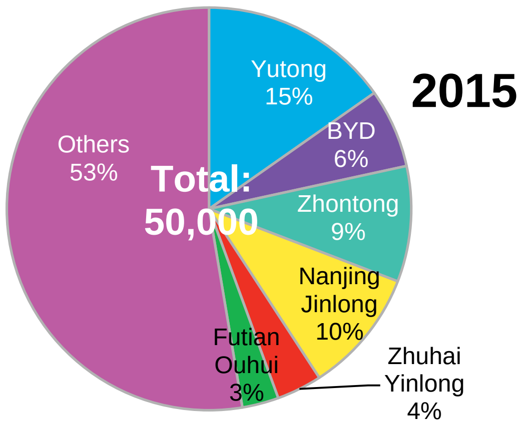
Blank slate. Many Chinese cities are building entirely new public transport networks while in Europe or the U.S., bus operators need to find ways to incorporate new electric technology into well-established existing infrastructure. This has proved troublesome.

Industrial policy. China is pursing electric vehicles partially for industrial policy reasons. The government is aiming to develop local brands that will be competitive outside of the domestic market.

[1] The U.S. data does not include trolleybuses.

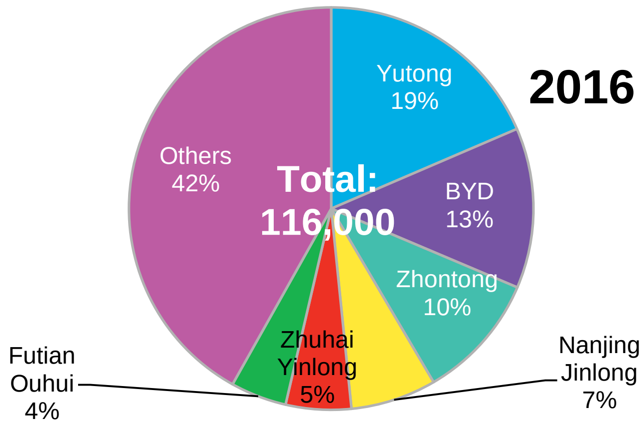
2.2. Major e-bus manufacturers

Figure 5: China pure electric bus producers



Source: Bloomberg New Energy Finance, OFweek

Figure 6: China pure electric bus producers



Source: Bloomberg New Energy Finance, OFweek

Chinese e-bus manufacturers dominate the global market in terms of units sold. The e-bus industry in China is fragmented, with the biggest producer, Yutong, taking just 19% of the market. The second biggest e-bus producer is BYD, which is also heavily invested in passenger electric vehicles and lithium-ion battery manufacturing.

Chinese e-bus manufacturers dominate the global market in terms of units sold, but they face strong competition from European and U.S. based producers.

BYD and Yutong have also been successful outside of China, both of them delivering e-buses to municipalities in Europe and the U.S. Chinese e-buses usually have lower upfront costs when compared to electric buses manufactured in the U.S. or Europe.

However, Chinese manufacturers are facing strong competition in Europe and the U.S. as the regions have several domestic bus manufacturers with proven track records and growing expertise in e-bus production. Bus producers like Solaris, Optare, VDL, Volvo or Proterra were quick to recognize the opportunities for electric buses and offer models for sale.

Their existing relationships with European municipalities and bus operators, as well as their expertise in the structure of the European public transport market, gives them an advantage over Chinese manufacturers. In the U.S. the two biggest competitors for BYD and Yutong are Proterra and New Flyer. Table 1 describes major e-bus manufacturers and their flagship electric bus models.

Table 1: Major e-bus manufacturers and their flagship models

OEM	Model	Length (meters)	Battery			Range (km)	Charging technology and duration	Units sold	Notes
			Size (kWh)	Type[2]	Supplier				
Yutong	Yutong E12	12	295	LFP	CATL	320	Plug-in at depot, at 60kW or 150kW rate	35,000 in 2015-2016	Yutong provides the chargers as well.
BYD	18MLE	18	324	LFP	BYD	250	Pantograph and plug-in at a rate of 2x40kW	80 in Europe	5-year battery warranty

[2] For terminology used throughout this report, please refer to Appendix A

	Double decker	10.2-12	345	LFP	BYD	330	Plug-in at depot at a rate 2x40kW	20,500 in China for 2015-2016	
	12m (China)	12	324	LFP	BYD	250	Plug-in at depot at a rate 2x40kW		
	12m (overseas)	12	324	LFP	BYD	320	Plug-in at depot at a rate 2x40kW		
Zhongtong Bus	LCK6122EVG	12	230	LFP	China first brand	414	Plug-in at depot, 120kW	20,000 in 2015-2016	Not disclosed
Proterra	Catalyst FC	11-13	79-105	LTO	Toshiba	80-100	On route pantograph at maximum 500kW, plug-in at depot compatible with SAE J1772 CCS connector at 60-120kW, wireless charging	100	6-year battery warranty, 1 year or 50,000 miles for the bus
	Catalyst XR	11-13	220-330	NMC	LG Chem	220-310			
	Catalyst E2	11-13	440-660			405-560			
Solaris	Urbino 8.9	8.9	160	LFP/LTO	Solaris	200	Plug-in at depot or pantograph; at 80kW or 300kW; at 1.33kWh/min or 5kWh/min	5	Up to 10-year battery warranty
	Urbino 12	12	240			266	Plug-in at depot, pantograph or induction; at 80kW or 450kW or 200kW;	93	Not disclosed
	Urbino 18	18	240			185		5	
VDL Bus & Coach	Citea LLE-99	9.9	180	NMC	Multiple		Pantograph, Combo 2, up to 270kW; Depot charging by Heliox 40/80/100/120 kW, CCS; fast charging pantograph by Schunk 200-600kW or Siemens (inverted) 50/300/450kW; fast charging by ABB – inverted pantograph, CCS, 150/300/450kW	67	Not disclosed
	Citea SLF-120	12	63-240	LpTO, NMC	Multiple (Akasol, Durapower, Microvast)		Pantograph, Combo 2, up to 350kW		
	Citea SLF-180	18	63-180	NMC			Pantograph, Combo 2, up to 270kW		
Optare	Solo EV	9-10	138	LiFeMgPO4	Valence	270	Plug-in at depot, 42kW	56	5-year battery warranty
	Metrocity EV	10.8				205		13	
	Versa EV	10-11						13	
	Metrodecker	10.5	200		TBD		Plug-in at depot, 40kW	-	Announced model
BYD-ADL	Enviro 200EV	10.8-12	324	LFP	BYD	250	Plug-in at depot at 80kW rate, Mennekes, Type 2	51	Battery warranty differs by contract
Volvo Bus	Volvo 7900 Electric	12	76	LFP	SAFT	96	Opportunity charging, overhead, conductive, pantograph on pole (ABB OppCharge).	11	Not disclosed
	Volvo 7900 Electric Hybrid (PHEV)	12	19	LFP	SAFT	8.1	Opportunity charging, overhead, conductive, pantograph on pole (ABB OppCharge).	39	Not disclosed
Van Hool	Exqui.City 18m	18.6	215	LFP	BFFT	120	Plug-in and inverted pantograph; 80kW and 250kW	40	5-year battery warranty
Bollore Group	Bluebus	12	240	LMP	BlueSolutions	180	Plug-in at depot, at 50kW rate	23	7-year battery warranty
Evopro	Modulo C68e	8	144	LFP	Valence	200-230	Conductive at 60kW	20	5-year battery warranty

	Modulo C88e	9.5	84	LFP		120-140			
Irizar	Irizar I2e	12-18	376	NaNiCl (ZEBRA)	FIAMM	250	Plug-in at depot, Combo 2 standard at 80-100kW rate;	13	Battery warranty for 2,000 cycles; base price of around $566,000
Hybricon Bus System	Arctic Whisper	12	40-120	LTO	Altair-Nano	30-55	Pantograph or depot charging at a 20-650kW rate;	-	3-year battery warranty
	City Bus HCB	12	38-265	NMC	BMZ	-	Pantograph or depot charging at a 20-200kW rate;	9	2-year battery warranty;
Bozankaya	Sileo S10 and S12	10.7-12	200-230	LFP	Bozankaya BC&C	235-260	Plug-in at depot at a rate of 4-100kW	8	4-year battery warranty
	Sileo S18	18	300			260	Plug in at deport at a rate of 4-200kW	-	
	Sileo S24	24	380			250	Plug-in at depot	-	
ADL	Enviro 400VE	10.3	61	NMC	Akasol	30	Opportunity - induction plates sunk into the road – and plug in overnight at depot	3	Battery warranty differs with contracts
Carrosserie Hess	TOSA	18.7	70	LTO	ABB	30	Conductive pantograph, at 600kW	1	>5-year battery warranty
Heuliez Bus	GX337 ELEC	12	349	NMC	Foresee	200	Plug-in Combo 2, CCS protocol, rate of 50-100kW (overnight) and 150kW (faster charge)	1	Not disclosed
	GX437 ELEC	18	106	LTO			Pantograph, CCS protocol, 300-450 kW	-	Not disclosed
DCGT	Temsa MD9	9.3	200	NMC	Mitsubishi	230	Plug-in at depot, 120kW rate	-	2-year warranty; introduced in March 2017
	Temsa Avenue	12	75	LTO	Microvast	50	Overhead and plug-in, rate 450kW	-	
Ebusco	Ebusco 12m	12	311	LFP	Ebusco	300	Plug-in at depot, rate 75kW/120kW	-	Ebusco does battery maintenance and replaces the battery at the end of cycle; base price of around $500,000
	Ebusco 18m	18	414			325	Plug-in at depot, rate 75kW/120kW	-	Not disclosed

Source: Bloomberg New Energy Finance, EAFO, ZeEUS e-bus report Note: Unless stated otherwise, e-bus models mentioned in the table are all pure electric.[3]

2.3. E-bus projects in the pipeline

The biggest e-bus deployments are currently taking place in China, but several U.S. and European cities are also moving quickly. The table below includes a summary of some of the noteworthy projects underway or announced.

[3] We have excluded trolleybuses from this table

Table 2: Selected e-bus municipal fleet projects, delivered or announced

City/transit agency	Country	Number of e-buses	Delivered by	Manufacturer (model)	Additional information on fleet size, prices and targets	Status
Shenzhen	China	1,000 3,600 16,500[4]	2012 2016 2017	BYD BYD	The city of Shenzhen fully electrified all of its buses (around 16,500 buses).	Delivered Delivered Delivered
Shangqiu	China	635 100	11.2016 Not disclosed	Yutong Yutong	With nearly 1,000 electric buses in operation, the city's entire bus fleet is now electric. Additional 100 e-buses to be bought from Yutong to be used on newly added routes.	Delivered Announced
Qingdao	China	347	Not disclosed	Zhongtong	Total value of the contract is 410 million yuan ($65 million). In 2017 the number of electric buses in the city was roughly 600 units, or over 40% of the city's total bus fleet.	Announced
Beijing	China	50 56 1,320 10,000[5]	07.2017 09.2017 09.2017 2020	 Zhongtong BAIC Foton	Beijing has a target of having 10,000 e-buses on the road by 2020	Delivered Delivered Delivered Announced
Stockton/ San Joaquin Regional Transit District	U.S.	12 5	08. 2017 03. 2018	Proterra (EcoRide) (Catalyst E2)	BRT routes. Price approximately $850,000 per bus.	Delivered Delivered
Los Angeles County Metropolitan Transportation Authority	U.S.	35 60 2,200[6]	2020 2021 2030	New Flyer BYD	In 2017, the Los Angeles County Metropolitan Transportation Authority voted to transition its fleet of 2,200 buses to be fully electric by 2030.	Announced
Los Angeles Department of Transportation	U.S.	25 359[7]	2019 2030	Proterra (Catalyst)	LADOT will receive the buses in 2019. The project was in part funded by the Federal Low-No grant.	Announced Announced
San Francisco Municipal Transit Agency	U.S.	185	2019	New Flyer[8] (XT40)	Equipped with In Motion Charging (IMC) technology from Kiepe Electric.	Announced
Pomona, San Gabriel Valleys/ Foothill Transit	U.S.	361	2030		Foothill Transit plans to electrify all of its 300 buses by 2030	Announced
Albuquerque	U.S.	20	2017	BYD	Buses will operate along the Albuquerque Rapid Transit route	Delivered
Clemenson Area Transit (South California counties)	U.S.	10	Not disclosed	Proterra (Catalyst E2)	Clemenson Area Transit partially financed the purchase with $3.9 million from the federal Low-or No Emissions program	Announced

4 Refers to the total number targeted by the city and not to the order size

5 Refers to the total number targeted by the city and not to the order size

6 Refers to the total number targeted by the city and not to the order size

7 Refers to the total number targeted by the city and not to the order size

8 Trolleybus capable of covering sections of the route without overhead lines in battery-powered mode

Porterville	U.S.	10	2018	GreenPower Motor (EV350)	California will use $9.5 million from the California Climate Investments to pay for the buses. Southern California Edison will provide special rates for bus charging	Announced
Park City	U.S.	6	2017	Proterra (Catalyst FC+)	E-buses are used in a free service providing transport to tourists and residents in the ski resort.	Delivered
Eindhoven	Netherlands	43	12.2016	VDL	In April 2017 Hermes reached 1 million kilometers travelled with the VDL e-buses.	Delivered
Trondheim	Norway	25	08.2019	Volvo (7900)	10 e-buses already in operation. Volvo will take care of vehicle and battery maintenance at a fixed monthly cost.	Announced
Krakow	Poland	17 3	08.2017 08.2017	Solaris (Urbino 12) (Urbino 18)	The Urbino 12 comes equipped with a 160kWh battery, and the articulated Urbino 18 with a 200 kWh battery	Delivered
Haifa	Israel	17	09.2017	BYD	Buses have a range of 124 miles	Delivered
Amstelland-Meerlanden	Netherlands	100 18	Not disclosed	VDL (Citea SLF) VDL (Futura)	Operated by Connexxion. Buses will be driven over 100,000 km per year	Announced
Den Haag HTM	Netherlands	5	Not disclosed	VDL (Citea SLF-120)	VDL will supply charging infrastructure. Pantograph will be used for opportunity and overnight charging.	Announced
Cologne	Germany	8	10.2015	VDL (Citea SLF)	E-buses in this project are using only pantograph charging, both en-route and at the depot. Batteries used have 123 kWh capacity.	Delivered
RATP (Paris)	France	23 4,500[9]	05.2016 2025	Bollore (Bluebus)	Each drives for around 180 km a day Paris aims to electrify all of its fleet of 4,500 buses by 2025.	Delivered Announced
Budapest	Hungary	20	04.2016	Evopro	Buses travel for around 128km per day and charging takes place at depot	Delivered
London	U.K.	14 36 56	2017 2018 Mid 2019	BYD/ADL (Enviro 200EV)	From 2020 all new single decker buses are to be zero emissions	Delivered Announced Announced
Alexandria Passenger Transportation Authority	Egypt	15	2018	BYD (K9)	Each bus can carry around 90 passengers	Announced

Source: Bloomberg New Energy Finance

9 Refers to the total number targeted by the city and not to the order size

Section 3. Major e-bus drivers and barriers

3.1. Drivers

Urban air quality concerns are rising around the world. E-buses can help cities meet their climate and air quality goals

Urban air quality is becoming a major issue in cities around the world. Nitrogen oxide emissions in particular have been shown to have significant negative health impacts and diesel engines have come into focus in recent years as they have much higher emissions in real world driving conditions than in laboratory testing.

As the world's urban population continues to grow, identifying sustainable, cost effective transport options is becoming more critical. Introducing electric vehicles – including electric buses – is one of the most promising ways of reducing harmful tailpipe emissions, reducing CO_2 and improving overall air quality in cities. Electric vehicles have zero tailpipe emissions and lower CO_2 emissions even in areas that derive a relatively high percentage of their power generation from coal and natural gas.[10] Cities around the world are deploying electric buses, supported by a combination of national and local policy, potential cost savings and other industrial and operational benefits. The number of cities implementing fleet electrification targets or ultra-low emission zones is rising. 13 cities have signed the C40 Fossil Fuel Free Streets Declaration[11], including Paris, Los Angeles, London and Mexico City, committing to procure only zero-emission buses from 2025. These cities have a combined population of 80 million people and 60,000 buses. Many signatory cities have targets that exceed the ambition of the declaration. Paris aims to electrify all of its 4,500 buses by 2025, Copenhagen has committed to procure only zero-emission buses from 2019, and Los Angeles has the same target for its fleet of 2,200 buses by 2030.

> *Despite strong ambition at the municipal level, national level policies will be necessary to enable the transition to electric public transport in smaller cities.*

But national level policies will be necessary to enable the transition to electric public transport in smaller cities. Several governments have set up e-bus specific incentives to help this transition. In the U.K. for example, a total of 30 million pounds ($39.5 million) was made available under the Low Emission Bus Scheme to be spent on new buses (between April 2016 and March 2019). In China, the move to electric transport is fully endorsed by the national government, which not only subsidizes the production of e-buses with an incentive of up to 180,000 yuan ($28,500) for the most efficient e-buses, but also included electric buses in its national level target of producing 2 million new energy vehicles (NEVs) a year by 2020.

Beyond improvements in air quality, there are other factors that will further help to push the adoption of e-buses:

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[10] BNEF's analysis found that CO_2 emissions from the operation of battery electric vehicles were about 39% lower on a per kilometer basis than those from average internal combustion (ICE) vehicles in 2017. This research was done for light duty vehicles but would be similar or better for electric buses.

[11] Auckland, Barcelona, Cape Town, Copenhagen, London, Los Angeles, Mexico City, Milan, Paris, Quito, Rome, Seattle, and Vancouver.

> *In certain configurations e-buses already have a lower total cost of ownership than comparable diesel or CNG buses today. Operational cost savings are one of the most important arguments cities have made for introducing e-buses.*

- **Lower total costs of ownership (TCO)**: in certain configurations – discussed in the TCO section below – e-buses have lower total cost of ownership than comparable diesel or CNG buses. Operational savings were one of the more important arguments supporting e-buses introduction in many cities.
- **Noise reduction and reduced downtime**: e-buses run more quietly than diesel or CNG buses, which reduces noise pollution. E-buses also require less maintenance.
- **Industrial policy considerations:** governments may see an opportunity to build a domestic industry around the electrification of transport. Job creation linked to e-bus production and supporting industries will be, for many, a major selling point.

3.2. Barriers

> *There is a unique opportunity for cities to change their procurement approach – from outright purchase to leases payments – and to focus more on lower total cost of ownership. Lease or loan repayments could be covered with operational costs savings, helping to enable much faster e-bus adoption.*

Despite all of the advantages of e-buses, there are still several factors that are holding back more aggressive growth in the sector:

Lack of charging infrastructure standardization is a major issue which adds complexity to establishing the residual value of e-buses.

- **High upfront costs**: although the TCO of an e-bus can look better than that of a diesel bus, the TCO is not always the main criterion for municipalities when making a purchase decision. Many cities do not have the funds to pay for e-buses with higher upfront costs, even with additional support from the government. This is currently slowing down e-bus adoption. There is a unique opportunity for cities to change their procurement approach from outright purchase to leases payments, and to focus more on lower total cost of ownership. Lease or loan repayments could be covered with operational cost savings, helping to enable much faster e-bus adoption
- **Scalability**: most of the e-buses on the road in the U.S. and Europe today were bought using national and regional level grants. This is not scalable. The upfront cost of e-buses will have to fall and become more cost competitive with diesel buses for the industry to mature. Until then, financing options like the battery lease program offered by Proterra, which lower the upfront costs of the e-bus, will play an important role.
- **Flexibility and operational experience:** electric buses can be less flexible than diesel buses, due to their range and reliance on different charging options. This makes it difficult to incorporate them into bus routes running for 24 hours. The lack of long-term experience with running e-buses on a commercial scale is also creating challenges for cities choosing to go electric.
- **Technology cost declines**: municipalities are aware that battery costs are falling. Some may be pushing their e-bus purchase decisions back to avoid the financing risks associated with further technology cost declines. While for some cities this may make sense, many others will want to start e-bus deployments early to provide enough time for step by step infrastructure upgrades to eventually meet the needs of a fully electric bus fleet.

- **Electricity charges, grid issues**: bus operators express their concerns over the potential for increasing electricity rates and demand charges with growing electricity demand from e-buses. Grid reinforcements are also often needed to support charging. Potential power outages, during for example extreme weather events, are also a concern. Space required for installing the chargers at a depot or bus stop can also be an issue – as can public disagreement to installing pantograph chargers at bus stops.
- **Lack of charging infrastructure standardization** is making it harder to establish the residual value of e-buses. The buyer of a used bus must already be using the same charging standard, otherwise an investment in new charging infrastructure will be necessary. Also, fragmentation of standards often locks bus operators into one e-bus manufacturer, or forces additional infrastructure investments, if they decided to change bus suppliers. This reduces competition. European bus manufacturers were first to address this issue, and in March 2016 Irizar, Solaris, VDL and Volvo agreed to ensure interoperability of electric buses they produce with charging infrastructure provided by ABB, Heliox and Siemens[12].

> *Cities will need to work closely with bus suppliers, charging equipment providers and grid operators to help minimize the impact the electric buses have on the local power network.*

[12] For overnight, plug-in charging at the depot DC CCS Type 2 in Europe and DC CCS type 1 in the U.S. were agreed on. For opportunity charging, a common interface for the inverted pantograph system will be supported.

Section 4. Business models for e-bus deployment

4.1. E-bus financing options

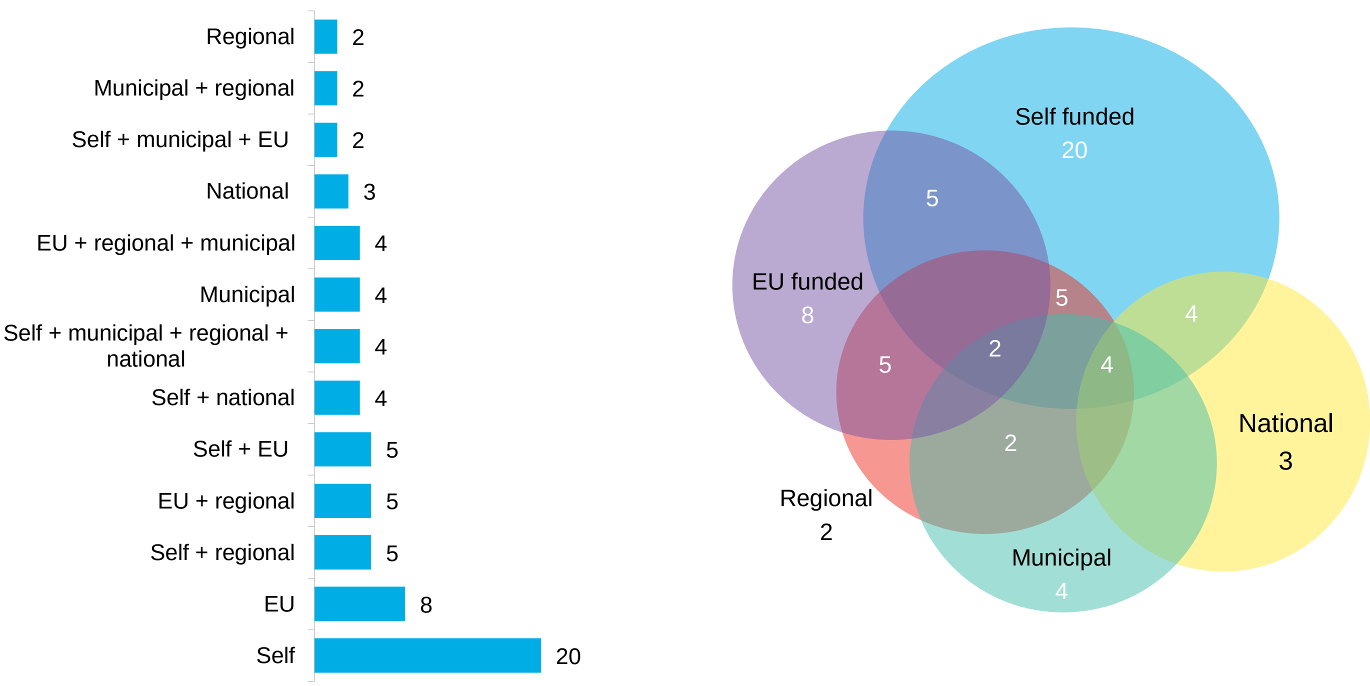
In the U.S. the current e-bus projects were funded predominantly using the Federal Low-No grant combined with state level support.

Most of the e-buses on the road in the U.S. and Europe were paid for upfront, either by the municipality or the bus operator. The most popular method of financing e-bus projects in Europe today is a combination of self-funding and various levels of grants, including EU, national, regional or municipal grants. The grant funding covers much of the cost with the rest coming from state and local governments and the bus operator itself. Figure 7 illustrates how complicated buying electric buses in Europe can become, when grants from different agencies have to be used.

The situation is similar in the U.S. where the existing e-bus projects were funded predominantly using the Federal Low-No grant (Low or No Emission Vehicle Program) combined with state level support. This is, however, not sustainable. The grants are usually limited and irregular, and are only enough to buy a few buses at a time.

Figure 7: Electric bus funding sources for selected European e-bus projects

Number of identified projects by funding source



Source: Bloomberg New Energy Finance, ZeEUS Project

To ease the upfront cost issue, new business models are emerging, such as battery leasing, joint procurement and bus sharing. Most of these are being implemented in the U.S. and Europe, where e-bus purchase prices on average are much higher than in China.

The biggest challenge is that cities often still make procurement decisions based on the upfront cost of the bus. Therefore the high upfront cost of e-buses compared to equivalent diesel buses makes it very difficult for many bus operators to transition to electric. Moreover, as battery prices are falling, some public transit operators are delaying their electrification plans in the hope that falling battery prices will bring the cost of an electric bus closer to that of a diesel option and missing an opportunity to save on operational costs.

To ease the upfront cost issue, new business models are emerging, such as battery leasing, joint procurement and bus sharing. Most of these are being implemented in the U.S. and Europe, where e-bus purchase prices on average are much higher than in China.

Battery leasing: Proterra's Park City project

The biggest challenge for e-buses is that bus procurement is often still decided on upfront costs.

One of the attractive ways of lowering upfront costs is to pay for the bus, but lease the battery. This option was first introduced by Proterra in the U.S. It brings the capital costs of an e-bus closer to the level of a diesel city bus, and payments for the battery are included in fixed service payments for the lifetime of an asset, or shorter. Renault offers a similar model for its passenger EV sales in Europe.

Park City Transit (in Utah, U.S.) bought six fully electric buses this way, the Proterra Catalyst FC+. For the city, entering into a 12-year service provider agreement to lease batteries from Proterra was a way to purchase more buses with the available grant funds[13], and lease the batteries out of operational funds. This way, Park City could reduce the risk around battery longevity and replacement. Park City Transit spent $3.9 million on the six buses, or around $650,000 per bus.

However, the scalability of such initiatives may be limited for smaller e-bus manufacturers. With the increasing size of e-bus orders, there will be new opportunities for larger third-party financiers.

Joining forces: San Francisco Municipal Transportation Agency and King County

Another way of reducing upfront costs is to take advantage of economies of scale, team up with another city or bus operator and work with the electric bus supplier on a better deal for a bigger contract.

In 2013, King County Metro (Washington, U.S.) entered into a contract with New Flyer, a Canada-based manufacturer of trolley buses and fully electric buses, for the procurement of 500 electric trolley buses over a five-year period, with an option to expand the contract with 200 additional trolleybuses.

Following this announcement, on December 6, 2013, the city of San Francisco entered into a 'Bus Options Assignment Agreement' with King County and New Flyer, under which King County assigned to the city the right to purchase up to 333 trolleybuses from New Flyer from the options

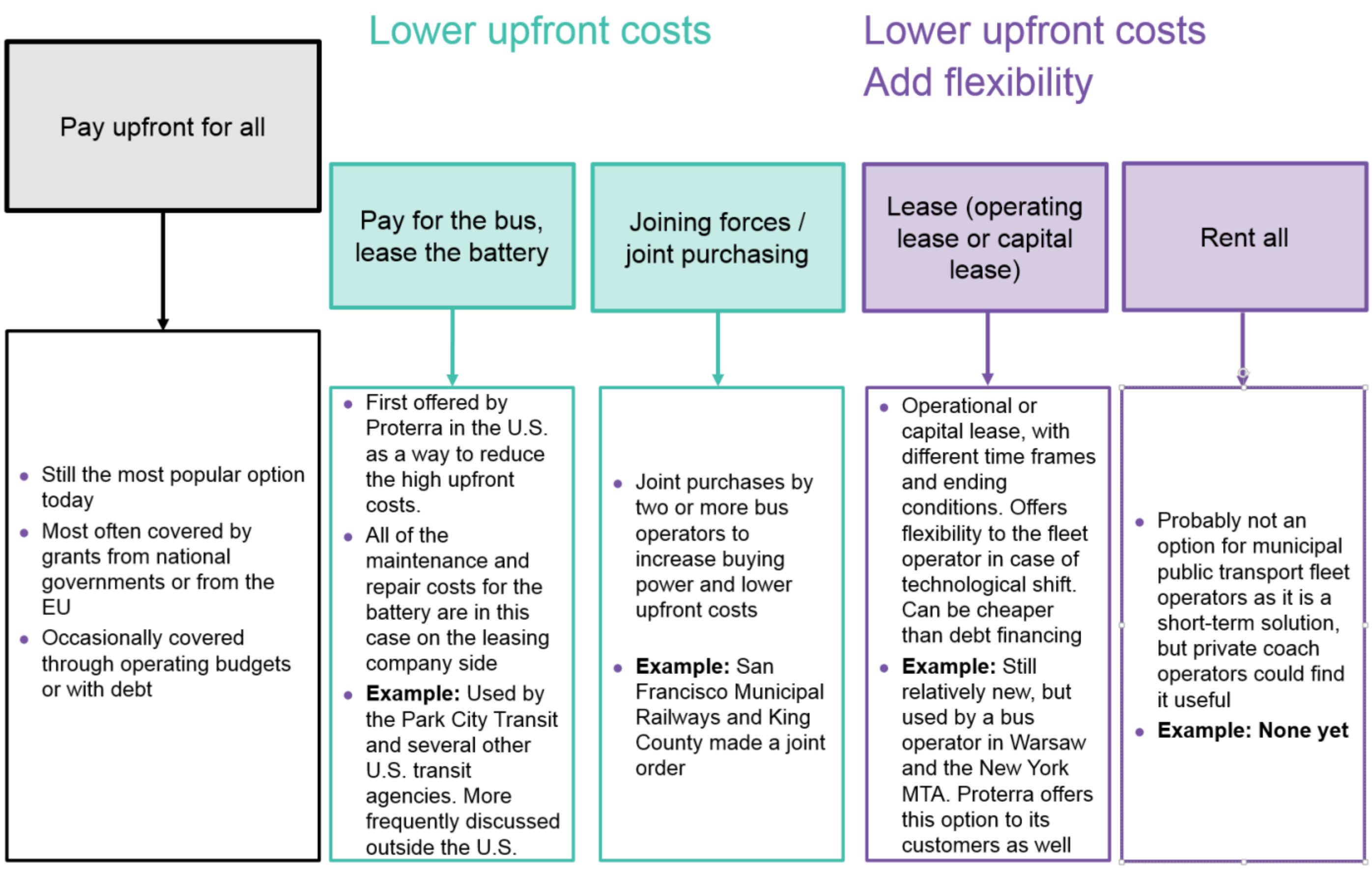
[13] FTA Low-No Emission Grant Program, awarded through Utah Department for Transportation – Park City was awarded $3.9 million in August 2016. Park City matched the grant with 20% of the overall cost.

under the bus procurement contract – a move that ensures both King County and SFMTA receive the most competitive pricing.

> *Another way of reducing upfront costs is to take advantage of economies of scale, team up with another city or bus operator and work with the electric bus supplier on a better deal for a bigger contract.*

Bringing together more than one player can have challenges. Many cities will have different technical requirements for their e-buses, timelines for potential deliveries may not align, and drafting contracts that unify all of the requirements can be time consuming. However, it can be worthwhile in cost savings.

Figure 8: Different e-buses financing approaches



Source: Bloomberg New Energy Finance

The potential for further reductions in battery prices has prevented some municipalities from moving on e-buses.

Electric bus capital lease: Warsaw's and New York's approach

The potential for further reductions in battery prices has prevented municipalities without explicit electrification commitments from moving on e-buses. Shorter-term leases can take this technological risk away from the bus network operator, and ensure that the given city's fleet is always the most cost-effective.

> *Capital leases are considered a low-cost financing tool for local governments. Often it may be cheaper than the upfront purchase of an electric bus, as the leasing company – which remains the owner of the asset – can offer better conditions.*

On July 18, 2017, a consortium of Solaris Bus & Coach and BZ WBK Leasing signed a leasing agreement with transit operator Miejskie Zaklady Autobusowe (MZA) in Warsaw. The agreement is for the delivery of 10 Solaris Urbino12 e-buses and it totaled just short of 30.5 million Polish zloty ($8.3 million). . It is a simple capital lease agreement, under which MZA operates and manages the buses and after six years becomes their owner. The lease can be paid either from grants or from operating revenue.

Capital leases are considered a low-cost financing tool for local governments. Often it may be cheaper than the upfront purchase of an electric bus, as the leasing company – which remains the owner of the asset – can offer better conditions. Unlike in Warsaw, other cities may also choose a slightly more complicated option, in which after the leasing agreement ends, the city/bus operator does not become an owner of the asset, and instead the bus is transferred to another city or country, where similar leasing agreements do not yet exist.

Operating lease

In contrast to a finance/capital lease, an operating lease keeps all of the risks and advantages of ownership on the side of the leasing company. An operating lease will generally run for a short period of time, during which the customer gets to use the asset in return for rental payments – however, these payments do not cover the full cost of the asset. Therefore, quite often operating leases contain additional components, like vehicle maintenance contracts.

Replacing the traditional ownership model with a leasing model is good news to municipal fleet operators, but represents a new challenge to manufacturers, who need to provide the capital for the vehicle inventory.

Short-term leases can also serve as testing periods – where the bus operator and the bus supplier sign a short-term lease to test a specific vehicle under the conditions specific to a city. In April 2017, New York's Metropolitan Transportation Authority Board approved the leasing of five electric buses, out of 10 to be leased in 2017, for a pilot program which aims to test the performance of e-buses in the city. The first five buses came from Proterra, and the company also leased six depot charging stations. The e-buses started operation in December 2017 and the value of the lease is $4 million for the three-year period. Over the lease term, the buses' economic, environmental and performance benefits will be evaluated. The pilot will provide the MTA and manufacturers of electric buses with actionable data on what works best in New York's metropolitan environment. The MTA will use the results to refine and develop bus specifications for future electric bus procurement.

> *In contrast to a finance/capital lease, an operating lease keeps all of the risks and advantages of ownership on the side of the leasing company. An operating lease will generally run for a short period of time, during which the customer gets to use the asset in return for rental payments – however, these payments do not cover the full cost of the asset.*

Although replacing the traditional ownership model with a leasing model is potentially good news to municipal fleet operators, it represents a new challenge to manufacturers, who now need to provide the capital for the vehicle inventory. At the same time, it creates an opportunity for third-party capital providers to enter the market.

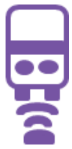
Section 5. E-bus charging configurations

There are three main types of infrastructure for charging electric buses: plug-in systems, inductive charging and conductive pantograph (overhead) charging (Table 3). Traditional plug-in charging is the most common and the cheapest charging system in use with e-buses today. It offers a range of charging rates, from slow to rapid and it is provided by a range of companies, including Heliox, APT, Siemens and ABB.

Pantograph (overhead) charging is growing in popularity for new e-bus fleets in Europe and the U.S. It also offers a range of charging rates, but rapid charging for battery top-ups makes most sense with this technology. It will predominantly be used by municipalities which are considering e-buses with smaller batteries. The main technology providers are ABB, Siemens and Heliox.

Wireless charging is currently the most expensive option and only used in pilot projects with e-buses. Stationary wireless charging is available commercially, but dynamic wireless charging is still only in the demonstration phase. Similar to pantograph charging, wireless charging can offer a range of charging speeds but rapid charging for battery top ups will make most sense. Technology providers include companies like Primove, Wave, Momentum Dynamics and Witricity.

Table 3: Types of charging infrastructure used with e-buses

Traditional plug-in charging	Pantograph charging	Inductive charging (wireless)
		
Currently the cheapest available option and one of the most common systems for charging overnight at the depot or during a daytime layover. Using a slow charger (15-22kW), an e-bus can usually be fully charged in around 10 hours. Fast (22-50kW) and rapid (50-120kW) charging units enable quicker charge times of around 2-6 hours.	Pantograph charging uses roof-mounted equipment to make an electrical connection between the bus and an overhead power supply. The pantograph can be installed either on the roof of the bus, or at the overhead mast (inverted pantograph), and charging begins when the bus arrives at the charging site and the pantograph is extended to make contact with the charger. Such systems are usually located at bus stops, or at bus terminals. The power output of the charger is usually 150-300kW, allowing for a rapid top-up of the battery. There are several providers of pantograph charging technologies today, and such systems are offered as an option by many of the leading e-bus producers: Proterra, Solaris, VDL, Volvo or Van Hool.	Wireless charging uses coils installed under the road surface that can transfer energy to matching coils fitted beneath the floor of the bus. Two types are available: stationary and dynamic. In stationary charging, the vehicle needs to be positioned over the roadway coils to activate the charging. Such systems are commercially available and offer a range of benefits, from improving the convenience of charging, to allowing battery pack sizes in buses to be reduced. Systems with up to 200kW rating are available, enabling rapid battery top-ups. Stationary charging units are usually installed at the terminals – to allow battery top-up during layover time – or at selected bus stops to allow battery top up while passengers are boarding. In dynamic wireless charging, vehicles are being charged while in motion. The technology is still in pilot and demonstration stages.

Source: Bloomberg New Energy Finance

5.1. Optimizing charging options

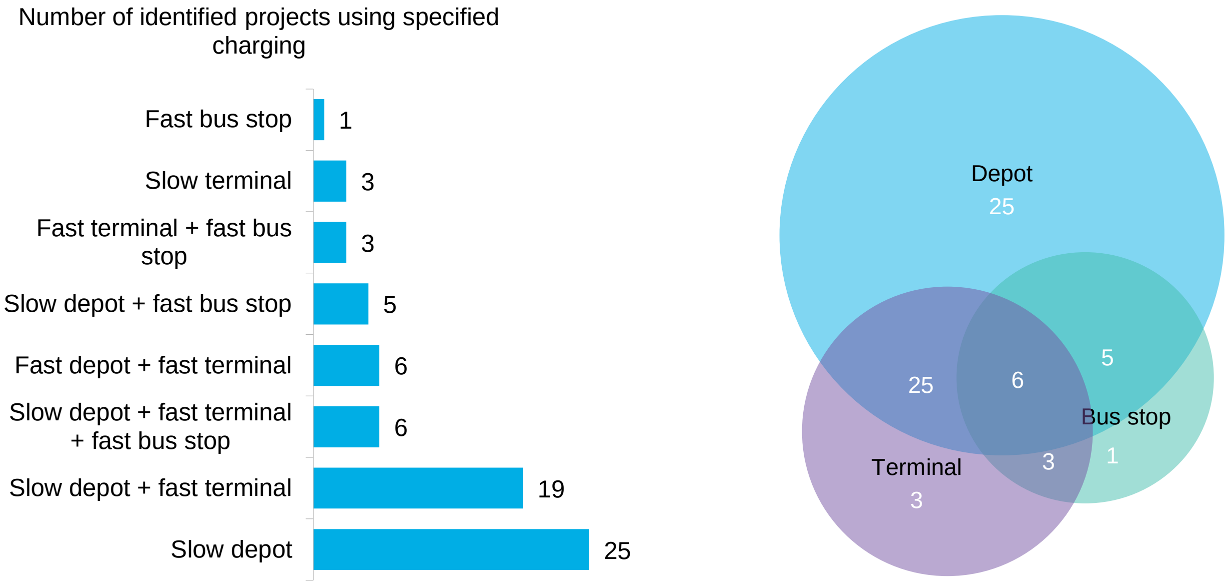
Bus operators consider operating range, passenger capacity, topography of the route, and heating and cooling needs when deciding on the right e-bus and charging configuration.

Depending on the route characteristics and the battery capacity, a range of different operating and charging strategies can be implemented. Before deciding on the appropriate e-bus and charging infrastructure, the bus operator will consider things like the operating range, passenger capacity, topography of the route, and other factors such as heating and cooling needs.

> *Slow, overnight charging at the depot is the most popular e-bus option today, followed by the combination of depot charging and fast charging top-ups – pantograph or plug-in – at the terminal and bus stops.*

Another major factor that will be considered is the number of e-buses needed to cover the route. This is affected by the charging infrastructure choices. For example, more comprehensive (and more expensive) charging infrastructure and en-route charging options can lower the number of required buses. The operational strategy has to be planned so that there is some reserve battery capacity on every bus (in case of traffic jams), and that reserve buses are available.

Figure 9: Different types of electric bus charging configuration for selected European e-bus projects



Source: Bloomberg New Energy Finance. Note: this is not an exhaustive list of e-bus projects. Data is from the ZeEUS (Zero Emission Urban Bus System) project, an EU funded project focusing on the challenges of the electrification of bus systems with an objective of collecting statistically valid data from the deployment of e-bus systems and then analyzing the data to deliver a "lessons learned" guidelines. Terminal refers to the last stop on buses' route, where layover happens.

Slow, overnight charging at the depot is the most popular option today, followed by the combination of depot charging and fast charging top-ups – pantograph or plug-in – at the terminal and bus stops (Figure 9). However, although slow depot charging offers the cheapest charging solution, there are some challenges connected to relying on depot charging alone.

Those will include space limitations (depots with many buses parked usually do not have enough space for installing chargers, and have limited space for maneuver) and most importantly power

Slow charging at the depot allows charging to take place mostly at night, when electricity prices are the lowest

capacity constraints connected to all of the buses charging at the same time. Another major challenge associated with using depot charging alone, is the need for larger battery packs, which leads to higher capital costs. Additionally, there may be a conflict between the weight of the necessary battery and the number of passengers that can be taken on board.

One of the major advantages, however, is the potential to move the charging operations to nighttime hours when electricity prices are the lowest. This will create issues if the e-bus fleet in question is large. Having all buses charge at the same time means increases the number of required chargers, which in turn significantly increases the capital costs and space requirements.

Combining depot charging with fast charging en route (at the terminal or bus stops) allows for smaller batteries which in turn should lower the upfront cost of the bus. The high initial costs of the pantograph systems diminish with the increasing number of e-buses in the fleet as the utilization rates increase. In Table 4 below we analyze different charging strategies in more detail and look at their pros and cons and associated costs.

Table 4: Selected charging strategies for e-buses

Charging concept	Infrastructure cost	E-bus battery requirements	Overall system cost	Feasibility
Slow plug-in overnight at depot	**Low** – chargers required only at depots, but the charger to bus ratio is high.	**High** – buses using only overnight charging will require higher capacity batteries to be able to cover their routes. Higher costs.	**Medium** – battery prices are the major component today. As prices decrease the overall system cost can be lowered. By using night off-peak tariffs for charging, savings on electricity costs can be significant.	Most popular option today, feasible on a smaller scale when the number of buses is low. On a larger scale, there can be localized problems when charging all the buses at the same time (space, power supply, grid impacts). Risky in places where the depot is far from the bus route. Large batteries mean weight issues and compromises on the number of passengers.
Slow plug-in at depot and fast charging at terminal	**Medium** – two types of chargers required, and in two locations.	**Medium** – buses can top up at terminals in a relatively fast manner, so they can have smaller battery packs.	**Medium** – higher cost of the fast charging system is balanced with savings from a smaller battery. There may still be need for changes in normal bus operations, but in theory layover time can be used for top-up.	Second most popular option today, but issues around parking space at bus terminals may arise. If the number of buses required on the route is steady throughout the day, then a reserve bus can be added for the bus that is charging.
Super-fast charging at terminal and bus stops (wireless / pantograph only)	**High** – pantograph and wireless systems are the most expensive installations today.	**Low** – there is no need for big battery packs as buses charge en route.	**High** – wireless charging is currently very expensive, but requires the least change to normal bus operations. It is, however, dedicated to a single bus route, which limits flexibility. To be the only charging option the installation would need to cover most of the route.	Pantograph charging is becoming more and more popular. The economics improve as the number of e-buses in the fleet rises – more vehicles using the system reduces the cost per kilometer of charging delivered.
Plug-in at depot and pantograph en route	**High** – pantograph systems are still expensive today.	**Medium** – because buses can top up at bus stops, they can have smaller battery packs.	**Medium** – very expensive technology, but costs can be spread over several e-buses. As with the option above, pantograph installations are dedicated to a single bus route, which limits flexibility.	Pantograph charging is becoming more and more popular. The economics improve as the number of e-buses in the fleet rises – more vehicles using the system reduces the cost per kilometer of charging delivered.

Source: Bloomberg New Energy Finance

Section 6. E-bus lithium-ion battery market review

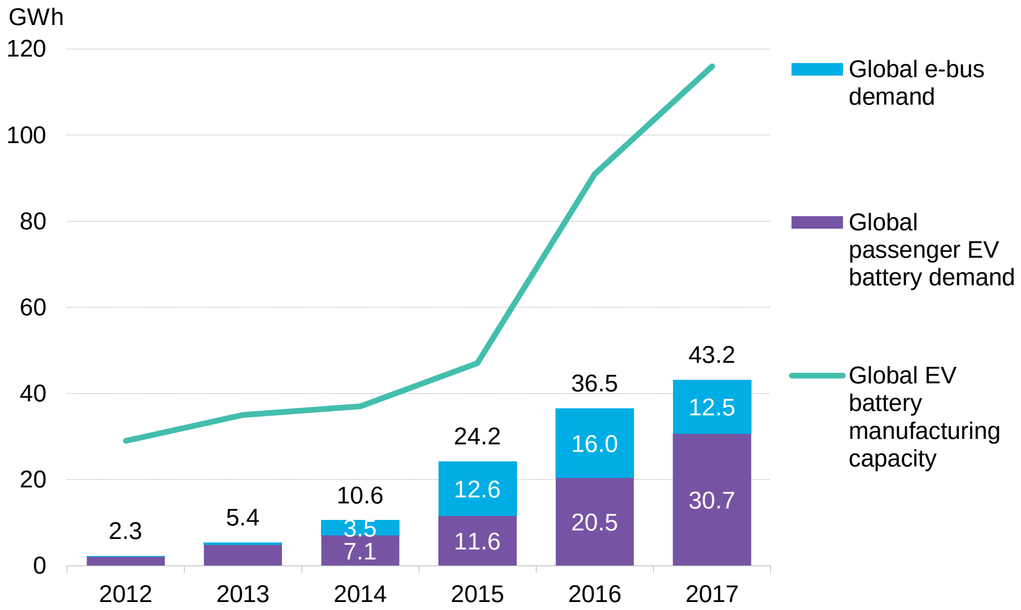
The demand for lithium-ion batteries from electric vehicles – both e-buses and passenger EVs – is increasing. However, battery manufacturing capacity is increasing much faster than demand, which puts pressure on battery prices. As a result battery prices have fallen by 79% since 2010. The sensitivity of battery cycle and calendar life, and the challenges around predicting future battery life make warranties critical to e-buses. Since e-buses have only come to prominence in the last five years the true performance of their batteries may not yet be fully understood.

6.1. Battery demand and manufacturing capacity

The majority of lithium-ion battery manufacturing capacity is located in China.

We estimate that the demand for lithium-ion batteries from the sales of electric buses in China, Europe and the U.S. increased to 12.5GWh in 2017 from 0.3GWh in 2012 – equivalent to 11% of 2016 global EV lithium-ion battery manufacturing capacity. In 2017 battery demand from e-buses was slightly lower than in 2016, as a result of the drop in e-bus sales in China. Even after including the 30.7GWh of demand from electric passenger cars globally, lithium-ion battery producers were running at overcapacity in 2017. The majority of lithium-ion battery manufacturing capacity is located in China.

Figure 10: Global e-bus lithium-ion battery demand and global EV lithium-ion battery manufacturing capacity



Source: Bloomberg New Energy Finance

The overcapacity was created as battery manufacturers rushed to add manufacturing capacity in anticipation of growing demand from passenger electric vehicles. Although delayed, we expect the demand from passenger EVs to increase significantly in the coming years – up from 30.7GWh in 2017 to 123GWh in 2020 – as sales of passenger EVs accelerate. However, we expect cities will move carefully in the procurement of e-buses, held back by concerns around high upfront costs, imminent falling technology costs, infrastructure investment and limited e-bus model choice.

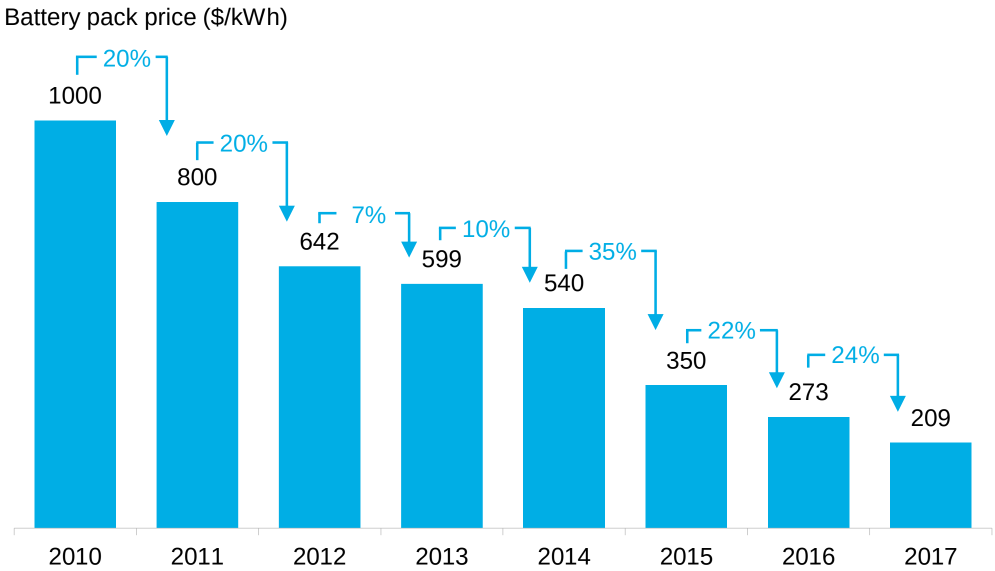
The overcapacity is putting pressure on battery prices, as major manufacturers are willing to sell their batteries cheaper in order to gain market share. Moreover, as industry players commission larger manufacturing plants, economies of scale remain an important driver of lithium-ion battery price reductions.

The price for lithium-ion battery packs has fallen by 24% since 2016 and 79% since 2010.

The location of battery manufacturing also plays an important role in determining costs. Factors such as local electricity costs, labor and financing will also affect the cost of manufacturing. Battery prices in China are currently the lowest at both pack and cell level, due to a combination of scale of manufacturing, labor costs, electricity prices and favorable local conditions. This in turn allows e-buses made in China to be considerably cheaper than in the rest of the world. We estimated the manufacturer's price for the electric BYD K9 at around 1.75 million yuan ($264,000)[14] – significantly less than e-buses on offer in Europe or the U.S.

6.2. Battery prices

Figure 11: BNEF lithium-ion battery price survey results – volume-weighted average



Source: Bloomberg New Energy Finance. Note: Prices are a weighted average for BEV and PHEV and energy storage and include both cells and packs. As of 2017, cell prices were around $147/kWh.

[14] The manufacturer declined to provide pricing for this report

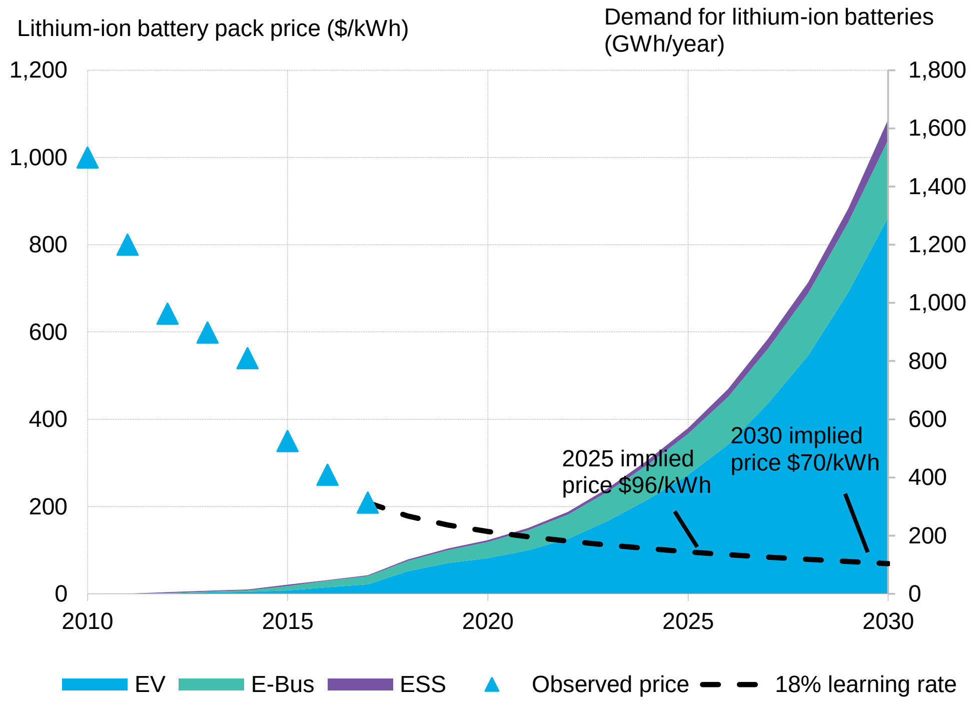
> *Our 2017 survey of companies active across the lithium-ion battery value chain has found that the weighted average price of lithium-ion battery packs is $209/kWh. This includes pricing data from battery electric vehicles, plug-in hybrid electric vehicles, e-buses and stationary storage. The price for battery packs overall has fallen by 24% since 2016 and 79% since 2010.*

Our 2017 survey of companies active across the lithium-ion battery value chain has found that the weighted average price of lithium-ion battery packs is $209/kWh. This includes pricing data from battery electric vehicles, plug-in hybrid electric vehicles, e-buses and stationary storage. The price for battery packs overall has fallen by 24% since 2016 and 79% since 2010.

Lithium-ion battery prices will continue to fall in the coming years

The historic learning rate for EV lithium-ion battery prices from 2010-2017 was around 18%. This means that for every doubling of cumulative volume, we observe an 18% reduction in cost. Based on this, we expect battery prices to continue to decline, reaching $96/kWh in 2025 and $70/kWh in 2030 (Figure 12).

Figure 12: Lithium-ion battery pack price forecast



Source: Bloomberg New Energy Finance. Note: ESS is stationary energy storage applications.

6.3. Lifetime and warranties

The life of a battery can be measured in two main ways.

- The number of years that a battery can operate for is referred to as the calendar life.
- The number of cycles a battery can perform is referred to as the cycle life.

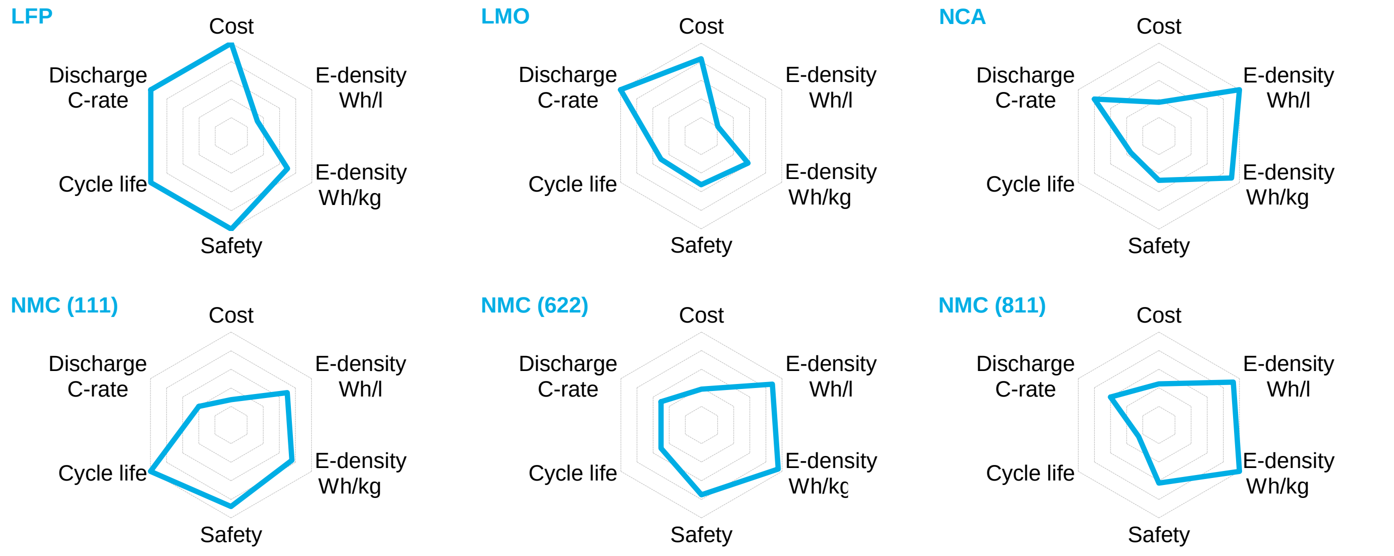
A battery is typically considered to have reached the end of its life when it has less than 80% of its initial capacity, rather than being completely exhausted. However, many battery warranties now define end-of-life to be reached when the battery's capacity falls to between 60-80% of its original capacity. The warrantied end-of-life capacity is an important factor to consider, as the lower the capacity at the end of its life, the fewer miles an e-bus can drive.

Cycle life

> *NCA (lithium nickel cobalt aluminum oxide) may be chosen over LFP because of NCA's higher energy density, requiring less room for a given pack size (kWh), despite its shorter cycle life.*

The cycle life of a battery is affected by both the chemistry and cell used. Each chemistry has its own advantages and disadvantages and chemistries are chosen depending on the performance specifications of the specific use case. Lithium iron phosphate (LFP) is safe and has a high cycle life (Figure 13) but it has a low volumetric energy density (Wh/l). NCA (lithium nickel cobalt aluminum oxide) may be chosen over LFP because of NCA's higher energy density, requiring less room for a given pack size (kWh), despite its shorter cycle life.

Figure 13: Characteristics of lithium-ion battery cathode chemistries



Source: Bloomberg New Energy Finance, NEI Corporation, BASF, academic journals. Note: E-density refers to the energy density, Cost refers to the cost of raw materials in December 2017, energy density in Wh/l is based on the tap density of the material. LFP lithium iron phosphate, LMO lithium manganese oxide, NCA lithium nickel cobalt aluminum oxide, NMC lithium nickel manganese cobalt oxide. The C-rate refers to how quickly it can be charged or discharged. The C-rate is inversely proportional to the charge/discharge time, so a battery that is charged at 2C would charge in 30 minutes.

There are three different cell designs that are used in lithium-ion battery manufacturing: cylindrical cells, prismatic cells and pouch cells. For large e-bus battery packs it may be more practical to use large pouch cells, as these would require fewer connections than if using small cylindrical cells, while also having a reasonable energy density.

In e-buses, space for locating a battery pack is not as limited as in a passenger EV and it is important to have a long cycle life, so as to maximize the return on the cost of the bus.

In e-buses, space for locating a battery pack is not as limited as in a passenger EV and it is important to have a long cycle life, so as to maximize the return on the cost of the bus. In this situation, an LFP battery may be viewed as the most suitable choice. There are exceptions where having a high energy density battery is preferable, particularly in long distance buses where ranges may be in the hundreds of miles. However, with the cost of cobalt increasing and high-nickel-content lithium nickel manganese cobalt oxide (NMC) chemistries still not providing sufficient cycle life for use in e-buses, it is likely that LFP will remain the chemistry of choice for most e-buses in the near-term.

There are three different cell designs that are used in lithium-ion battery manufacturing: cylindrical cells, prismatic cells and pouch cells. For large e-bus battery packs it may be more practical to use large pouch cells, as these would require fewer connections than if using small cylindrical cells, while also having a reasonable energy density. However, low cobalt chemistries such as NCA and NMC (811) cannot currently be used with pouch cells due to safety issues, further suggesting that LFP may be the chemistry of choice for e-buses for the foreseeable future.

Calendar life

The calendar life of a battery is the number of years a battery will retain 80% of its capacity. Batteries have calendar lives because of the continuous chemical reactions that occur within the battery. These occur regardless of use but can be exacerbated by exposing the battery to unfavorable conditions, such as high temperatures. When used regularly, batteries can have calendar lives greater than 10 years. However, when not being used regularly (less than once every 3 months), the calendar life of a battery can be drastically reduced. As e-buses are expected to be used on a daily basis this should not be a concern for e-bus operators.

Warranties

Concerns around battery life make warranties critical for all e-bus projects.

As battery manufacturers, automakers and system integrators become more confident in their understanding of battery performance, the length and structure of warranties will likely improve.

The sensitivity of battery cycle and calendar life, and the challenges around predicting future battery life make warranties critical to all e-buses. Given e-buses have only come to prominence in the last five years, the true performance of their batteries may not yet be fully understood. Although some lessons can be learnt from the passenger EV industry, the usage and charging profile of e-buses varies enough such that battery performance may also differ. In contrast to passenger EV warranties, which define usage by kilometers traveled, e-bus warranties are generally structured around calendar life (Table 5). As battery manufacturers, automakers and system integrators become more confident in their understanding of battery performance, the length and structure of warranties will likely improve.

Table 5: Selected e-bus warranties

OEM	Model	Battery			Range (km)	Charging technology	Battery warranty
		Size (kWh)	Type	Supplier			
Yutong	Yutong E12	295	LFP	CATL	320	Plug-in at depot, at 60kW or 150kW rate;	4,000 cycles
BYD	18MLE	324	LFP	BYD	250	Pantograph and plug-in at a rate of 2x40kW	5 years
	Double decker	345	LFP	BYD	330	Plug-in at depot at a rate 2x40kW,	
Proterra	Catalyst FC	79-105	LTO	Toshiba	80-100	On route pantograph at maximum 500kW, plug-in at depot	6 years
	Catalyst XR	220-330	NMC	LG Chem	220-310		
Solaris	Urbino 8.9	160	LFP/LTO	Solaris	200	Plug-in at depot or pantograph; at 80kW or 300kW;	Up to 10 years
Optare	Solo EV	138	LiFeMgPO4	Valence	270	Plug-in at depot, 42kW	5 years
BYD-ADL	Enviro 200EV	324	LFP	BYD	250	Plug-in at depot at 80kW rate	Battery warranty differs by contract
Volvo Bus	Volvo 7900 Electric	76	LFP	SAFT	96	Opportunity charging, overhead, conductive, pantograph on pole	Additional battery contract, including performance monitoring, available.
Van Hool	Exqui.City 18m	215	LFP	BFFT	120	Plug-in and inverted pantograph; 80kW and 250kW	5 years
Bollore Group	Bluebus	240	LMP	BlueSolutions	180	Plug-in at depot, at 50kW rate	7 years
Evopro	Modulo C68e	144	LFP	Valence	200-230	Conductive at 60kW	5 years

Source: Bloomberg New Energy Finance, EAFO, ZeEUS e-bus report Note: Unless stated otherwise, e-bus models mentioned in the table are all pure electric.

6.4. Recycling and reuse

Based on the information gathered on e-bus battery warranties, the average expected life of an e-bus battery is around seven years. The problem of what to do with end-of-life batteries from e-buses and passenger EVs is now a key issue for the industry. Automakers had initially planned on recycling batteries once they were removed from EVs; however, some automakers, such as Nissan, are finding that the batteries that are coming out of their vehicles still have sufficient capacity left to be used for second-life applications.

Table 6: Annual battery demand and availability of used e-bus batteries

Year	Amount of used e-bus batteries available (GWh)	Battery demand for stationary storage (GWh)	Battery demand for e-buses (GWh)
2018	0	5	13
2020	0.4	6	13
2025	11	20	9

Source: Bloomberg New Energy Finance. Note: e-bus batteries are assumed to reach their end-of-life after seven years and to have 80% capacity left. The stationary storage demand for batteries comes from BNEF's long-term energy storage forecast.

Second-life applications

Second-life storage projects use 'end-of-life' EV batteries in stationary storage applications. The batteries that are expected to come out of e-buses in 2022-23 could provide enough capacity for all of the storage projects that are expected to be commissioned in those years, even taking into account the potential capacity loss (Table 6).

The cost of repurposing e-bus packs is around $49/kWh, significantly lower than the cost of new batteries.

We estimate the cost of repurposing used EV battery packs for use in stationary applications to be around $49/kWh. This covers expenses like labor, transport costs and overheads needed to get the used battery packs ready for use in these new applications. This is significantly lower than the cost of new batteries on a kWh basis. However, there are likely to be concerns for developers around the use of second-life batteries with regard to their expected lifetime and safety. As new battery pack prices continue to fall, the cost of second-life battery packs and the associated cost of repurposing may eventually become uneconomical.

Despite the concerns around second-life batteries, many automakers are using used EV batteries in pilot storage projects. Renault, a French automaker, recently announced that it would install used EV batteries on the Portuguese island of Madeira. BYD, a Chinese automaker, announced that it would be installing second-life EV batteries at an energy storage project in Hunan Province, China. Also in China, China Tower – owner and operator of roughly two million telecom towers – signed an agreement with 16 companies involved in the battery supply chain to use second-life batteries to replace the existing lead-acid batteries providing backup power to the towers. Assuming a 10kWh battery is required for each tower, replacing all of China Tower's existing lead-acid batteries with used EV batteries represents a 20GWh market. These projects will help to develop understanding of the potential for using e-bus batteries in second-life applications in the future. If economically attractive, this could help boost residual e-bus values.

Recycling

The chemistry used in a battery and current commodity prices have a big impact on the economics of recycling.

If e-bus batteries are not re-used they may be recycled. Currently, the disposal and handling of used batteries in the EU is covered under the EU directive 2006/66/EC. However, this legislation is largely structured around minimizing the release of mercury and cadmium. The EU is expected to release new legislation dealing specifically with used batteries from electric vehicles at the end of 2018.

Increasingly, hydrometallurgical recycling processes for lithium-ion batteries are being developed. These processing methods are more expensive but can produce refined materials that can be re-used in lithium-ion battery manufacturing. However, the cost of the processing must be considered and weighed against the price and volumes of the materials recovered.

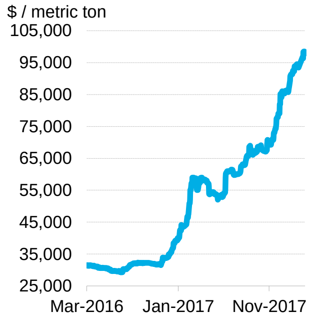
The current recycling methods used for lithium-ion batteries tend to be based on a pyrometallurgical process). This involves smelting the battery components into a slag which can sometimes be sold on for further processing, but doesn't produce material of high enough purity to be re-used in battery manufacturing.

Increasingly, hydrometallurgical recycling processes for lithium-ion batteries are being developed. These processing methods are more expensive but can produce refined materials that can be re-used in lithium-ion battery manufacturing. However, the cost of the processing must be considered and weighed against the price and volumes of the materials recovered.

The chemistry used in a battery and current commodity prices have a big impact on the economics of recycling. Cobalt is trading around three times higher than it was two years ago (Figure 14). With current commodity prices we estimate that the hydrometallurgical recycling of a 24kWh NMC (111) battery pack could provide up to $3,934 of revenue (Figure 15).

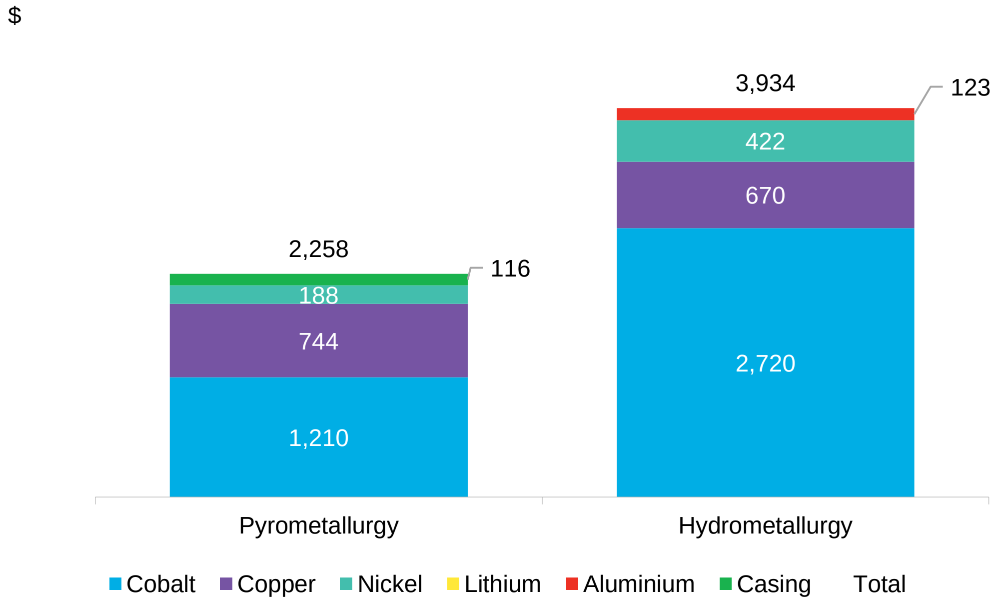
However, in 2015-2016 only 9% of e-buses sold used NMC based batteries, while 89% used LFP. LFP batteries do not contain the same high value metals found in NMC batteries. Therefore recycling these batteries via a hydrometallurgical route may not be practical.

Figure 14: Cobalt spot price



Source: Bloomberg Note: Shanghai spot price, correct as of March 6, 2018

Figure 15: Estimated revenue from recycling a 24kWh NMC (111) lithium-ion battery pack



Source: Bloomberg New Energy Finance Note: based on commodity prices on March 6, 2018.

Section 7. Cost outlook for e-buses

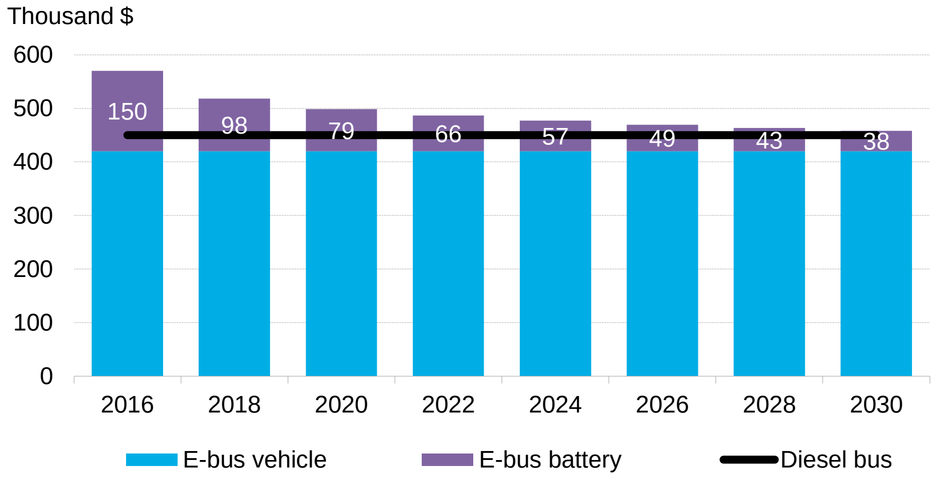
The high upfront costs of electric buses are still the single largest barrier holding back mass adoption of the technology. Many cities lack funding to support higher spending when faced with a technology choice for fleet replacement, but some are deliberately delaying the purchase decision because they know battery prices are falling, and they expect e-buses to be cheaper in the future. In this section, we use our lithium-ion battery price predictions to model when electric buses will reach cost parity on an upfront basis with an average diesel bus. According to our analysis shown in this section, upfront cost parity will not be reached until 2030. However, the next section will show how TCO parity is arriving much sooner.

7.1. 10 years to up-front cost parity

We see electric buses reaching upfront cost parity with diesel buses by 2030.

Municipalities expecting the upfront cost parity to come sooner rather than later may be disappointed. To model when upfront cost parity comes for an average e-bus, we have assumed an electric bus with an average 250kWh battery purchased for $570,000[15]. This price corresponds to e-buses available for purchase from European e-bus manufacturers. However, batteries used in e-buses and prices of e-buses vary greatly between individual contracts – due to limited data available we have assumed the above-mentioned battery size and e-bus price as an average.

Figure 16: European e-bus and diesel bus upfront price forecast



Source: Bloomberg New Energy Finance. Notes: E-bus with a 250kWh battery, initial battery price at $600/kWh.

We expect future cost reductions to come mainly from the battery pack, as there is little scope to further reduce the price of the other components of the vehicle. To start with, we have assumed a battery price at the higher end of the spectrum, at $600/kWh. According to our battery price index, the price range for lithium-ion battery packs in 2016 was between $190/kWh to $500/kWh, but low

15 All figures in the report are in 2017 dollars, unless stated otherwise

volume orders can have higher prices per kWh. Most e-buses purchased in Europe or the U.S. are still low volume orders. This is not necessarily true for the Chinese electric bus manufacturers, as high-volume orders in China likely allow e-bus manufacturers there to negotiate much lower battery prices.

We compare the e-bus with a diesel bus priced at $450,000. In our modelling, we assume this price remains constant, as there are no major regulatory drivers for heavy-duty vehicles and buses which would require significant improvements to ICE bus fuel efficiency which could drive up the price of a conventional bus.

> *Based on the above assumptions, we see electric buses reaching upfront cost parity with diesel buses by 2030. By then, the battery pack in the average e-bus should only account for around 8% of the total e-bus price – down from 26% in 2016*

Based on the above assumptions, we see electric buses reaching upfront cost parity with diesel buses by 2030. By then, the battery pack in the average e-bus should only account for around 8% of the total e-bus price – down from 26% in 2016 (Figure 16).

The larger the battery pack in the e-bus, the longer it will take for e-buses to be price-competitive with diesel buses upfront. According to our analysis, lowering the battery size to just 200kWh brings cost parity a little forward to 2028, while for buses using bigger battery packs – around 350kWh – upfront cost parity would come after 2030.

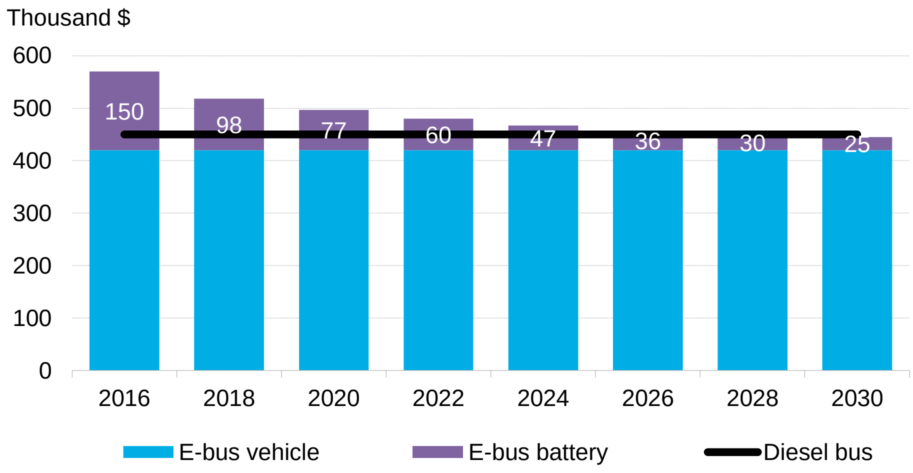
7.2. Increasing demand for e-buses will bring prices down faster

> *However, increasing demand for e-buses can potentially bring e-bus battery prices down much faster, bringing them closer to the high-volume prices that automakers are able to get for passenger EVs. In this scenario, electric buses would reach cost parity with diesel buses sooner, around 2025-27.*

In the analysis above we have assumed battery prices decline at the same rate as we have observed for passenger EVs. However, increasing demand for e-buses can potentially bring e-bus battery prices down much faster, bringing them closer to the high-volume prices that automakers are able to get for passenger EVs. In this scenario, electric buses would reach cost parity with diesel buses sooner, around 2025-27[16] (Figure 17).

[16] *In the base case scenario, battery prices for e-buses follow the same reduction rate as passenger EVs, but start at the higher price of $600/kWh – by 2030 battery prices for e-buses reach $153/kWh. In the scenario where e-buses battery prices merge closer with the passenger EV battery prices, we see battery price reach $100/kWh by 2030.*

Figure 17: European e-bus and diesel bus upfront cost forecast



Source: Bloomberg New Energy Finance. Note: E-bus battery price decline accelerates to match passenger EVs battery prices and reached $100/kWh in 2030.

Section 8. Total cost of ownership outlook

Electric buses are on average cheaper to run than conventional buses, which is an important decision factor for many municipalities and bus operators. However, not all e-buses will deliver the same operational cost savings today.

This section compares electric, diesel and CNG buses on a total cost of ownership basis, exploring a variety of different assumptions. We find that most real-life configurations of e-buses already offer lower total cost of ownership when compared to diesel and CNG buses, and that annual distances travelled make a big difference – longer distances favor e-buses. The data indicates that larger cities already have a number of e-bus options with lower TCO and a strong potential for long-term cost savings.

This picture is rapidly changing, as falling battery prices will lead to e-buses being fully competitive on a total cost of ownership basis across most different operating scenarios in the within this year.

8.1. Total cost of ownership (TCO) scenarios - methodology

The total cost of ownership of an e-bus is very sensitive to fuel prices, electricity prices, average driving distances, charging configuration and financing costs

There are many different factors affecting the total cost of ownership of a bus. We have run several scenarios comparing the total cost of ownership of electric, diesel and compressed natural gas (CNG) buses. Important variables include e-bus battery size, e-bus charging configurations, CNG and diesel fuel prices and whether investment in refueling infrastructure for diesel and CNG buses is included.

We have made a range of assumptions around the capital costs of the buses, their annual kilometers travelled, their lifetime, running costs, efficiency and fuel prices. The table in the Appendix shows the assumptions behind the different inputs used for the modelling of e-buses in our scenarios. There is large variability in all of these inputs depending on the operational conditions of each city and individual contracts with bus manufacturers. The TCO calculations below illustrate a range of outcomes based on these assumptions and their sensitivity.

Diesel and CNG buses: the baseline comparison

The assumptions behind our baseline TCO scenario of diesel and CNG buses are in Table 7 below. We have run our analysis for three different annual distances traveled by a bus in different types of cities to illustrate the most likely e-bus configurations in small, medium and large cities.

Table 7: Associated costs comparison for diesel and CNG buses

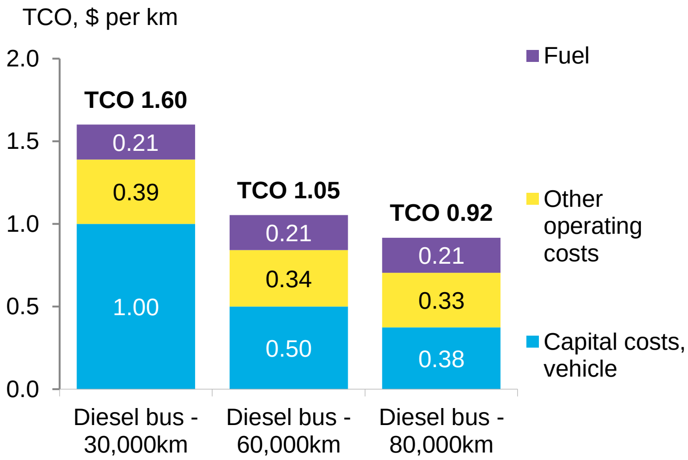
Variable	Diesel	CNG
Lifetime	15 years	
Distance travelled per year	30,000km, 60,000km, 80,000km	
Vehicle efficiency	4.1 miles per gallon	21 miles per MMBtu
Vehicle capital costs	$450,000	$540,000

Refueling infrastructure costs	$91,600[17]	$40,000[18]
Other operating costs	$34,877 per year	$34,877 per year
Fuel price	$2.5 per gallon	$15 per MMBtu

Source: Bloomberg New Energy Finance Note: Other operating costs include costs like labour, insurance, repair and maintenance and exclude fuel costs.

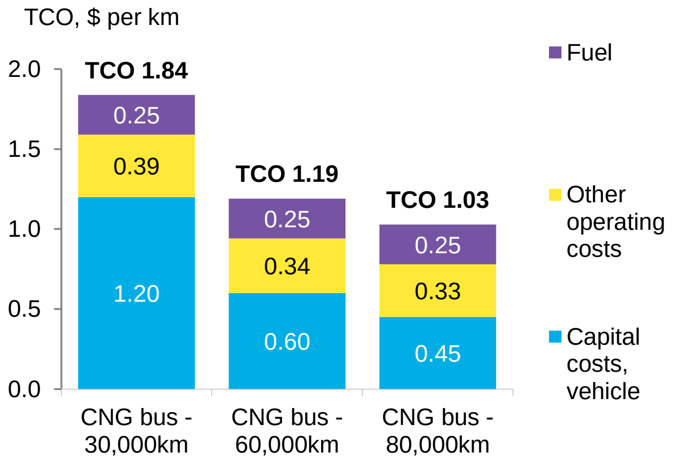
In our analysis, the TCO of diesel and CNG buses varies considerably depending on whether refueling infrastructure is included in the calculation or not. When the TCO of diesel and CNG buses is calculated without including any additional refueling infrastructure investment – we assume that in established cities this infrastructure already exists – the TCO of a diesel bus is significantly lower at $1.60/km, $1.05/km and $0.92/km (depending on the annual distance) compared to $1.84/km, $1.19/km and $1.03/km respectively for a CNG bus (Figure 18, Figure 19). However, cities building entirely new bus networks (or lines) would have to include the price of new refueling infrastructure for a diesel or a CNG bus at $91,600 and $40,000, respectively. This changes the economics slightly in favor of the CNG bus, with the TCO increasing to $1.80/km, $1.16/km and $0.99/km for the diesel bus and $1.93/km, $1.23/km and $1.06/km for the CNG vehicle.

Figure 18: TCO comparison of a diesel bus, no refueling infrastructure



Source: Bloomberg New Energy Finance, AFLEET, Advanced Clean Transit – Cost Assumptions and Data Sources (California Air Resources Board).

Figure 19: TCO comparison of a CNG bus, no refueling infrastructure



Source: Bloomberg New Energy Finance, AFLEET, Advanced Clean Transit – Cost Assumptions and Data Sources (California Air Resources Board).

17 The cost of diesel-fueled transit bus refueling infrastructure are from data provided in the AFLEET Tool 2016, Argonne National Laboratory: 1 tank and 1 dispenser.

18 The cost of CNG fueled transit bus refueling infrastructure comes from the Advanced Clean Transit – Cost Assumptions and Data Sources published by California Air Resources Board.

8.2. Kilometers matter: the impact of longer routes

The choice of the size of the battery in an e-bus will depend heavily on the required range of the e-bus and how many kilometers per day it will be required to run. In the largest cities, where the daily distance travelled by a bus can often exceed 300 km/day, operators are more likely to deploy e-buses with larger batteries. Medium and small cities with average driving distances of around 160 km/day, will likely be better served by cheaper e-buses with smaller batteries. In this section, we analyze how daily distances travelled affect the economics of e-buses versus diesel buses. For the analysis we selected four types of e-buses with different charging configurations:

- 350 kWh e-bus using slow charging at the depot
- 250 kWh e-bus using slow charging at the depot
- 110 kWh e-bus using slow charging at the depot
- 110 kWh e-bus using slow charging at the depot and wireless charging en-route

Table 8 below summarizes our assumptions behind the different inputs used throughout the report for modelling the TCO of e-buses.

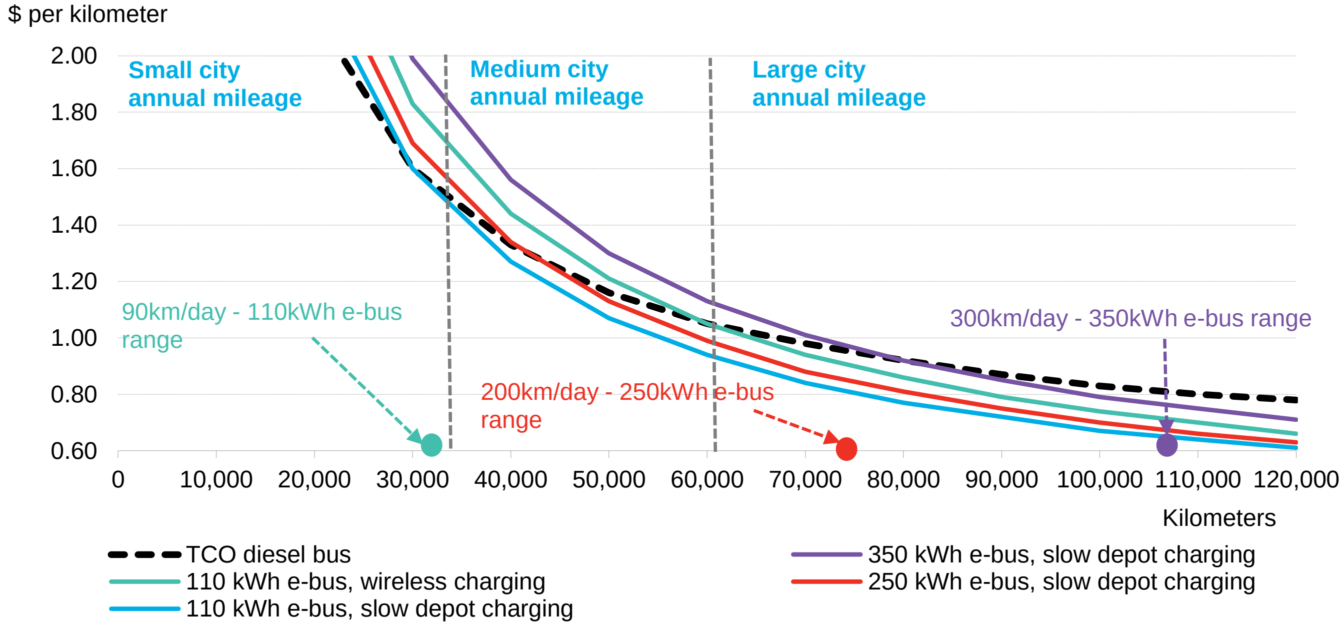
Table 8: Associated cost comparison for electric buses

Variable	350 kWh e-bus	250 kWh e-bus	110 kWh e-bus
Lifetime	15 years		
Distance traveled	Variable. Distance used depends on the type of city: small city (30,000km per year), medium city (60,000 per year) and large city (80,000km per year).		
Vehicle efficiency	0.48 miles per kWh	0.50 miles per kWh	0.52 miles per kWh
Vehicle capital costs	$700,000	$570,000	$530,000
Refueling infrastructure	We model different charging configurations: Slow depot charging at $50,000 per charger. Bus-to-charger ratio 2:1. Fast terminal charging at $110,000 – bus-to-charger ratio 20:1 Pantograph charging at $230,000 per pantograph – bus-to-charger ratio 20:1 Wireless charging at bus stop at $400,000 – installed at five bus stops, bus-to-charger ratio 20:1		
Other operating costs	$26,127 per year		
Fuel price	$0.1 per kWh		

Source: Bloomberg New Energy Finance, AFLEET Note: Other operating costs include costs like labour, insurance, repair and maintenance and exclude fuel costs.

Figure 20 shows the TCO comparison of these e-buses and diesel buses at different annual distances travelled. While all buses benefit from lower TCO (per kilometer) at higher utilization rates, e-buses benefit more than diesel buses, leading to crossover points where e-buses become cheaper than diesels.

Figure 20: TCO comparison for e-buses and diesel buses with different annual distance travelled



Source: Bloomberg New Energy Finance. Notes: Diesel price at $0.66/liter ($2.5/gallon), electricity price at $0.10/kWh, annual kilometers traveled – variable. Bus route length will not always correspond with city size.

The TCO of all selected electric bus configurations improves significantly in relation to diesel buses as the number of kilometers traveled annually increase. The 110kWh e-bus coupled with the most expensive wireless charging reaches TCO parity with diesel bus at around 60,000km travelled per year (37,000 miles). This means that the bus with the smallest battery, even when coupled with the most expensive charging option, would be cheaper to run in a medium sized city, where buses travel on average 170km/day (106 miles). Indeed, a bus with such a small battery would need some form of on-route or intra-day charging to achieve these distances.

The same e-bus, but charging only once per day at the depot, reaches TCO cost parity with a diesel bus at around 30,000km travelled per year. This indicates that it will be cheaper to run in a small city, if a bus travels an average of around 80km/day. However, we estimate the range of the 110kWh e-bus at around 90km. The TCO parity for this e-bus in this charging configuration comes in at the upper end of its operating range and leaves little contingency. Average route distances may also hide variations and many bus routes may exceed this length. On the face of it, this e-bus configuration only has a narrow window of opportunity. However, in practice, some cities may still choose this option for shorter routes, as the cost penalty against diesel is small even below 30,000km/year. This option also becomes more attractive as battery costs fall.

The TCO of all selected electric bus configurations improves significantly in relation to diesel buses as the number of kilometers traveled annually increase. The 110kWh e-bus coupled with the most expensive wireless charging reaches TCO parity with diesel bus at around 60,000km travelled per year (37,000 miles).

At around 80,000 annual kilometers, the 350kWh e-bus reaches TCO parity with a diesel bus.

At around 80,000 annual kilometers (50,000 miles), the 350kWh e-bus reaches TCO parity with a diesel bus. This means that the bus with the biggest battery should only be considered for the biggest cities, where buses run at least 220km/day (137 miles). However, cities with high variability between their route lengths may still opt for these buses to ensure the fleet is flexible.

At around 50,000 annual kilometers (31,000 miles), the 250kWh e-bus coupled with depot charging and the 250kWh e-bus coupled with fast terminal charging, are already cheaper in terms of total operating costs than the respective diesel bus. This means both will be a suitable option for cities where buses run at least 139km/day.

> *This means that large cities could further improve their TCO savings by opting for the smaller and cheaper 250kWh e-bus coupled with opportunity charging rather than the 350kWh e-bus.*

Interestingly, at 80,000km traveled, the 250kWh e-bus – even when coupled with the most expensive wireless charging – remains cheaper over its lifetime than the 350kWh e-bus using slow depot charging. This means that large cities could further improve their TCO savings by opting for the smaller and cheaper 250kWh e-bus coupled with opportunity charging rather than the 350kWh e-bus.

8.3. City-level choices

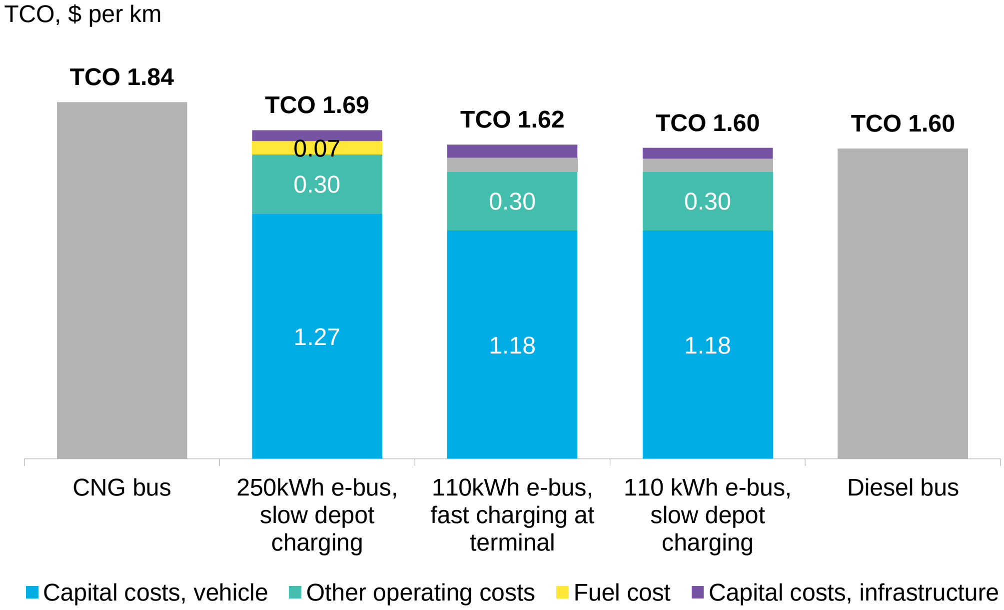
Small city: 30,000km traveled annually

According to our analysis, a small city where buses travel on average 83km/day has to make a finely balanced choice when it comes to electric buses, assuming total cost of ownership is the main criteria.

Due to the short distances travelled, the 110kWh e-bus charging once per day at the depot would be the cheapest electric option small cities could consider. At $1.60/km it is at TCO parity with a respective diesel bus, and it is cheaper to run than a CNG bus. As described above, range may be an issue for this configuration. One option to overcome this would be to combine the 110kWh e-bus with fast charging at terminal. This charging configuration brings its TCO up to $1.62/km, slightly above the TCO of a diesel bus but still broadly competitive. It is still cheaper in terms of the total cost of ownership than the CNG bus in this scenario. The relatively small battery would usually require the 110kWh e-bus bus to be paired with the most expensive wireless charging, however, there could be a scenario where an e-bus with such a small battery is run using only depot and occasional fast charging at the terminal. This could work on very short distance routes, with limited traffic and fairly mild weather conditions.

If a city in this scenario were choosing between a CNG bus and an electric bus, then the 250kWh e-bus charging slowly at the depot would also be an option. At $1.69/km its TCO is around $0.15/km lower than the CNG bus.

Figure 21: TCO comparison for the most likely e-bus configurations in a small city



Source: Bloomberg New Energy Finance, AFLEET, Advanced Clean Transit – Cost Assumptions and Data Sources (California Air Resources Board) Note: Diesel price at $0.66/liter ($2.5/gallon), CNG price at $15 per MMBtu, electricity price at $0.10/kWh, annual distance traveled – 30,000km.

Medium city: 60,000km traveled annually

Increasing the annual distance traveled to 60,000km brings the TCO of several e-bus configurations below those of diesel and CNG buses.

Cities where buses travel on average 166km/day could opt for a 250kWh e-bus slowly charging once per day at the depot. In this configuration the e-bus has lower total cost of ownership than diesel or CNG buses, at $0.99/km. However, manufacturers of 250kWh electric buses claim an average range of around 200km. This may be challenging for some cities because it would leave little battery capacity at the end of daily operations. This could be addressed by additionally installing fast chargers at the terminal to enable battery top ups during a layover – this charging configuration does not affect the TCO of the 250kWh e-bus significantly at this mileage.

The cheapest possible e-bus configuration in this scenario is the 110kWh e-bus using slow depot charging once a day and pantographs located at three bus stops for fast charging. At $0.98/km the TCO of this configuration is lower than that of a CNG and diesel buses. Pantograph charging is still a more expensive fast charging option, but it is becoming increasingly popular. It could be used in cities where not all bus routes have terminals and the daily operations are more continuous with fewer breaks. However, it may not always be possible to install pantographs at bus stops due to space restrictions and local planning regulations. Pantographs are also exposed to all weather conditions, which can sometimes influence their operability during periods of extreme weather.

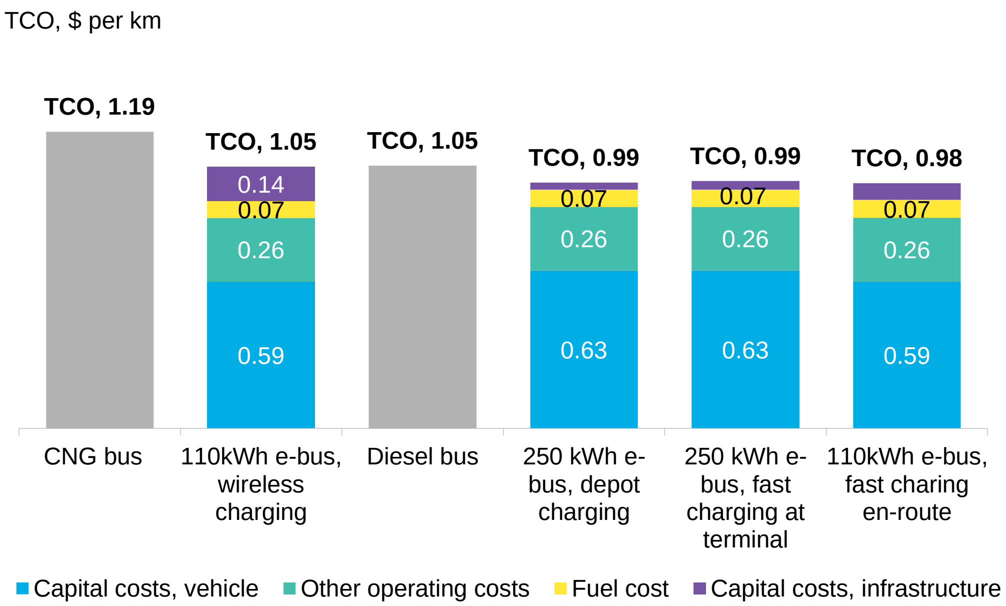
> *When compared to diesel and CNG, most e-buses configurations present a lower TCO with a daily bus mileage of 165km, potentially generating between $64,000 and $183,000 in lifetime cost savings when using the 250kWh e-bus instead of a diesel or CNG bus respectively. This figure can increase to $157,000 and $220,000 when diesel or CNG refueling infrastructure is included, making e-buses the clear choice for cities that are building entirely new public transport networks or adding new lines.*

Without opportunity charging, the 110kWh e-bus will not be able to operate at 167km/day due to range restrictions. Some of the drawbacks of the pantograph charging options could be overcome by opting for wireless charging.

Wireless e-bus charging technology is still in the pilot phase and it has not been proven on a commercial scale. This means it is currently the most expensive charging configuration – we estimate it costs around $400,000 to install wireless charging technology at a bus stop. It is currently seen as the technology most suitable for e-buses with the smallest batteries.

In this configuration, assuming wireless chargers are installed at five bus stops, and buses use both slow charging at depot and wireless charging at bus stops, the 110kWh e-bus is at TCO parity with a diesel bus, but it remains cheaper than the CNG bus.

Figure 22: TCO comparison for the most likely e-bus configurations in a medium city



Source: Bloomberg New Energy Finance, AFLEET, Advanced Clean Transit – Cost Assumptions and Data Sources (California Air Resources Board) Note: Diesel price at $0.66/liter ($2.5/gallon), CNG price at $15 per MMBtu, electricity price at $0.10/kWh, annual distance traveled – 60,000km.

However, the 110kWh e-bus coupled with wireless charging remains competitive with both diesel and CNG buses if investment in diesel and CNG refueling investment[19] is included. This brings the fossil fueled buses' TCO up to $1.16/km and $1.23/km respectively, making e-buses the clear choice for cities that are building entirely new public transport networks or adding new lines. Such cities have an even bigger incentive to deploy electric buses to serve their new routes as the cost of adding diesel and CNG buses refueling infrastructure[20] tips the scales in favor of e-buses.

When compared to diesel and CNG, most e-buses configurations present a lower TCO with a daily bus mileage of 165km, potentially generating between $64,000 and $183,000 in lifetime cost savings when using the 250kWh e-bus instead of a diesel or CNG bus respectively. This figure can increase to $157,000 and $220,000 when diesel or CNG refueling infrastructure is included, making e-buses the clear choice for cities that are building entirely new public transport networks or adding new lines.

Large city: 80,000 km traveled annually

Large cities with high annual bus mileages can choose from a number of electric options, all cheaper than diesel and CNG buses.

> *This indicates that in a megacity, where buses travel at least 220km/day, using even the most expensive 350kWh e-bus instead of a CNG bus could bring around $130,000 in operational costs savings over the 15-year lifetime of a bus.*

The most expensive electric bus in this scenario is the 350kWh e-bus. It has the biggest battery and is slowly charged once per day at the depot – most likely at night. Based on currently available models, the capital costs for an electric bus with a 350kWh battery are around $700,000. At 80,000km per year, this puts its TCO at $0.92/km, just at par with diesel buses. Compared to a CNG bus, it is around $0.11/km cheaper in terms of the TCO. This indicates that in a megacity, where buses travel at least 220km/day, using even the most expensive 350kWh e-bus instead of a CNG bus could bring around $130,000 in operational costs savings over the 15-year lifetime of a bus. As indicated in the sensitivity analysis in the previous section, increasing the traveled distance further brings the total cost of ownership of the 350kWh e-bus even lower - below both the diesel and CNG options.

Because of the expensive batteries used in e-buses, opting for a bus with a smaller battery delivers the most cost effective solution, capable of coming in below even the cheapest scenarios for diesel and CNG buses. A 110kWh e-bus coupled with wireless charging is cheaper in terms of its total cost of ownership than both CNG and diesel options and around $0.06/km cheaper than the 350kWh e-bus charging once per day at the depot. Cheaper still is the 250kWh e-bus charging once per day at the depot and topping up during layover time at the terminal. At $0.81/km in this scenario it is significantly cheaper than CNG, diesel and the 350kWh e-bus options.

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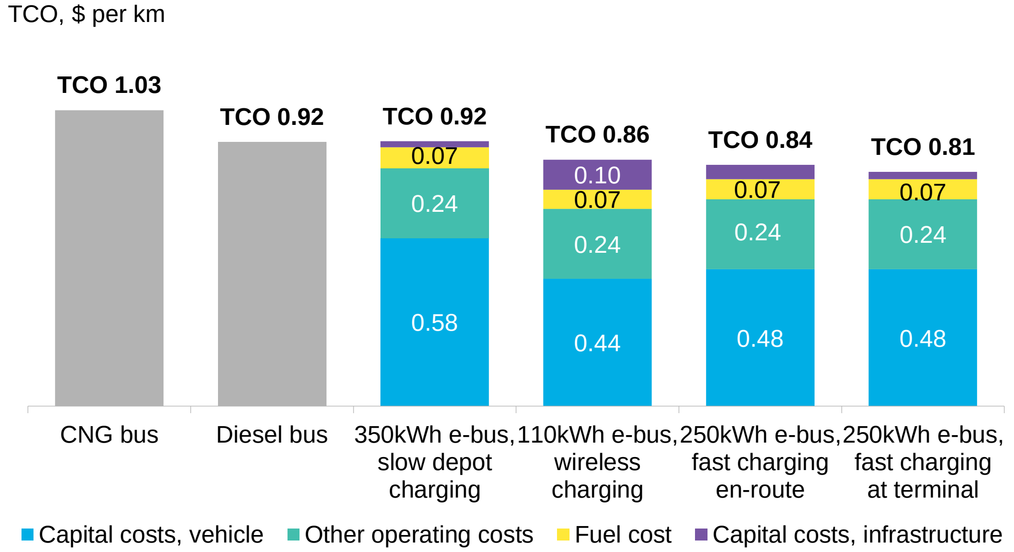
[19] The cost of CNG fueled transit bus refueling infrastructure – at $40,000 – comes from the Advanced Clean Transit – Cost Assumptions and Data Sources published by California Air Resources Board. The cost of diesel-fueled transit bus refueling infrastructure – at $91,600 – are from data provided in the AFLEET Tool 2016, Argonne National Laboratory: 1 tank and 1 dispenser.

This is good news for established large cities where buses operate on average 220km/day or more. Megacities do not have to rely on the most expensive e-buses, and instead – where possible – could further reduce their total operating costs by combining smaller batteries with innovative charging options.

Figure 23: TCO comparison for the most likely e-bus configurations in a large city



Source: Bloomberg New Energy Finance, AFLEET, Advanced Clean Transit – Cost Assumptions and Data Sources (California Air Resources Board) Note: Diesel price at $0.66/liter ($2.5/gallon), CNG price at $15 per MMBtu, electricity price at $0.10/kWh, annual distance traveled – 80,000km.

8.4. Sensitivity to diesel prices

At a diesel price of around $0.50/liter the smallest 110kWh electric bus, using the most expensive wireless charging, becomes cheaper to run than a corresponding diesel bus.

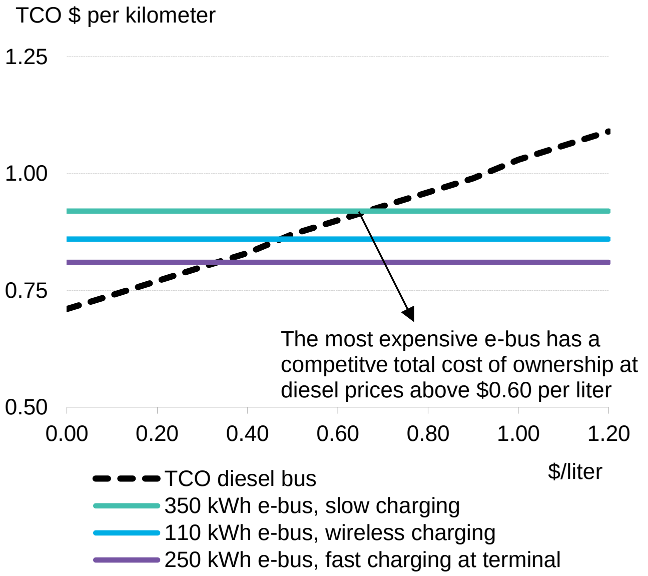
Higher diesel prices would improve the TCO competitiveness of electric buses. In a large city, at a diesel price of around $ 0.50/liter ($1.9/gallon), with electricity prices unchanged at $0.1/kWh, the smallest 110kWh electric bus becomes cheaper to run than a corresponding diesel bus, even using the most expensive wireless charging.

For the most expensive 350kWh e-bus, using slow overnight charging at the depot, the diesel price needs to be around $0.65/liter ($2.5/gallon) for the e-bus to be cost competitive from a TCO perspective.

However, lower diesel prices would harm the economics of e-buses. At diesel prices of $0.3/liter or lower, none of the analyzed e-bus configurations would have lower TCO than a diesel bus, even at a relatively high annual distance travelled. Diesel prices can be below $0.3/liter in countries where the fuel is subsidized, such as Saudi Arabia, Ecuador or in countries where fuel prices are controlled by the government, as in Egypt.

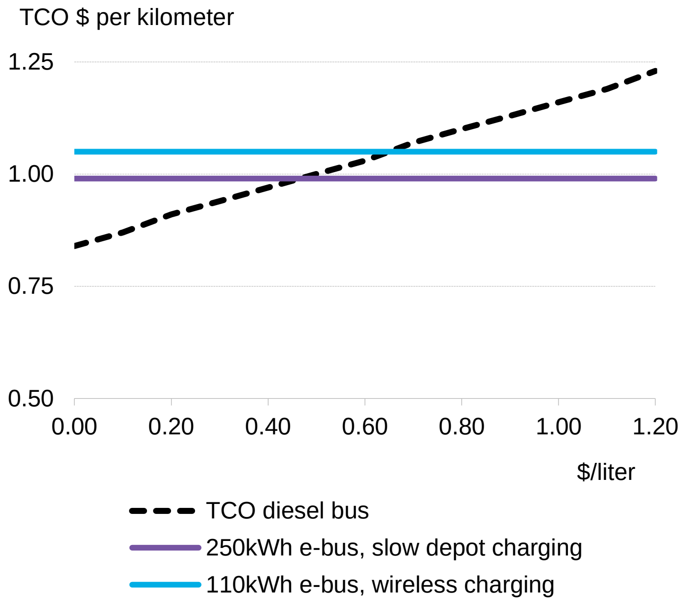
In a medium-sized city, the 250kWh e-bus using only slow charging at the depot becomes cheaper to run than a corresponding diesel bus at diesel prices of around $0.50/liter ($1.9/gallon). The wirelessly charged 110kWh e-bus requires diesel prices at around $0.7/liter ($2.65/gallon) to have a lower TCO than a diesel bus.

Figure 24: Large city TCO comparison for e-buses and diesel buses with different diesel prices



Source: Bloomberg New Energy Finance. Notes: Diesel price – variable, electricity price at $0.1/kWh, annual miles travelled at 80,000 kilometers (50,000 miles).

Figure 25: Medium city TCO comparison for e-buses and diesel buses with different diesel prices



Source: Bloomberg New Energy Finance. Notes: Diesel price – variable, electricity price at $0.1/kWh, annual miles travelled at 60,000 kilometers (37,000 miles).

8.5. Sensitivity to electricity prices

Table 9: Average industrial power prices in select countries, 2016

Country	Power price ($ per kWh)
Argentina	0.09
China	0.08
Germany	0.22
India	0.10
Norway	0.03
U.K.	0.18
U.S.	0.12

Source: Bloomberg New Energy Finance

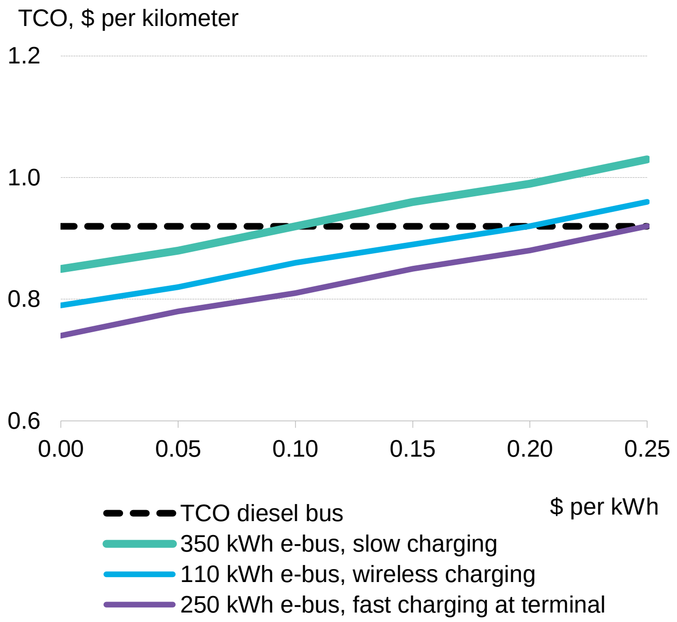
In our base case (above), with diesel fuel prices at the initial $0.66/liter ($2.5/gallon), and the diesel bus TCO at $0.92/km, the biggest battery e-buses coupled with the cheapest slow charging (at the depot) is only just competitive. In a large city, the 350kWh bus is just about TCO competitive with an average diesel bus, with industrial electricity prices at $0.10/kWh. Lower power prices would help; higher prices would tip the balance in favor of diesel buses.

The competitiveness of an average 250kWh e-bus, using both depot charging and fast charging at terminal, shows greater resilience to increasing electricity prices. The price of electricity would need to increase by 150% from our base-case scenario of $0.10/kWh in order for this e-bus to be more expensive to run than diesel bus. Electricity prices tend to be less volatile than diesel or CNG prices but could still see increases over the ownership lifetime of the bus.

Interestingly, the 110kWh e-bus coupled with the most expensive wireless charging remains cheaper to run than the average diesel bus up until industrial electricity prices reach around $0.19/kWh. This is higher than all but the most expensive countries.

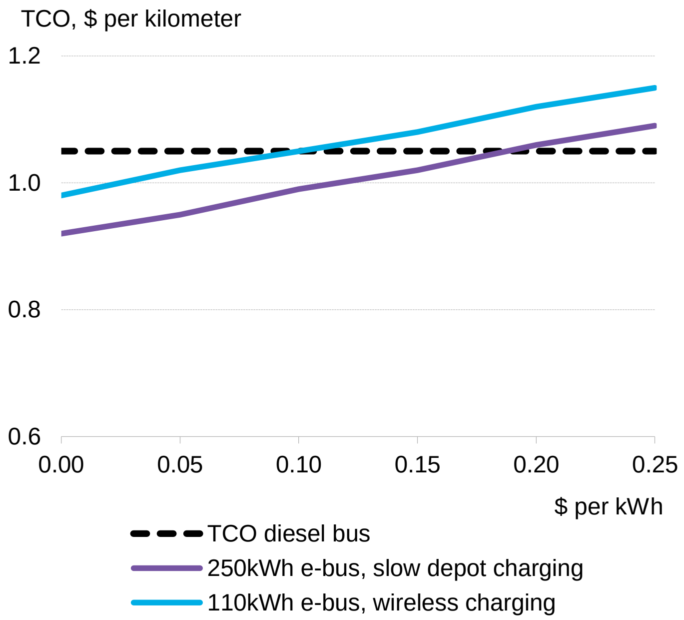
In the medium-sized city scenario, in order for the 110kWh e-bus coupled with wireless charging to remain TCO competitive with a diesel bus, electricity prices would have to be $0.10/kWh or lower. The price of electricity would need to double from our base-case scenario of $0.10/kWh in order for the 250kW e-bus to be more expensive than the diesel bus.

Figure 26: Large city TCO comparison for e-buses and diesel buses with different electricity prices



Source: Bloomberg New Energy Finance. Note: Diesel price at $0.66 per liter ($2.5 per gallon), electricity price - variable, annual kilometers travelled at 80,000 kilometers (50,000 miles).

Figure 27: Medium city TCO comparison for e-buses and diesel buses with different electricity prices



Source: Bloomberg New Energy Finance. Notes: Diesel price at $0.66 per liter ($2.5 per gallon), electricity price - variable, annual kilometers travelled at 60,000 kilometers (37,000 miles).

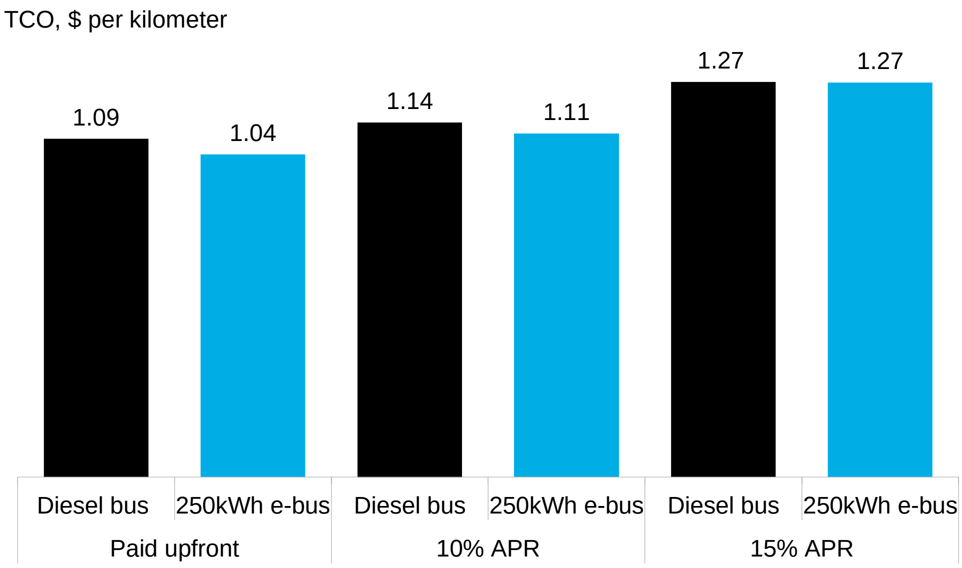
8.6. Financing matters

If a 250kWh bus needed to be financed, it will still have a cheaper TCO than a diesel bus as long as financing costs are less than 15%.

As mentioned in the previous sections, the majority of e-buses on the road today were purchased using a combination of national and local grants and self-funding. Therefore when analyzing the TCO we have assumed there were no loans involved in buying the buses, so in our analysis the cost of finance was set at zero.

However, grants are not available everywhere and with the e-bus sector starting to mature, we will likely see more loan financing involved. In developing countries, which may struggle with high borrowing costs, this may be particularly punitive if they rely purely on private financiers. Development finance institutions may be able to provide lower cost financing in these countries. If the 250kWh bus needed to be fully financed using a loan, then at annual interest rates of up to 15%, its TCO would still be lower than that of a diesel bus.

Figure 28: TCO comparison with varied financing costs



Source: Bloomberg New Energy Finance. Note: Annual distance traveled 56,000km. The paid upfront scenario assumes buses were purchased without loans and the discount rate was set at 10%. In the following scenarios we assume the bus needs to be nearly fully financed with loans, with either 10% or 15% APR and a discount rate set at 10%.

8.7. Falling battery prices will bring TCO parity for all e-buses in 2018

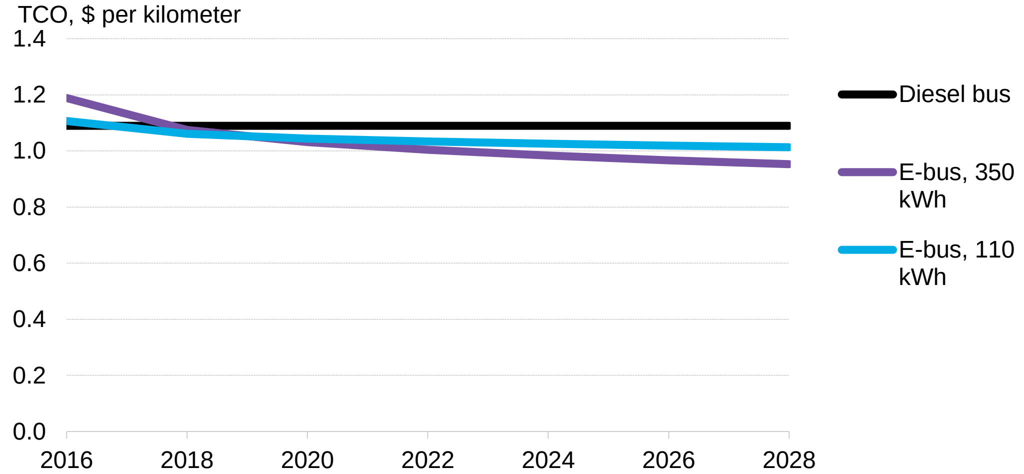
Battery prices will continue to fall, making e-buses competitive on a TCO basis in almost all configurations

> *The TCO for the most expensive e-bus configurations – the 350kWh e-bus coupled with slow charging at the depot and the 110kWh e-bus coupled with wireless charging – will reach TCO competitiveness with a diesel bus as soon as this year (2018).*

As battery prices continue to decline, e-buses will have a lower total cost of ownership than comparable diesel or CNG buses for all of the options discussed here, even at lower annual distances covered.

Using the same battery price projections as in the upfront cost analysis, we estimate that the TCO for the most expensive e-bus configurations – the 350kWh e-bus coupled with slow charging at the depot and the 110kWh e-bus coupled with wireless charging – will reach TCO competitiveness with a diesel bus as soon as this year (2018). In this scenario we have assumed no additional costs for diesel bus refueling infrastructure Figure 29.

Figure 29: E-bus TCO forecast



Source: Bloomberg New Energy Finance Note: For the purpose of the TCO forecast we have assumed the analyzed e-buses run on average 56,000 kilometers (35,000 miles).

Section 9. Insights from global cities

This section summarizes insights gleaned from interviews with city-level officials working on e-buses and transportation. In total we interviewed representatives of eight cities, with the aim of identifying the major issues that different cities face around the introduction of electric buses.

We have grouped the cities into four main archetypes based on a number of indicators that we believe most often determine the feasibility of e-bus projects in cities. The purpose of this exercise was to evaluate how cities with different characteristics perceive e-buses and how different their needs may be.

9.1. Different cities, different needs

The four archetypes we used in the process are:

- Fast-growing megacity
- Wealthy, established megacity
- Mid-sized regional hub
- Emerging economy regional hub.

Figure 30: Selected city indicators in four archetypal cities

Source: Bloomberg New Energy Finance. These are relative ratings and are for illustrative purposes only. Actual cities will vary on these metrics.

The selected city indicators that served us in building the archetypal city outline include indicators around city characteristics – GDP per capita, population density, air quality, fuel prices, congestion level and grid reliability. They also include bus fleet characteristics, such as the daily distance travelled by a bus and availability of financing (grants, access to leasing and loans). The figure below summarizes how each of the identified archetypal cities performs on the mentioned indicators.

Fast-growing megacity

Finding suitable locations for charging can be a challenge for e-bus deployments

This city archetype is characterized by relatively low GDP per capita and high population density. The city struggles with air quality (measured with particulate matter – PM10 – levels) and grid reliability. SAIDI[21] and SAIFI[22] scores – measures minutes and frequency of power outages per customer per year – are relatively high in this city. Diesel prices are around $0.79/liter ($3/gallon) with industrial electricity prices at around $0.10/kWh.

These are typically larger cities where buses travel around 300 kilometers per day on average, and congestion is an issue. Their rapid growth implies that these cities have access to grants from national and local governments for the purchase of new bus fleets.

There are certain characteristics of this city that will be conducive to the introduction of electric buses. The relative balance of diesel and industrial electricity prices indicate that the average 250kWh battery e-bus will be cheaper to operate than a corresponding diesel bus. Indeed, the long bus routes in these cities indicate that most e-buses, regardless of battery size and charging configuration, will be cheaper to run than diesel buses.

At the same time, the long distance travelled daily by the buses will encourage bigger batteries, overnight depot charging and fast opportunity charging options for top-ups. This will drive up capital requirements, and require local authorities to find locations with enough reliable power supply for both opportunity and depot charging in cities where grid reliability is poor.

Wealthy, established megacity

This city archetype is characterized by relatively high GDP per capita and medium population density. The city experiences issues with air quality, and it is a concern. Grid reliability is not an issue, although there may be some localized issues in the future as the fleet of electric vehicles expands.

Diesel prices are high (in the region of $1.06 -$1.32/liter) with industrial electricity prices at the higher end of the spectrum as well at around $0.12/kWh. These are large cities where buses travel around 200km per day on average, but congestion is an issue. Driven mainly by

21 SAIDI – System Average Interruption Duration Index

22 SAIFI – System Average Interruption Frequency Index

environmental goals, the national and local authorities provide financial support for the purchase of new, low-emissions bus fleets.

Similar to the fast-growing megacity, the relationship between diesel and industrial electricity prices indicates that the average 250kWh battery e-bus will be cheaper to operate than a corresponding diesel bus. Although daily routes are somewhat shorter, most e-buses, with the exception of the 350kWh e-buses, should still be cheaper to run today than diesel buses. However, the average daily distance of 200km will still push the city towards buses with bigger batteries and likely towards opportunity charging options.

The wealthy, established megacity is not experiencing major issues with grid reliability, which gives the city more options when it comes to the location of charging. Finding locations with enough supply to match the e-bus routes and operating schedules will still require planning. The fact that this is already an established city, densely populated, congested and with existing developed public transport infrastructure will add a layer of complexity in fitting e-buses and charging infrastructure into already-complex usage patterns and infrastructure.

Mid-sized regional hub

Cities in the mid-sized regional hub category may struggle to finance the e-buses as their access to grants is irregular.

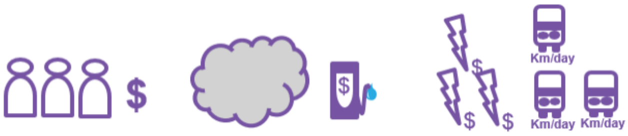
This city archetype is characterized by medium level GDP per capita and lower population density. The city is not experiencing major issues with air quality, but it is still a concern. The reliability of the grid is still an issue and the system is strained at times, but the situation is improving quickly. Diesel prices are around $0.79/liter ($3/gallon) with industrial electricity prices relative low at $.08/kWh.

This is a medium-sized city where buses travel around 160km per day on average. Congestion is an issue, but it is still manageable. Cities in this category have access to grants from the national and local governments for the purchase of new bus fleets, but those grants are rather patchy in their frequency and not always large enough to cover a considerable number of buses.

There are certain characteristics of this city that will be conducive to the introduction of electric buses. The balance of diesel and industrial electricity prices indicates that the average 250kWh battery e-bus coupled with depot and fast charging at terminal and the 110kWh e-bus coupled with wireless charging would be cheaper to operate than a corresponding diesel bus. The shorter average distance of 160km/day allows more flexibility in terms of the required battery size. Buses with large batteries will not be the default choice here.

However, cities in this category may still struggle to finance the more expensive e-buses as access to grants is somewhat irregular. Making up for the difference in capital with increasing ticket prices may also not be an option in a less wealthy city.

Emerging economy regional hub



This city archetype is characterized by low GDP per capita and lower population density. The city regularly experiences major issues with air quality, which is a big reason for considering electric buses. The reliability of the grid is an issue and there are parts of the city with poorly developed grid infrastructure. Diesel prices are low, at around $0.5/liter ($1.89/gallon), with industrial electricity prices at around $0.10/kWh.

This city covers a large area, buses travel around 300 kilometers per day on average, and congestion is an issue. Cities in this category do not have access to grants from the national and local governments for the purchase of new bus fleets, and often will have limited access to loan financing and vehicles leases. If the latter exists, financing costs may be punitively high.

The relationship between diesel and industrial electricity prices in this city archetype makes the choice of bus technology trickier. Choosing the best possible technology will require careful balancing of the diesel and industrial electricity prices with average distance travelled. This will significantly limit the available choice of e-buses. According to our analysis, in this case only the 250kWh e-bus coupled with depot and fast opportunity charging will be comfortably cheaper to run than a diesel bus.

The long distances travelled daily by buses improves the economics of the e-bus compared to diesel – even when faced with low diesel prices – but it also pushes the city towards bigger batteries with overnight depot charging and fast opportunity charging options to achieve enough range for daily operations. The 350kWh e-buses using only overnight depot charging are still not competitive with diesel in this scenario. As in the first archetype example, this choice drives up capital requirements, and requires local authorities to find locations with reliable power supply to accommodate the mixed charging in a city which struggles with grid reliability.

9.2. Major drivers and barriers to e-bus adoption as identified by the cities

During the interviews, we asked representatives of each city to identify major drivers for e-bus adoption in their respective public transport bus fleets. We also asked them to identify the main barriers they face in introducing and operating electric buses.

Drivers

Regardless of the archetype, all cities mentioned environmental credentials as one of the major reasons for considering electric buses.

Regardless of the archetype, all cities mentioned environmental outcomes as one of the major reasons for considering electric buses. There are two main environmental issues that the cities hope electric buses will help them address: reducing carbon dioxide emissions from transport and most importantly lowering local pollution levels by eliminating emissions of nitrogen oxides and particulates. Moreover, all of the interviewed cities mentioned zero-emission bus deployment targets as another common driver. Such targets are often only indicative – there are no penalties for missing them – but several interviewed cities have obligatory fleet replacement targets in place.

Other drivers that came up during the interviews were specific to certain city archetypes. For fast growing megacities, electric buses are an important element of their industrial policy, with the aim of creating local e-bus supply chains: from battery and e-bus manufacturing to servicing and parts suppliers. In case of the mid-sized regional hubs, the potentially lower TCO of an e-bus when compared to diesel or CNG was another important driver for the technology choice.

Wealthy, established megacities prize the higher quality of electric buses and the possibility of keeping them in their fleets for longer than diesel and CNG buses. Cities in this category recognize their role as technology facilitators. As first movers, wealthy cities see their role in helping the market to scale up, mainly through helping drive prices down.

Table 10: Major drivers for e-buses as identified by the cities

Drivers		Fast-growing megacity	Wealthy, established megacity	Mid-sized regional hub	Emerging economy regional hub
Policy	Clean bus deployment targets	✓	✓	✓	✓
	Industrial policy	✓			
	Environmental credentials	✓	✓	✓	✓
Operational	Lower TCO	✓	✓	✓	✓
	Vehicle quality		✓		
Other	Technology facilitators		✓		
	Staying up-to-date	✓	✓		

Source: Bloomberg New Energy Finance

Barriers

The list of barriers mentioned was significantly longer. This does not necessarily mean that identified barriers are prohibitive and will stop the wider adoption of e-buses in cities. It rather shows that even if few in numbers, the arguments for the introduction of e-buses are strong and the exhaustive list of possible barriers is proof that cities are giving e-buses a lot of thought. The table below shows the summary of all of the mentioned barriers, with a more detailed analysis of each in the following section.

Table 11: Major barriers for e-bus introduction as identified by the cities

Legend: [green] identified by all respondents in a given archetype; [yellow] identified by some respondents in a given archetype

Barriers		Fast-growing megacity	Wealthy, established megacity	Mid-sized regional hub	Emerging economy regional hub
Fleet operations	Uncertain residual value	All	All	Some	Some
	Lower flexibility of e-buses		All		All
	Lack of experience in operating e-buses		All		
	Cold weather – higher energy consumption	All	All	All	All
	Underdeveloped public transport network				All
Vehicle	Underdeveloped supply chain		All	Some	Some
	Lack of local supply chain	All			Some

Battery	Capital costs
	Unclear second life options
	Potential battery failures affecting the fleet
	Falling battery prices
Charging infrastructure	The cost and time of installation
	Capital cost
	Underdeveloped supply chain
	Public perception and space restrictions
	Lack of standards
Electricity, grid	Location of supply
	Constrained grid areas
Financing	Uncertainty for finance companies
	Lack of financing options
Government support	Lack of indirect support (LEZ)[23]
	Lack of direct support (grants, fleet targets)
Modal shifts	Falling bus use
	Competition from alternatives (metro)

Source: Bloomberg New Energy Finance.

9.3. Options to overcome common barriers

As part of the project we have made some basic recommendations for how cities in any archetype can overcome the identified barriers and better facilitate the introduction of e-buses.

Common issues

A number of barriers were common[24] to all city archetypes, and we believe our suggested solutions to those should be universal as well. Table 12 below gives an overview of common barriers and suggested solutions.

More policy certainty around end-of-life battery disposal and value will be helpful in overcoming uncertainty around e-buses

Fleet operation

In this category, cities identified uncertain residual values and cold weather as the main barriers to e-bus adoption. Colder temperatures can significantly reduce battery performance and vehicle range, especially if there are additional heating requirements for the interior of the bus.

The uncertainty around the residual value of an e-bus has predominantly to do with the uncertainty around battery lifetimes and their end-of-life options. One solution to address this issue would be to introduce policies that would regulate the end-of-life options for batteries, or at least indicate the parties responsible for the proper disposal. In February 2018, Shanghai issued its new local EV program, in which it asked automakers and their respective dealers to be responsible for used batteries coming from EVs. Each battery pack must be tracked through an

23 LEZ – Low Emissions Zone

24 To be considered a common issue it has to be attributed to at least three archetypes

independent supervision system and automakers are required to prove that they have used battery handling capacity that is in line with their local EV sales. Although an industry standard for used batteries is still lacking, this is a good first step to regulating the used batteries market.

Table 12: Proposed solutions to e-bus barriers common in all archetypes

Barriers		Solution 1	Solution 2	Solution 3	Solution 4	Solution 5
Fleet operations	Uncertain residual value	Guaranteed loans	Regulation on used batteries disposal	Battery lease	Extended manufacturer warranty	Extended lease or loan for the vehicle
	Cold weather – higher energy consumption	Renewable biofuel powered generators	Heat pumps	Trial bus in winter to understand additional power needed for heating		
Vehicle	Capital costs	Capital or operational lease	Battery lease	Joint purchase agreements	Extended lease or loan for the vehicle	
	Underdeveloped supply chain	Fleet electrification targets can send clear signal to bus manufacturers				
Battery	Unclear end-of-life options	Battery lease	Extended manufacturer warranty	Extended lease or loan for the vehicle	Regulation on used battery disposal	
	Falling battery prices	Vehicle lease				
Charging infrastructure	Capital cost	Standardization	Bundling the price of a charger with the price of a bus during the tendering process	Partnership with utilities		
	Installation costs	Standardization	Partnership with utilities			
	Public perception and space restrictions	Education	Re-locate bus stops			
Electricity supply and grid issues	Location of electricity supply	Partnership with utilities	Consider new depot in new location	Solar panels at depot		
	Constrained grid areas	Batteries assisted chargers	Solar panels and depot			
Financing	Uncertainty for finance companies	Bus manufacturers could take on the role of financing companies	Government guaranteed loans	Involve finance companies in long term strategy		
Government support	Lack of indirect support measures (low emissions zone)	Involve national governments in e-bus deployments	City authorities explore introducing such policies			

Mode of transport	Falling use and increasing competition	Offering Wi-Fi on board	On demand bus services	BRT and bus lanes

Source: Bloomberg New Energy Finance

Uncertain residual value of e-buses can make them more difficult to finance, as financiers may not yet feel comfortable with this risk. Government-guaranteed loans could be used to lower the risk to financing companies. In the U.S., the Department of Energy offers loan guarantees for projects that employ new technologies that are not yet supported at a commercial level, and such loans played a significant part in building some of the U.S. based next-generation biofuel plants.

Moreover, leasing the battery (as described in the previous section) or extended manufacturer warranty could be used to mitigate risks around the battery end-of-life, by pushing the risk away from the bus operators to the bus or battery manufacturers. We believe that this will become more feasible and more popular once the battery end-of-life markets become more regulated. Also, as battery manufacturers, automakers and system integrators become more confident in their understanding of battery performance, the length and structure of warranties are likely to improve.

Vehicle

In this category, cities identified capital costs and underdeveloped supply chain as the main barriers to e-bus adoption.

High capital costs could be addressed through innovative financing models – leasing the vehicle, leasing the battery or joint-purchase agreements – all described in the business models section.

The number e-bus models available is still limited, and does not cover all use cases

Underdeveloped supply chain was another issue shared by the majority of the interviewed cities. Cities believe the e-bus model offering is still very limited, and does not sufficiently cover all of the cities' needs. Cities need to work closely with e-bus manufacturers to show the demand for specific types of e-buses. We believe that with the right demand signals in place, e-bus manufacturers will expand their offerings. One way of sending very clear demand signals would be through setting annual fleet-electrification targets.

Battery

In this category, cities unanimously identified unclear end-of-life options and falling battery prices as the main barriers to e-bus adoption.

The best way to address the falling battery prices is through vehicle leasing. Shorter-term vehicle operating leases can take the technological risk away from the bus network operator, and ensure that the given city's fleet is always the most cost-effective.

Charging infrastructure

Partnering with local utilities should help lower the costs of chargers and their installation.

In this category, cities identified capital costs, installation costs, public perception and space restrictions as the main barriers to e-bus adoption.

> *A lack of standards around e-bus charging creates additional barriers for e-bus operators in terms of interoperability of the vehicles with different chargers. It often leaves e-bus operators locked in to one bus or charger maker, and can make it difficult to sell the e-buses on to another city in the future. Standardization is crucial*

to overcome those barriers, and cities would do well to work collectively with national governments to push for the adoption of global standards.

The issue of relatively high capital and installation costs of e-bus chargers will improve with increasing scale, growing adoption of e-buses and more extensive supply chain knowledge. However, to speed the process up, standardization is required. A lack of standards around e-bus charging creates additional barriers for e-bus operators in terms of interoperability of the vehicles with different chargers. It often leaves e-bus operators locked in to one bus or charger maker, and can make it difficult to sell the e-buses on to another city in the future. Standardization is crucial to overcome those barriers, and cities would do well to work collectively with national governments to push for the adoption of global standards.

Partnering with local utilities should help lower the costs of chargers and their installation. Utilities stand to benefit from the increased power demand coming from the growing e-bus sector, and should potentially be interested in sharing some of the costs associated with enabling the technology. Bundling the price of a charger together with the vehicle during the tendering process could help to push some of the costs to e-bus manufacturers and lower the capex for buyers. This solution could work only when combined with a lease agreement where the manufacturer could roll the additional costs into the lease repayment. It is quite common today for e-bus manufacturers to supply the charging infrastructure as well.

Public perception and space restrictions were identified as issues with installing pantograph chargers at bus stops, as it is common for local residents to oppose such plans. Educating local residents on the merits of e-bus adoption and the need for chargers at bus stops should be a first step in overcoming this issue. Re-locating bus stops to accommodate the chargers could solve space limitations, but these sites are often chosen for specific reasons. E-buses do not have the same ventilation requirements as diesel or CNG buses, so areas with sufficient space could use underground depots for charging. Paris is pursuing this approach which also reduces the amount of valuable surface real estate used for e-bus charging.

Electricity supply and grid issues

In this category, cities identified location of electricity supply and local grid constraints as the main barriers to e-bus adoption. Cities mentioned that existing bus depots, terminals or bus stops are often located in places where the power supply is not adapted to charge bigger fleets of e-buses. Grid-constrained areas throughout a city can also make deploying e-buses on new routes tricky.

Involving local utilities and grid operators from the beginning of planning e-bus deployment should be the first step to addressing this challenge. As mentioned previously, energy companies are set to benefit from the increase in power demand from e-buses and should be interested in enabling the deployment of this technology and minimizing the negative grid impacts. Partnerships with utilities should also be useful in identifying best sites for new depots if there was no other way (or if it was too expensive) to overcome the power supply issue. Several cities are considering building or buying new depots because either the power supply is inadequate or because they do not currently own their own depots.

In grid-constrained areas solar panels and battery-assisted chargers play a role, although the latter technology is still in a testing and demonstration phase. In September 2017, Leclanche, an energy storage company, announced its partnership with Fastned, a developer of fast charging stations for EVs. Under the agreement, Leclanche will provide scalable lithium-ion battery energy storage systems for Fastned, which will use them to install several fast chargers per site and at the same time reduce the strain on the grid and avoid peak-demand charges. The system will also be used to store energy from the solar roofs installed on site. Other charging network operators are implementing similar plans for on-site energy storage. Using battery-assisted chargers opens up an opportunity for used batteries coming out of e-buses.

Financing

In this category, cities identified uncertainty for finance providers as the main barrier to e-bus adoption.

In addition to the solutions described in the uncertain residual value section above, bus manufacturers could provide financing in situations where traditional finance providers may not be willing to get involved. Volvo Bus already provides financial services to its customers and offers a range of packages from capital and operating leases to all-inclusive contracts combining lease services with repair and maintenance contracts. Also, involving finance companies in long-term strategy should help mitigate some of the risks. The China Development Bank, for example, has been working closely with BYD, and in March 2017 agreed to provide financing to all buyers of BYD e-buses and e-taxis with no down payment.

Government support

In this category, cities identified the lack of indirect support measures – low-emission zones, congestion charges – as the main barrier to e-bus adoption.

City authorities should consider introducing low-emission zones, which have played an important part in increasing transport electrification in cities like London. Low-emission zones or congestion charges are often seen as a clear signal to potential investors as to the cities' plans for transport. However, quite often cities will not have the legislative powers to introduce such restrictions, so it will be crucial to work closely with national governments.

Mode of transport

The attractiveness of buses could be improved by introducing new services that are usually not offered in other modes of transport – such as on board Wi-Fi connections

In this category, cities identified falling use of buses and competition from alternative modes of transport as the main barriers to e-bus adoption.

The two factors are connected. In many developed cities, bus utilization rates decrease as passengers switch to private car ownership or alternative modes of public transport such as trains or subway. Bus utilization rates are likely decreasing as a result of congestion and the passengers' perception that buses are usually stuck in traffic and not running on time.

One way to overcome this issue would be to improve the attractiveness of buses compared to other means of transport. This could be done through the introduction bus-specific lanes, which limit buses' exposure to traffic conditions. Bus Rapid Transit (BRT) is another type of public transport system design, which aims at improving the system's capacity and reliability. It usually involves a whole roadway dedicated to buses, and gives priority to buses at intersections. It could also be achieved by introducing new services that are usually not offered in other modes of transport, such as onboard Wi-Fi connections.

9.4. Solutions by city type

Wealthy, established megacity

Some barriers identified by the cities were mentioned only by cities in one or two archetypes. It does not mean that those barriers are specific only to a given type of city. It does show that certain issues become more apparent at different stages of e-bus fleet deployments.

Table 13: Proposed solutions to e-bus barriers specific to wealthy, established megacity archetype

Barriers		Solution 1	Solution 2
Fleet operations	Lower flexibility of e-buses compared to diesel	Contingency buses to cover additional range on routes if necessary	Routes re-designed to accommodate E buses
	Lack of experience with e-buses	Consider short-term lease for testing	Data sharing from pilot trials between cities
Charging infrastructure	Lack of standards	Work with national governments to introduce standards	Work with e-bus manufacturers to agree on common charging standards

Source: Bloomberg New Energy Finance

Cities in the wealthy, established megacity archetype raised several new issues, which most likely stem from their greater experience with e-buses, since some cities in this category can be considered early adopters.

Wealthy, established megacities worry about the lower flexibility of e-buses compared to conventional buses. An example of this would be when a bus route has to be temporarily altered, for example when a festival, a major sport event or road works are taking place in the city and certain parts of the road network are closed. In this scenario, fast chargers at the terminals or bus stops would also have to be moved or would not be accessible and e-buses operating on the route would not be able to continue to operate. It would probably serve the city well if some of the contingency buses used as replacement buses were fueled conventionally and could occasionally be used on altered routes.

Cities also admit that the lack of experience with operating e-buses makes it very difficult for them to choose the best possible technology. This is where short-term lease contracts with e-bus manufacturers could come in handy and serve as testing grounds for the technology, before the longer-term commitment is made. Data sharing between the cities on the operational results of the pilot trials of e-buses is also crucial and will provide more clarity in the sector.

Mid-sized regional hub

Table 14: Proposed solutions to e-bus barriers specific to mid-sized regional hubs

Barriers		Solution 1	Solution 2
Charging infrastructure	Installation time	Remove concession requirement for e-bus fleet operators	Policy regulating building charging stations for e-buses

Source: Bloomberg New Energy Finance

Cities should work with grid regulators and national governments to remove or fast-track concession requirements if the charging equipment was to be used by e-buses or e-taxis.

Cities in the mid-sized regional hub category have concerns about the long installation times for e-bus charging infrastructure. Some claimed it could take over 18 months to obtain all necessary concessions for connection to the grid. Cities should work with grid regulators and national governments to remove or fast-track concession requirements if the charging equipment is to be used by the city fleets (e-buses or e-taxis). Regulating or mandating installation of a certain number of charging points at bus stops and depots could also help standardize the process.

Fast-growing megacity

Cities in this category identified lack of access to different financing options as one of their bigger struggles. For some cities, national level regulations can forbid leasing of the vehicles, for example, while in other cities the cost of finance may be punitively high. When loans or leasing are not an option, the way to lower the upfront costs of the buses would involve working in partnership with other cities on joint purchase contracts (described in more detail in the business model section). Long-term purchase option contracts with a single e-bus manufacturer could also encourage it to lower its upfront costs in exchange for long-term guaranteed demand.

Table 15: Proposed solutions to e-bus barriers specific to fast-growing megacity

Barriers		Solution 1	Solution 2	Solution 3	Solution 4
Financing	Lack of financing options	Work with other cities on joint purchase contract	Consider long-term purchase option contracts		
Vehicle	Lack of local supply chain	Attract investors through tax exemptions and similar fiscal measures	Joint ventures between local manufacturers and more experienced foreign companies	E-bus deployment targets as demand signals	R&D investment and grants

Source: Bloomberg New Energy Finance

Lack of current public transport is a challenge in emerging economy cities, but also an opportunity because entirely new charging networks can be designed from the ground up to match public transit needs

As mentioned earlier in the report, many countries will view e-buses as an important part of their industrial policy. Developing and growing a local supply chain is therefore a key ingredient for success in these countries. In order to promote local manufacturing of e-buses and batteries, countries could introduce favorable conditions, such as corporate tax exemptions, to attract foreign investors to set up local manufacturing plants. Joint ventures between local manufacturers and foreign companies with more know-how and experience around electrified technologies is also a popular way to encourage local production. One example is the joint venture between Alexander Dennis (ADL), a British bus manufacturing company, and BYD, a Chinese manufacturer of e-buses, passenger EVs and lithium-ion batteries. Under the joint venture, ADL is building the buses in the U.K. with batteries supplied by BYD.

Emerging economy regional hub

Representatives from the emerging economy regional hub category mentioned an underdeveloped public transport network as one of the hurdles to the introduction of e-buses. Bus operations in cities in this category can sometimes be rather chaotic, with no structured bus stops or terminals and with buses run independently by a number of private operators with little regulation or oversight from the local government. This does not necessarily have to be considered a barrier, as in such a case, bus routes could be designed and built to match electric bus characteristics.

Table 16: Proposed solutions to e-bus barriers specific to emerging economy regional hub

Barriers		Solution 1
Fleet operation	Underdeveloped public transport network	Routes operated by e-buses could be designed from the ground up
Government support	Lack of direct support (grants, subsidies)	Work with other cities to put pressure on the national government
Charging infrastructure	Underdeveloped supply chain	Bundle delivery and installation of charging infrastructure together with e-bus contract

Source: Bloomberg New Energy Finance

However, to do this, cities in this category will require money, and the lack of direct support for the purchase of e-buses (such as purchase subsidies or grants) is a significant obstacle. To address that, cities should work with other municipalities in a given country to put pressure on the national government to introduce more structured support. Cities should highlight the benefits of running electric fleets – lower local pollution, operational costs savings and healthier residents.

Appendices

Appendix A. Terminology

Battery chemistry

LFP – lithium iron phosphate battery

LMO - lithium manganese oxide battery

LTO – lithium titanate battery

LiFeMgPO4 – lithium iron magnesium phosphate battery

LMP – lithium metal polymer battery

NCA – lithium nickel cobalt aluminium oxide battery

NMC – lithium nickel manganese battery

NaNiCl – sodium nickel chloride battery (molten-salt battery)

E-density Wh/l – refers to the energy density based on the tap density of the material

C-rate – refers to how quickly a battery can be charged or discharged

Bus operations

Depot – refers to the place where buses are stored when not in service

En-route charging – refers to a bus charging when in service. Usually this would include charging at a terminal during a layover or at a bus stop

Terminal – refers to the last stop on buses' route, where layover happens

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