by Messer and Toyota Tsusho

Planning for a European Zero-Emission Bus Rollout at Scale

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Bus operators are faced with clear pressure to transition their respective fleets to zero-emission (ZE) vehicles, coming both from legislators and populations worried about climate change. Over the past few years there have been several conferences and articles addressing the opportunities and challenges of decarbonizing public transport (e.g. the ZEB Conference 2023). The following article addresses some of the key findings of these sources with the goal of providing fleet and particularly bus operators with inspiration towards a strategic, ZE technology selection.

1. Introduction

According to ACEA[1] there are 684,285 buses in circulation on the EU's roads. Whilst diesel-driven vehicles still dominate the fleet, diesel represents a declining proportion of new buses sold. According to the most recent UITP[2] survey, the share of new diesel-only buses registered is now lower than the share of battery electric buses. This marks the first time that a zero-emission technology has become the leading drive-train option in a road transport sector in Europe.

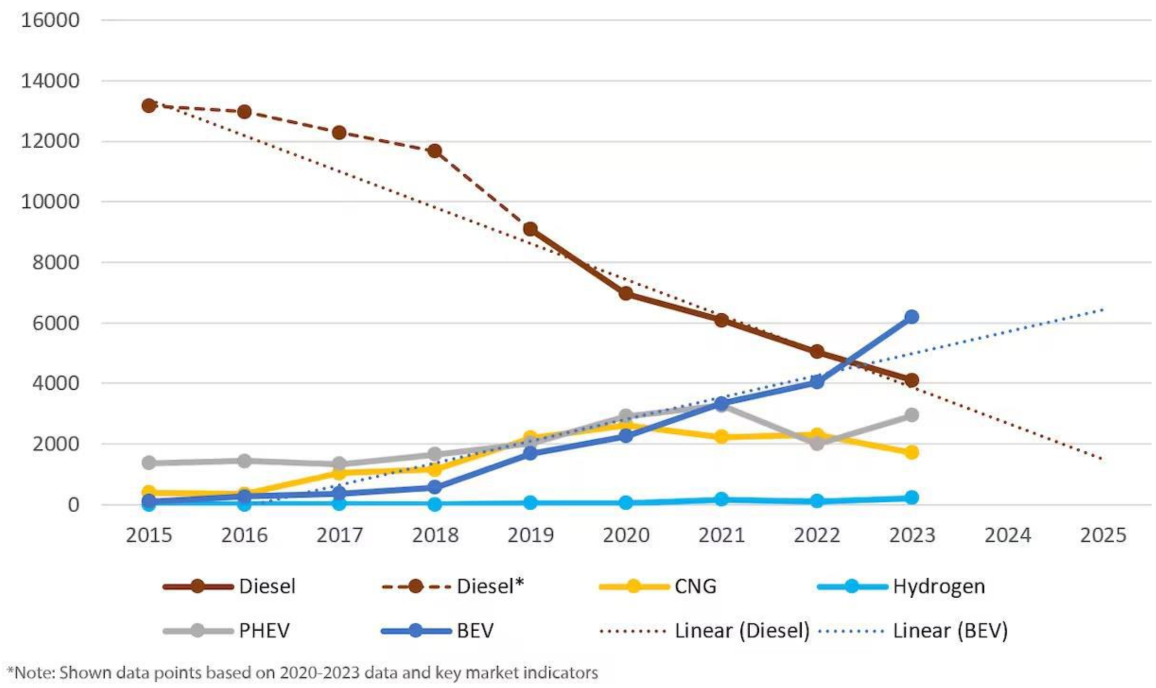


Figure 1 Yearly sales of city buses in the EU by type of alternative drive, 2015-2025
Source: Rabobank, 'Fast track to green: European city buses ahead of schedule', 26. February 2024

In the EU, several Member States have long pledged to convert their entire bus fleet to zero-emission by as early as 2030, as is the case in the Netherlands. Even more ambitious targets are evident at the local level, with Amsterdam and Copenhagen planning for a fully zero-emission bus fleet by as early as 2025, and over half of all European capital cities planning for a fully-zero emission fleet by 2040[3].

1 'Fact Sheet – Buses', ACEA, 27.11.2022
2 'Electric City Bus Sales Overtake Diesel in Europe', UITP, 25.5.2023
3 'The Rapid Deployment of Zero Emission Buses in Europe', UITP, 19.9.2022

The Clean Vehicles Directive (CVD[4]) which came into play in August of 2021 is proving to be important. It requires Member States operating public service contracts to purchase *at least* 24%–45% alternatively fuelled buses between August 2021 and December 2025 (the targets vary by country). A sharp drop in diesel-only bus sales was seen at the end of 2021. Half of these targets need to be achieved through zero-emission powertrains. The targets increase for the period from 2026 to 2030 to 33%–65%, so we can expect to see further declines in the share of diesel in new bus registrations.

Indeed, in May 2024 the European Council formally adopted a regulation[5] requiring higher CO_2 emissions standards for heavy duty vehicles. Specifically, it is required that every new urban bus registered in the European Union by 2035 be zero-emission. 90% of new urban buses registered must be zero-emission by 2030.

The recent revision of the Renewable Energy Directive (RED3[6]) has ensured that renewable fuels and renewable electricity in the transport sector will contribute to its decarbonisation. Specifically, it set a combined energy -based target for advanced biofuels and biogas and ‘renewable fuels of non-biological origin’ (RFNBO – mainly hydrogen), including a minimum share for RFNBOs alone. The achievement of these targets should be ensured by obligations on fuel suppliers which may be met by tradeable credits for the supply of renewable energy to the transport sector.

As a result of these legislative developments the market for zero-emission buses, including fuel-cell electric buses, must continue to grow rapidly to meet already mandated demand for 2030. Indeed, the transition will accelerate.

2. The challenge of scaling up ZE bus fleets in Europe

Throughout Europe there have been many smaller-scale trials with both fuel-cell electric buses (FCEB) and battery electric buses (BEB) over the past decade and more. Typically, 10-20 buses have been deployed in commercial service, backed-up by legacy diesel operations. As a result, both fuel-cell electric and battery-electric technologies have been seen to be technically feasible, with some advantages unique to each. Both FCEB and BEB have improved markedly under the pressure of service on commercial routes where they must deliver the performance, and the reliability required of an operational vehicle. Capital costs have begun to fall as volumes have risen and the effect of the learning curve has kicked in.

However, if Europe is to transition its huge fleet of city buses to zero-emission technologies as required by the Clean Vehicle Directive and the new CO_2 emissions standards for heavy duty vehicles, then such technologies as batteryelectric and fuel-cell electric buses must be deployed at scale. A small city may have ~100 buses operating from one depot, whilst a large city may have ~1000 buses operating from two or three depots. Consequently, a key question that bus operators now face is that of “scalability”. Operating a large fleet of zero emission buses poses several challenges and it is essential that bus operators succeed in implementing a seamless technology transition. To do so, the individual operational requirements of each bus operator are key and in combination with financial circumstances will ultimately drive a respective technology selection.

4 Directive (EU) 2019/1161: https://eur-lex.europa.eu/eli/dir/2019/1161/oj
5 Heavy-duty vehicles: Council signs off on stricter CO2 emission standards - Consilium (europa.eu)
6 Directive (EU) 2023/2413: https://eur-lex.europa.eu/legal-con ten t/EN/TXT/?uri=OJ:L_202302413

Battery or fuel-cell?

The first point to consider are the current technical and operational requirements of the respective fleet. Naturally, the specifications of the according zero emission technology must be able to fulfill these requirements. Key factors in this equation are the range and refueling time of the vehicle.

According to a study in Germany more than 80% of the interviewed bus operators demanded ZEBs have a range of at least 200km and 20% required a range of at least 350 km[7]. A separate case study analyzed the usage of ZEBs of 13 bus operators, five of which were operating blocks of bus routes between 200 and 250 km/day[8]. To put this into context for BEBs, current battery capacities are between 230 kWh (opportunity charging) and 500 kWh (depot charging)[9,10]. Regarding the electricity consumption of BEBs it is important to note that the energy required for heating has a significant impact. A supplementary diesel heating system can be used but does not represent an emission free solution. If the buses should indeed be electrically heated, the operation in winter months may reduce the achievable ranges by up to 50%. On average BEBs consume 1.3 kWh/km with and 1.8 kWh/km without diesel heating respectively. The maximum consumption for BEBs on the other hand comes in at 1.9 kWh with and 2.6 kWh without auxiliary heating[11]. Consequently, one can expect BEB driving ranges to be between 88-385 km. FCEBs, on the other hand, carry between 27 and 38,5 kg of hydrogen. In Europe H_2 consumptions between 5-10 kg/100km have been observed for FCEB in various trials under real conditions (depending on temperature and topography). Consequently, effective ranges of 270 – 770 km can be expected. The consumption differences between winter and summer are not as pronounced in FCEB as for BEB.

One potential work-around for the limited battery range is to use an opportunity charging strategy. However, this does not come without its challenges. The main reason being that bus operators must ensure the availability of public fast charging stations with a capacity of 250 – 450 kW per charging point (ideally situated at the end of the bus route). For large fleets this charging approach ultimately needs to be facilitated by municipalities as part of a wider decarbonization and grid extension plan. This may be one of the reasons that 87% of the projects funded by the BMDV in Germany (for 12m buses 97%) decided to implement a full depot charging strategy[12]. Overall, one charging point per BEB bus is recommended at the depot where the vehicle can be charged overnight, which also applies to buses with additional opportunity charging. The following graph provides a rough indication of the required charging infrastructure based on desired charging time. The values assume a constant charging rate (Crate=1) and show that in the case of depot charging (50 – 75 kW) buses need between 4-8 hours to fully recharge.

7 NOW_Abschlussbericht_Begleitforschung-Bu s.pdf (now-gmbh.de)
8 CVD study: transformation to ZEB , sphera 2021
9 NOW_Abschlussbericht_Begleitforschung-Bu s.pdf (now-gmbh.de)
10 Increases in Battery Capacitites, Sustainable Bus 2024
11 CVD study: transformation to ZEB , sphera 2021
12 NOW_Abschlussbericht_Begleitforschung-Bu s.pdf (now-gmbh.de)

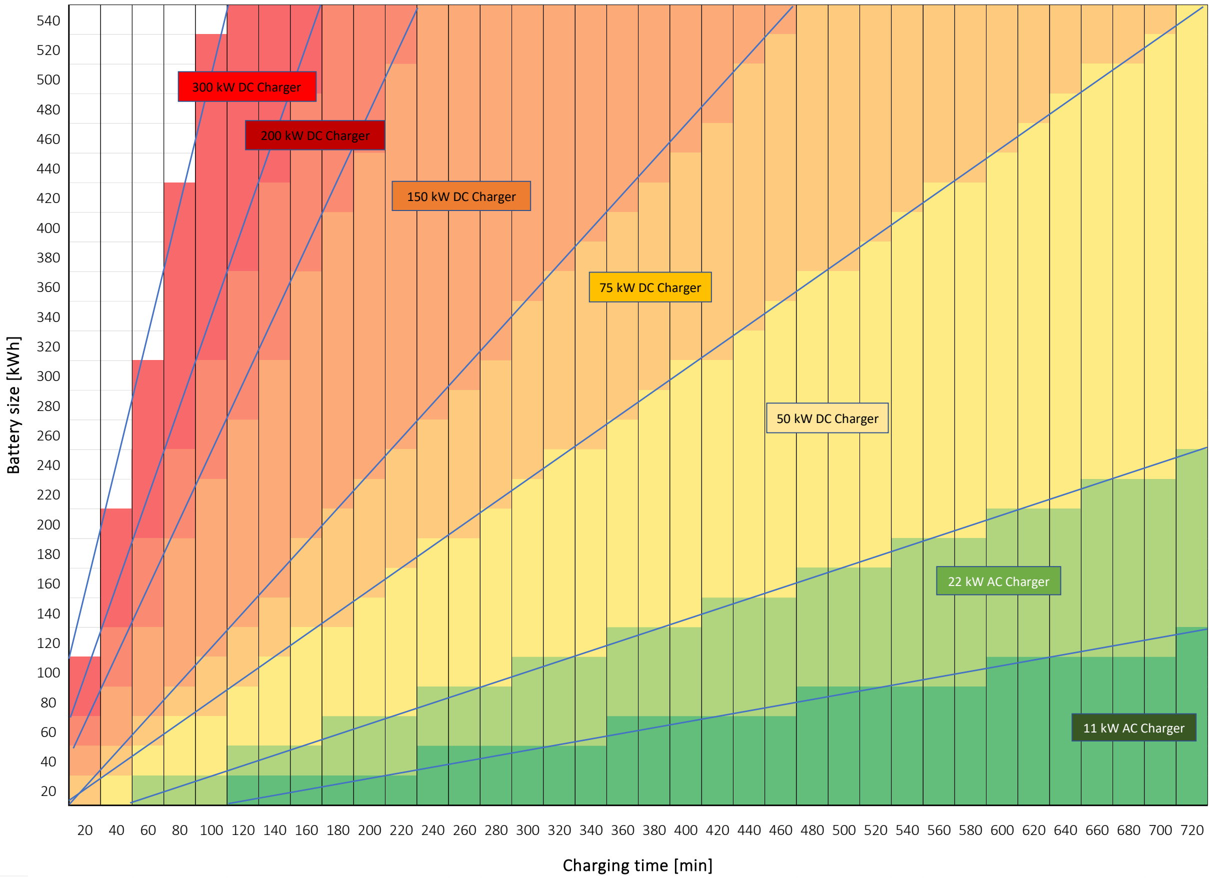


Figure 2: Indicative overview of EV charging times based on installed infrastructure

Another point warranting consideration is that when charging battery electric buses for several hours overnight, the grid power purchased is not necessarily correlated with the availability of renewable power. As a result, BEB's may in fact be charged with a proportion of non-renewable or even fossil electricity. This can be observed in the figure below that showcases the share of electricity from fossil fuel generation in Europe, based on the time of day.

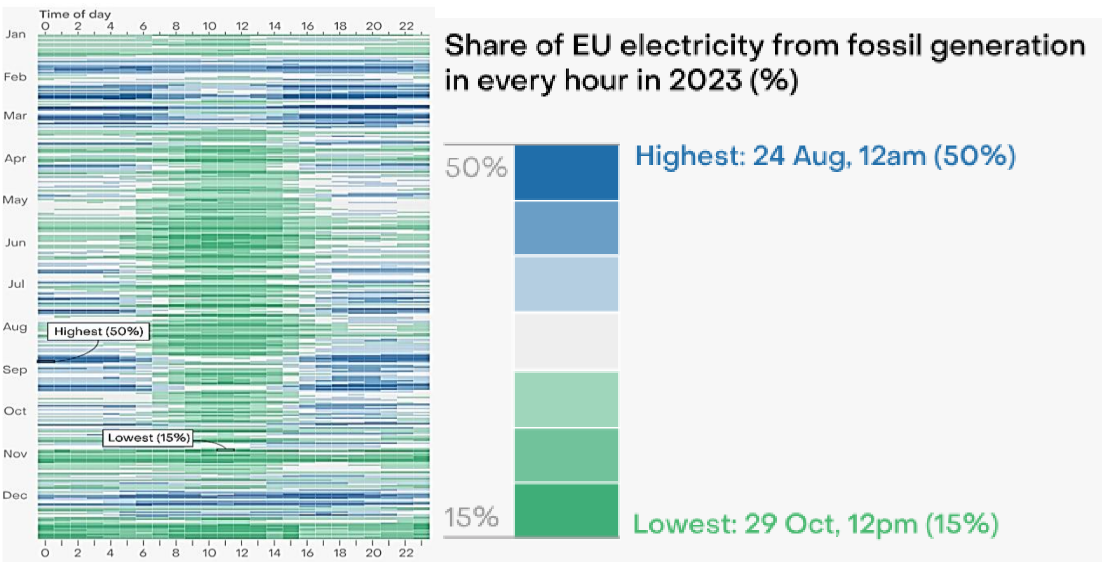


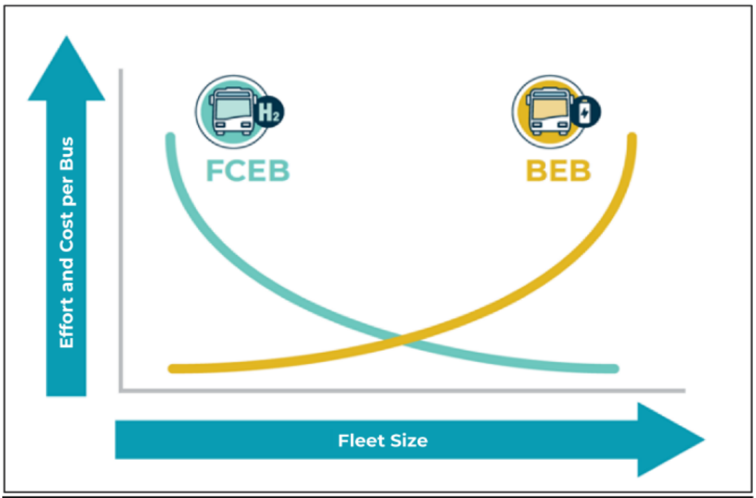
Figure 3: Share of EU electricity from fossil generation in every hour in 2023 (%)
Source: https://ember-climate.org/insights/research/european-electricity-review-2024/

According to the EU'S delegated act for RFNBOs, renewable hydrogen can only be produced using fully renewable power. The use of renewable power via hydrogen can be correlated with its availability since electrolysers are flexible production assets and hydrogen can be stored. Hydrogen can be produced when the wind is blowing, the sun is shining, and electrical power is both green and cheap. It can then be filled into vehicles quickly as and when required. Over the last few years that has been an increase in Europe of extended periods during the day when very low power prices have been observed. This is an important opportunity to optimise the cost of hydrogen.

The main challenge with hydrogen infrastructure for an FCEB deployment is that it entails a significant investment in equipment and permitting which does not suit trials with a small number of buses. However, for large scale fleets hydrogen infrastructure benefits from economies of scale and offers a flexible operation with short refueling times, typically <10min. In combination with the greater range of FCEBs, hydrogen is able to replicate a diesel operation without the need for additional buses.

Data from small scale-trials (typically < 20 buses) have shown that the cost of recharging or refueling small fleets is generally lower for BEB than FCEB. The main reason is the comparatively low CAPEX required for installing a small number of chargers, which can typically be fit into existing depot infrastructure. Long charging times can be absorbed by an operator able to rely on a large back-up diesel fleet.

Importantly, however, *"As fleets grow, the costs and complexity associated with incremental BEB charging infrastructure and associated facility and electrical infrastructure upgrades increase exponentially. Conversely, hydrogen fueling infrastructure scales efficiently, and therefore offers advantages over BEB infrastructure with larger fleets."* Source: Jaimie Levin, Director of West Coast Operations, Center for Transportation and the Environment (CTE).



- **FCEB:** High initial cost for hydrogen fueling stations can be leveraged over many buses in larger fleets.
- **BEB:** More equipment and infrastructure required to support larger fleets

Figure 4: Conceptual graph illustrating the relative cost and effort of deploying FCEB and BEB fleets. Source: A Zero emission transition for the U.S. transit fleet

In other words, once hydrogen demand is high enough to justify the higher initial infrastructure investment, as will be the case when transitioning a larger fleet of 50 or more vehicles, the FCEB fleet costs per km can be highly competitive. Conversely, in large ZEB fleets the challenges for BEB charging may become more severe.

Whilst no general statement can be made regarding the technology to be preferred since many factors are to be considered, it is crucial that bus operators plan their bus fleet's transition with the end goal of 100% ZEB in mind.

3. ZEB Rollout & Planning

To date in Europe ZEB sales have been driven by EU-sponsored pilot projects and a desire amongst leading operators to be seen to be 'doing something' in the face of the CVD objectives. In California a longer-term, more coordinated approach has been taken, which may be instructive. In 2018 all bus operators ('transit agencies') were required[13] to submit a 'ZEB rollout plan', approved by their governing body, by 1. July 2023, which would:

- Achieve the goal of full transition to zero-emission buses by 2040;
- Identify the types of ZEB to be deployed, such as BEB or FCEB;
- Schedule the construction of facilities and infrastructure modifications or upgrades, including charging, fueling, and maintenance facilities, to deploy and maintain zero-emission buses;
- Schedule bus purchases and lease options, identifying bus types, fuel types, and number of buses.

The many ZEB rollout plans that have been published in California show that transitioning a fleet necessitates considerations that don't apply to a small pilot project within a large fleet of diesel vehicles. The joint presentation by Foothill Transit and CTE during the Zero Emission Bus conference (2023) provided key insight into this Californian learning experience:

"Foothill Transit, California, has been at the forefront of adopting hydrogen fuel cell buses. With 33 FCEBs and 19 BEBs, they have seen significant benefits in terms of reliability and emissions reduction. Roland M. Cordero, Director of Maintenance and Vehicle Technology at Foothill Transit, also highlighted the challenges associated with batteryelectric buses, including limited range and high operational costs. In contrast, hydrogen fuel cell buses have performed well, supporting the shift towards a more sustainable public transportation system."

Underpinning this statement is the cost comparison[14] below, based on analysis conducted by Foothill Transit in conjunction with the development of its own ZEB rollout plan.

"*The chart shows the comparative costs between BEBs and FCEBs over 12 years of life. The chart demonstrates that the costs of operating BEBs on Line 486 are higher than FCEBs over a 12-year period by $12.9 million. The cost differential stems from the higher capital costs of BEB buses due to having to operate more buses to accommodate its limited range capacity. The costs of fueling infrastructure for FCEBs and mid-life maintenance are also lower compared to BEBs."*

12-Year Lifecycle Cost Comparison		
	34 BEBs	20 FCEBs
Capital Cost – Buses	$30,260,000	$25,300,000
Capital Cost - Fueling Infrastructure	$10,948,000	$4,000,000
12 Year Fuel Cost	$11,839,973	$15,661,340
12 Year PMI Cost	$626,453.58	$1,879,361
Mid-life Maintenance Cost	$6,800,000	$690,000
	$60,474,426	$47,530,700
Cost Savings with FCEB	$12,943,726	

** PMI (preventive maintenance inspection)*
** Mid-life Maintenance costs (Battery / Fuel cell replacement)*

Figure 5: 12-Year Lifecycle cost comparison

Source: Cost Comparison and Fuel Technology Direction - BEB vs. FCEB

13 Californian ICT Regulation, 2018
14 Cost comparison: BEB vs. FCEB', Foothill Transit, 24.7.2020

CTE's experience[15] in California, where working with bus operators to develop ZEB rollout plans has shown that denser urban environments remain better fits for BEBs, while lower density suburban and rural environments carry more strenuous operating requirements and are better suited for hydrogen fuel cell technologies.

CTE recommends the following fleet expansion and mixed fleet vehicle ratios:

Bus Operations - Type	BEB Fleet Expansion Multiplier:	Feasible Fleet Mix:	BEB	FCEB
Rural	1,5		5%	95%
Suburban	1,3		70%	30%
Urban	1,15		90%	10%

Based on the experience gathered by CTE a suburban city bus operator considering a fleet of BEBs to replace all of its diesel buses might expect to need 30% more vehicles to provide the same service, whilst FCEB are drop-in equivalents for the current fleet. Not only are up to 30% more BEB required, but more parking space, more charging points, more drivers, and so on.

According to the article "Why US Towns are Changing Lanes from Electric to Hydrogen Buses, 23 June 2024" it seems that the lessons learned from the Californian experience have driven a shift in the decarbonization strategies of several bus operators across the US. A clear trend towards hydrogen can be seen by US transit agencies that have developed their rollout plans in preparation for last year's deadline: The number of transit agencies either deploying or planning to deploy FCEBs has risen from just 3 in 2018 to 22 in 2022 and 41 in 2023. The final proportion of FCEB amongst total ZEB in California is widely expected to be 20 to 40%.

In Europe, too, the latest JIVE report (July 2024) on '*The potential for hydrogen buses in Europe* ' identifies 20% of Europe's bus routes as not being 'manageable' with battery electric buses.

15 ‚A zero emission transition for the US transit fleet', CTE, 2021

4. Conclusions

Bus fleet operators who are required to decarbonise their operations in the coming years now need to take important decisions regarding the technology they will use, whether battery or fuel-cell electric. Deadlines within the Clean Vehicle Directive and the CO_2 Standards for Heavy Duty Vehicles are coming closer.

Key factors that need to be considered when considering ZEB options including battery-electric and fuel-cell-electric buses include the following:

- Total final ZEB fleet size
- Current refueling requirements and future strategy (timing, shifts, staff)
- Bus route requirements (range, topography, average speed)
- Target zero emission fleet conversion timeline
- Availability of grid connection and renewable energy at bus depot
- Availability of opportunity charging in the area of operation
- Available space at the bus depot (shunting, parking, footprint of additional infrastructure)
- Other depot constraints
- Climate conditions in the area of operation
- Available funding

Operators will naturally wish to combine these factors within an evaluation of the total cost of operation (TCO) as a basis for their decision-making.

Crucially, however, this evaluation should be based on a complete transition plan for each technology – i.e. a scenario showing how the fleet would be completely decarbonised. This ensures that any economies (or additional costs) related to scale are properly reflected in the TCO calculation from the outset. Further, it avoids erroneous choices, which might seem cheaper in the short term, but which would prove more expensive or even infeasible for the transition of the whole fleet.

European bus operators have the technological solutions to hand with which they can meet their decarbonization goals. As in California, they may benefit from preparing a plan with the end goal of a 100% ZEB bus fleet.

By working together with the end-goal in mind the transition to zero-emissions operation will be successful.

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