Electrification of public transportation

A Cape Town based company has successfully tested and deployed electric buses for daily commuter bus services

List of abbreviations

AC	alternating current
BESS	Battery Energy Storage System
BRT	Bus Rapid Transit
CCT	City of Cape Town
CO_2	carbon dioxide
DC	direct current
DMRE	Department of Mineral Resources and Energy
GABS	Golden Arrow Bus Services
GHG	greenhouse gas
kW	kilowatt
kWh	kilowatt-hour
LFP	Lithium Iron Phosphate
MW	megawatt
MWp	megawatt peak
N-m	newton-metre
PV	photovoltaic
SOE	State owned enterprise

1 Key insights

Market size:

Currently there are ~65 000 buses and midibuses in South Africa (comprising both public transport and the private sector) that can be replaced by electric buses in a phased approach.

Operational costs & GHG emissions:

Bus fleet operators can play a leading role in the growth of private offtake of renewable energy, thereby reducing operational costs and lowering GHG emissions in cities.

Pilot studies:

Demonstrate that there are no topographical or operational issues obstructing the successful roll-out of eletric buses in South African cities.

Charging:

Innovative opportunity charging models can be implemented by bus fleet operators taking into consideration fleet utilisation levels and peak renewable energy generation windows.

2 Purpose

This case study describes the successful piloting of electric buses and the use of solar energy for charging in the context of public transport services in Cape Town.

This case study is written for:

1. Investors in the electric mobility value chain and bus fleet owners in South Africa (both public and private sector) who are exploring the use of electric buses for public transport services and the use of renewable energy for charging.
2. Cities and municipalities that are seeking opportunities to build energy resilience through electric mobility solutions.

[1]Source: National Traffic Information System - eNatis (2022)

3 Background

The South African Green Transport Strategy has set a target of 5% electrification of the total annual fleet purchases by both the government, and State-Owned Enterprises (SOEs), to reduce the country's transportation-related greenhouse gas (GHG) emissions by 2050. One of the fleets that could be at the forefront of this electrification transition is the municipal bus fleet.

Municipal buses are well suited to electrification as they have defined routes, stops and schedules which enable *opportunity charging*[2] when possible. This type of charging could be done with renewable energy. Furthermore, low operational profit models can leave municipal bus fleets vulnerable to fuel price increases, the cost of which is then typically passed on to the commuter. This vulnerability could be mitigated through the transition to renewable energy charged electric fleets.

4 Company overview

Golden Arrow Bus Service (GABS) was established in 1861 and has been operating for 160 years. The company, which is the major public transport bus service operator in Cape Town, currently has a bus fleet size of 1 100 buses and a total of 2 500 employees. GABS currently transports 220 000 commuters per day on 1 300 operational bus routes.[3] GABS is thus an established market player in the public transport industry in Cape Town and is leading the way towards the transition to electric buses in the South African market. In 2021, GABS was the first commuter bus operating company in South Africa to pilot and field test the use of electric buses.

5 Barriers

There are a several barriers to electric bus uptake by bus fleet operators in South Africa. These include:

- A lack of local operational field test data that can be used to compare conventional diesel buses to battery electric alternatives.
- Opportunity charging models for electric bus rollouts need to be built around real world operational data.
- The use of Eskom's grid electricity supply (which is largely coal generated) for charging, erodes the environmental benefits of an electric bus transition.

[1]Opportunity charging here refers to the use of DC fast chargers which are placed strategically along bus routes based on operational requirements or at depots to enable charging when possible.

[2]For up-to-date company statistics and further information, see: www.gabs.co.za/AboutUs.

6 Solution

An innovative pilot project was designed and implemented with funding from the **Uyilo eMobility Programme**[1] to operationally test two electric buses along commuter bus routes in Cape Town. The following outputs were measured as part of the electric bus pilot project:

- Battery range
- Performance along local topography
- Energy cost savings
- Charging duration
- Maintenance impact
- Passenger satisfaction
- Energy efficiency

Although the pilot was done by a private bus company providing public transport services, the learnings apply to municipal bus fleets and demonstrate how the barriers listed above could be overcome.

Electric bus pilot project

GABS addressed the lack of electric bus operational field test data by implementing a successful 18-month pilot project with two battery electric buses. The bus bodies were manufactured and assembled locally in Cape Town by Busmark using imported electric bus chassis from BYD.

The two 37-seater Bus Rapid Transit (BRT) specification buses were tested along all operational bus routes in Cape Town, from April 2021 to September 2022, to assess, among others, the ability of the vehicles to manage the steep local topography.

[3]uyilo.org.za

Pilot test specifications[4]

The specifications for the two buses that were tested are presented in Table 1.

Table 1: BYD K9 Electric Transit Bus Specifications

DIMENSIONS	
Length (metres)	12.5
Width (metres)	2.6
Height (metres)	3.4
Seats	37
PERFORMANCE	
Top speed (km/hr)	100
Max grade (%)	17
Range (kms)	300
Turning radius (metres)	13.4
Approach/departure angle	≥ 8.6° / ≥ 8.6°
POWERTRAIN	
Motor type	AC Synchronous
Max power	150kW x two[5]
Max torque	550N-m x two
Battery type	Lithium Iron Phosphate (LFP)
Battery capacity	324kWh
Charging capacity	80kW
Charging time	3 hours

[4]Source: BYD 2019

[5]The BYD K9 electric transit bus has in-wheel hub motor technology which means that two electric motors are present in each bus, integrated into each of the front wheels, respectively.

Overview of field test

Around 7 000km of field testing was conducted without passengers, where the maximum potential passenger weight was modelled using sandbags. Safety and range were evaluated for an additional 50 000km when passengers were introduced in June 2021. The electric buses were taken on hilly routes to measure the performance of the electric drive train and battery system.

The field tests showed that the electric BYD buses were successfully able to operate on some of the steepest inclines in Cape Town, most notably Hospital Bend." Figure 1 below shows an elevation profile of the notoriously steep Hospital Bend bus route in Cape Town which was one of the bus routes used to test performance on inclines.

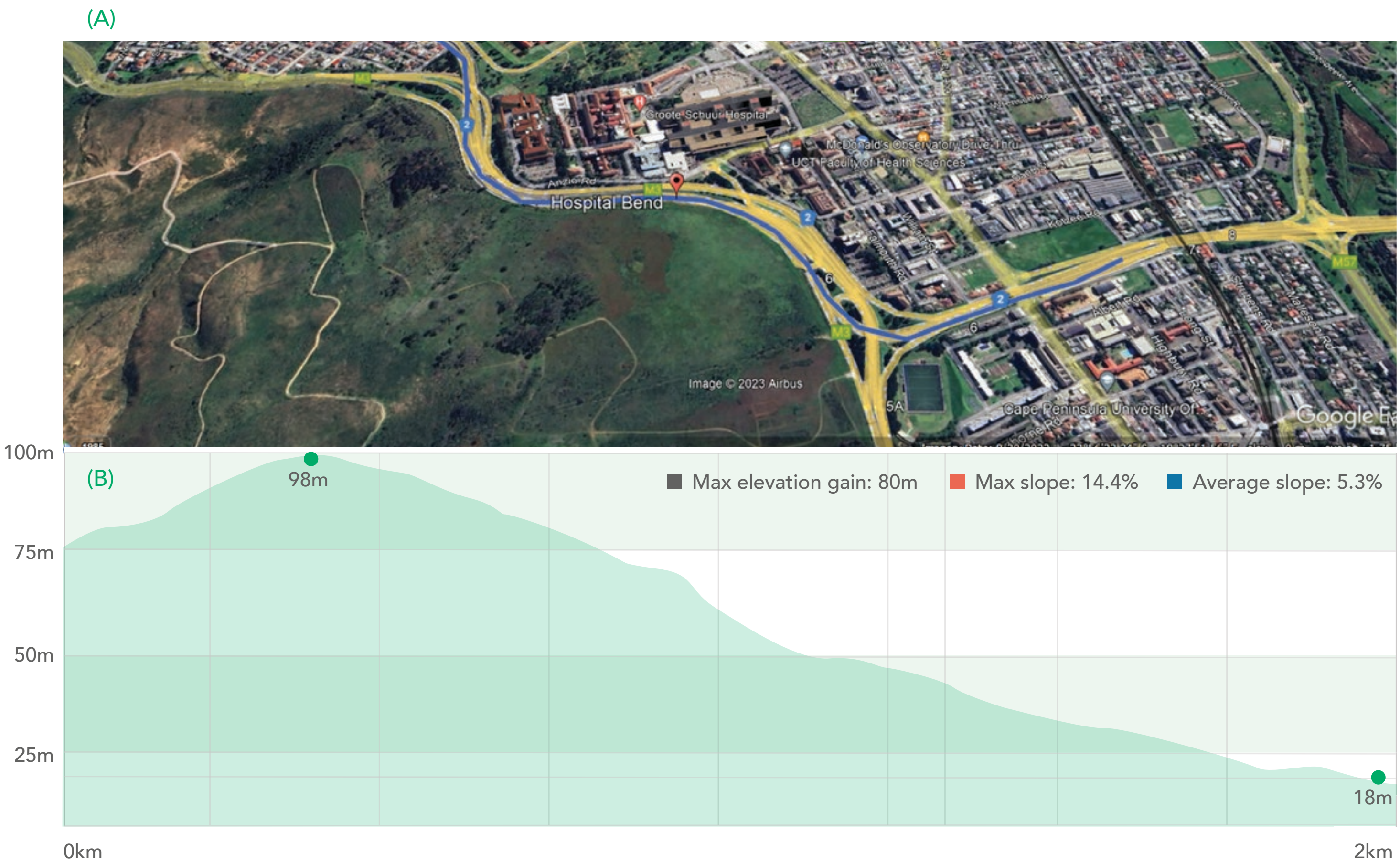

Figure 1: Aerial view (A) and elevation profile (B) of Hospital Bend (M3) in Cape Town (Source: Google Earth, 2023)

Figure 2: A GABS 37 seater FElectric BYD Bus in Operation in Cape Town (Source: GABS, 2022)

Summary of field test results

- Battery range was confirmed at 300km on a full charge.
- Charging duration was confirmed at 2 to 3 hours.
- Opportunity charging at the depots was possible during periods of low utilisation working in synergy with bus schedules.
- Energy efficiency was found to be around 0.99 kWh per km.
- Energy cost savings of almost 69% was achieved compared to a conventional diesel bus.
- Performance along local topography was confirmed to be good.
- Maintenance impact showed a 50% savings in spare parts and 80% savings in oils and lubricants.
- Passengers reported a quiet, comfortable ride with improved air quality at bus stops due to the reduction in fumes.

Roll out of solar PV at GABS depots in Cape Town

Eskom's grid electricity supply is primarily derived from coal and would therefore erode the environmental impact of an electric bus transition due to indirect GHG emissions. For this reason, GABS envisions that its future electric bus fleet would be powered using renewable energy that is either generated on-site or wheeled through the grid.

Since 2017, GABS has implemented a programme of installing grid-tied rooftop solar PV at six of its bus depots in Cape Town to reduce their operational energy costs and carbon footprint to prepare for a future fleet of electric buses. GABS will have a solar peak generation installed capacity of 1.7MWp by March 2023, which is a significant investment in its energy security needs.

The current (2022/23) applicable commercial electricity tariff from the City of Cape Town (CCT) is R2.30 per kWh. GABS has installed enough solar generation capacity to become a net electricity generator. Excess electricity that is generated at any point is fed back into the grid. Figure 3 shows the rooftop solar PV installation at the GABS head office in Epping, Cape Town consisting of around 2 400 solar panels and an installed capacity of 800kWp.

Included in the 1.7MWp installed generation capacity is the solar carport development at the GABS depot near Cape Town International Airport. It is understood that rooftop solar PV at all six of the existing depots is insufficient to produce enough renewable energy to charge a fleet of 1 100 electric buses.

Therefore, GABS is looking at solar carports and ground mounted solar PV installations where possible to fill the gap in renewable energy that is required for their future operations. It is estimated that GABS will need a peak installed generation capacity of 80 to 100MW of renewable energy to charge a fully electric bus fleet of 1 100 vehicles.

Figure 3: Solar PV rooftop installation at the GABS head office in Epping, Cape Town (Source: GABS)

Figure 4: Solar PV Car Port at the GABS depot near the Cape Town International Airport (Source: GABS, 2022)

Development of electric bus opportunity charging models

The peak utilisation graph of the current GABS diesel bus fleet of 1 100 vehicles is presented in Figure 5. There are two main operational utilisation peaks, one in the morning (04:00 to 09:00) and the other in the afternoon (15:00 to 21:30). During these peaks, there is a high fleet utilisation rate and low opportunity for charging at the depots.

The development of an electric bus charging strategy for GABS would look at the best possible periods for opportunity charging at the depots when bus utilisation is low, to have a limited impact on the everyday operations of public transport services. GABS currently has two AC chargers and one DC charger at their depot for charging. Future scenarios may involve the placing of DC fast chargers at certain bus stops to enable en route opportunity charging while the buses are away from the depots.

GABS has identified potential depot charging hours outside of the high utilisation peaks. The periods with the best charging conditions were found to be:

- Mid-day off-peak (09:00 to 15:00), 70% of the bus fleet is available to charge for six hours.
- Night-time off-peak (21:30 to 04:00), 95% of the bus fleet is available to charge for 6.5 hours.

The charging strategy is also depicted graphically in Figure 5. This shows the use of grid electricity charging at night, leveraging the off-peak electricity tariff and solar charging during the day. To enable night-time off-peak charging with green energy, GABS will require a grid-tied battery energy storage system (BESS) or wheeling off-site renewable energy to the depots during this window. The average charging time for an electric BYD 37-seater bus was confirmed to be two to three hours. An optimal number of charging stations would need to be designed based on the average charging time of an electric bus and the number of electric buses in the fleet that are not being utilised during the mid-day off-peak and night-time off-peak charging windows.

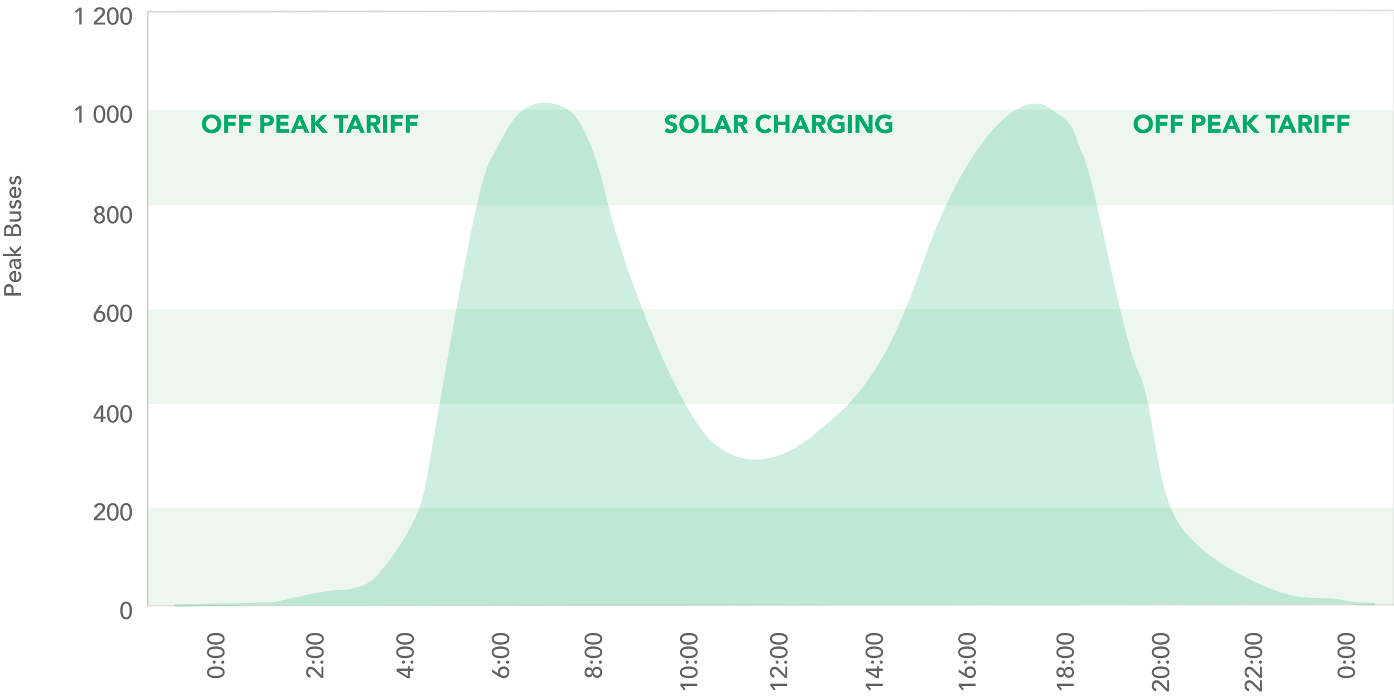

Figure 5: GABS peak bus utilisation and opportunity charging potential (Source: GABS, 2022)

7 Operational cost-benefit analysis

An operational cost-benefit analysis showed that, at current prices, GABS could save R359 460.00 in fuel costs per bus per year by switching from a diesel bus to an electric bus. Even though an electric bus is two to three times the cost of a diesel bus (due to import duties and ad valorem taxes), the fuel savings that are accrued by the bus fleet operator result in the electric bus paying for itself over its lifespan of 15 to 20 years.

Table 2: Operational Cost Benefit Analysis Per Bus

OPERATIONAL COMPARATIVE ANALYSIS	DIESEL BUS	ELECTRIC BUS
COST PER BUS (RANDS)	R2.7 million	R5.4 million to R8.1 million
ENERGY CONSUMED (UNITS PER 300KM)	120 litres of diesel	297 kWh of electricity
ENERGY COST (RANDS PER 300KM)	R2 480.00	R683.10
COST PER KM (RANDS)	R8.27	R2.28
FUEL SAVING PER YEAR PER BUS (RANDS)	R359 460.00	
RETURN ON INVESTMENT THROUGH FUEL SAVINGS	15 to 20 years	

8 Impact

The current fuel consumption of the GABS fleet of 1 100 buses is 25 million litres of diesel a year. The total mileage of the existing fleet is around 65 million km per year. An indication of the CO_2 emissions emitted by the Golden Arrow diesel bus fleet (within the City boundaries) is around 67 300 tonnes kg CO_2 per year.

The CCT's fleet, the MyCiti Bus Rapid Transit Fleet, consists of 374 buses and the CCT is considering the future procurement of electric buses. This is guided by the Council-approved Carbon Neutral 2050 Commitment and the Climate Change Action Plan which sets out ambitions for a completely electric public transport fleet by 2050. As has been demonstrated for the GABS fleet, such ambitions can not only have considerable GHG reduction benefits, particularly if the buses are powered with renewable energy, but could also lead to a reduction in noise and improved air quality.

The transition of the GABS electric bus fleet, particularly one powered by renewable energy, can thus make a considerable reduction in the GHG emissions associated with public transport in Cape Town.

[9]The CO_2 emission factor used was 2 692 kg per litre of diesel fuel consumed (Source: DEA, 2017, as cited in Kornelius *et al.*, 2022, This is the factor for the direct mobile combustion of diesel. It is important to note that the total potential annual amount of CO_2 emissions cited is thus indicative only of direct emissions and potential savings as a result of replacement of diesel buses by electric buses A full lifecycle assessment would need to be done to calculate the full operational carbon footprint of the fleet of diesel GABS buses and that of electric buses power with grid and/or renewable energy to obtain a more accurate estimate of the potential GHG reduction per bus and/or the full carbon footprint of the GABS fleet.

9 Lesson learned and future plans

GABS has proven that electric buses can be successfully deployed for public transport services in a South African city. Furthermore, the adoption of solar PV technology shows that bus fleet operators can play a leading role not only in the transition to electric vehicles but also in lowering the carbon footprint of cities when using renewable energy for charging purposes.

GABS procured an additional electric 65-seater BYD commuter bus, in September 2022, which was more suited to their operational requirements with regard to seat capacity. This bus was imported fully assembled for further pilot testing. A further year-long pilot trial of the new electric 65 seater BYD commuter bus is underway to compare to the energy efficiency results obtained for the initial 37-seater electric bus trial.

Thereafter, local bus body manufacturers will be identified to assist with the assembly of up to 60 electric buses a year using imported chassis. It is envisioned that GABS will replace its existing fleet with 60 electric buses every year from 2024 until its full fleet of 1100 diesel buses has been replaced. This represents an estimated annual investment cost of around R324 million to R486 million. GABS envisions that all future charging stations will be DC fast charging as more electric buses are acquired.

10 References

Department of Environmental Affairs (now Department of Environment, Forestry and Fisheries) (2017). Technical guidelines for monitoring, reporting and verification of greenhouse gas emissions by industry. Available at: dffe.gov.za/sites/default/files/legislations/technicalguidelinesformrvofemissionsbyindustry_0.pdf (Accessed: February 28, 2023).

Kornelius, G., Forbes, P., Fischer, T and Govender, M. (2022). "Determination of country-specific greenhouse gas emission factors for South African liquid and gaseous fuels". Journal of Energy in Southern Africa. 33(3), [online], Available at: scielo.org.za/scielo.php?script=sci_arttext&pid=S1021-447X2022000300001. (Accessed: February 28, 2023).

Acknowledgements

Thank you to Golden Arrow Bus Services and Company Engineer, Gideon Neethling for the provision of background information and the electric bus field test data, graphs and images that were instrumental in compiling this case study.

This case study was made possible thanks to the support of the City of Cape Town

CITY OF CAPE TOWN
ISIXEKO SASEKAPA
STAD KAAPSTAD
INVEST CAPE TOWN
RESILIENT CAPE TOWN

For more information and support contacts:

GreenCape: info@greencape.co.za | (021) 811 0250

GreenCape
Supporting the business of green