ELECTRIC MOBILITY TRANSITION & LOCALISATION

Towards Unlocking the NEV Value Chain for Africa

SITUATIONAL AND BASELINE ANALYSIS REPORT SERIES REPORT 3: MACHINERY AND EQUIPMENT



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1. INTRODUCTION

New Energy Vehicles (NEV) are seen as being an important step towards achieving global climate change objectives. This study has undertaken a comprehensive review of the relevant literature as it relates to the current NEV industry globally, for South Africa and the Rest of Africa (RoA), whilst identifying key role players and stakeholders and highlighting current and emerging gaps and opportunities, in the NEV market.

To evaluate the NEV segments, markets and policy along the value chain, the literature review has been structured to provide a comprehensive overview of the most important NEV sectors in a logical framework as follows:

1. **NEV Landscape Overview:** New Energy Vehicles (NEVs) are vehicles that are powered by electricity or fuels made from non-fossil fuel sources. In May 2021, the dtic released the green paper on NEVs[1] for public comment and the intention was clear that the South African Automotive Value Chain was ready to transition from 'Internal Combustion Engines' (ICE) to NEV. The Just Energy Transition Implementation Plan (JET IP) provides a means to achieve the transition through investments spearheaded by various government authorities, private institutions and development finance institutions (DFIs).

2. **Micro-mobility:** The context and rationale for micro-mobility, market developments and particularly the rise in electrified two and three-wheelers, four-wheeler 'last mile' delivery vehicles, conversions and eco-tourism markets, together with closing comments.

3. **Public Transport:** This section reviews buses from a global perspective and for best practice lessons, 'battery swapping' as an emerging trend, South African trends and developments, minibus taxis and case studies for Kenya, Ghana, Rwanda and Zimbabwe for consideration.

4. **Machinery and Equipment:** A review of the production and sale of zero-emission heavy-duty vehicles and equipment is undertaken, with trucks, mining equipment, agricultural equipment and the general electrification of various categories of machinery and equipment, together with ownership models being analysed. Conversion of fossil fuel-driven vehicles to NEV is also considered and then role players and stakeholders are identified, together with opportunities in the NEV value chains and for FCEV components.

5. **Infrastructure Providing Energy for NEV:** The NEV industry requires support infrastructure in the form of fuel supply infrastructure, charging stations and equipment, policy and incentives, together with other support and enabling investments, including finance and insurance. These issues are traversed and opportunities identified.

6. **Battery Value Chain:** The batteries in various NEVs are becoming an important technology in themselves and underpin certain elements of the NEV industry and opportunities. Battery types have been analysed with smaller and larger mobility issues traversed and a brief review of battery studies conducted in South Africa.

7. **Trade Policy Conformity:** A range of trade policies, incentives and tax schemes are considered that various countries employ to accelerate the transition to NEVs. Tariffs and regional integration for trade enhancement are considered, including Rules of Origin (RoO) and the implications of the African Continental Free Trade Agreement (AfCFTA) on the emerging NEV industry in Africa.

[1] DTIC, 2021. Auto green paper on the advancement of New Energy Vehicles in South Africa, the South African road to production of electric vehicles (The Roadmap, 18th May 2021)

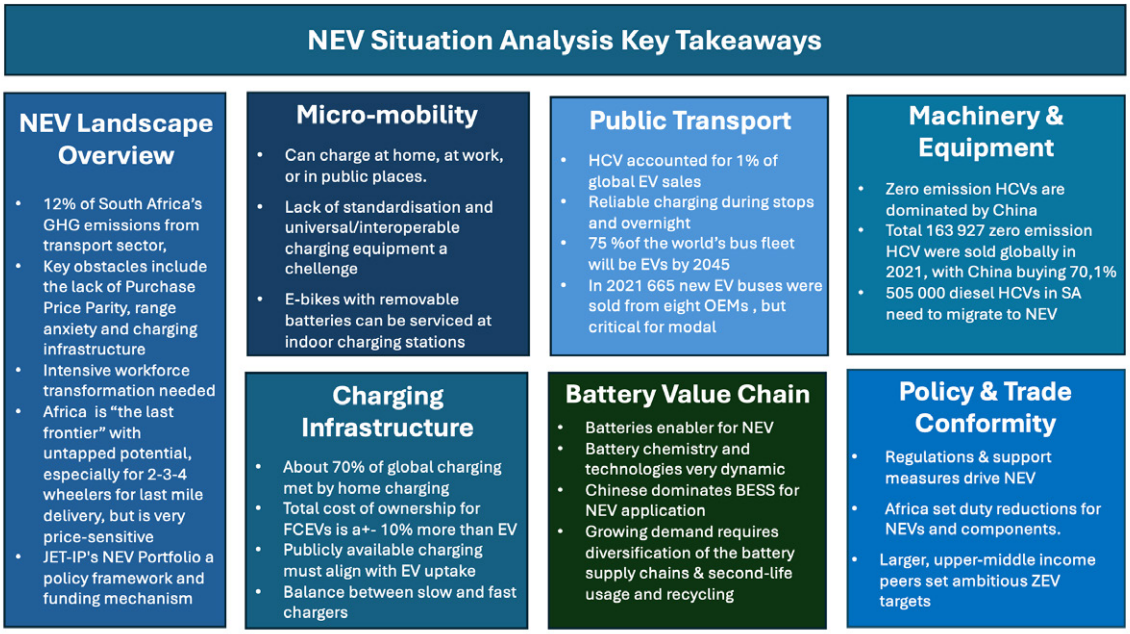


Figure 1: NEV Situational Analysis Key Takeaways

The key takeaways from each of the segments are summarised in the figure above. Each of these is dealt with in a separate chapter in the series review, highlighting key role players and stakeholders, culminating with an overview or statement of the opportunities which have been identified in the NEV segment considered.

2. MACHINERY AND EQUIPMENT

2.1 Trucks

2.1.1 Global performance

The production and sales of zero-emissions heavy-duty vehicles have been dominated by China. In 2009, there were less than 3 500 zero emissions heavy-duty vehicles sold globally and this number peaked in 2016, with over 200 000 sold. This was followed by a period of decline, resulting in just over 100 000 being sold in 2019 – 95% of which were delivered in China, by Chinese manufacturers, as seen in Figure 2. Since 2010 of the cumulative 760 000 zero-emissions heavy-duty vehicles sold, 82% were buses and only 18% were trucks. The type of technology applicable to truck sales also indicated a clear trend with 99,7% of sales being battery electric and only 0,3% being FCEV (ICCT, 2020).[2]

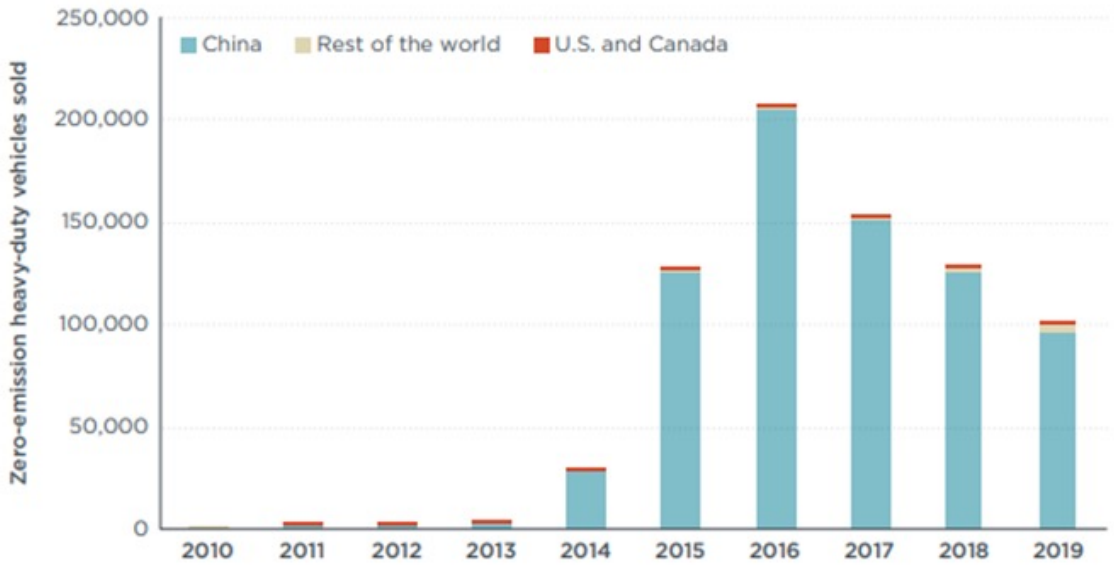


Figure 2: Global zero emissions heavy-duty vehicle sales per region, 2010 – 2019.[3]

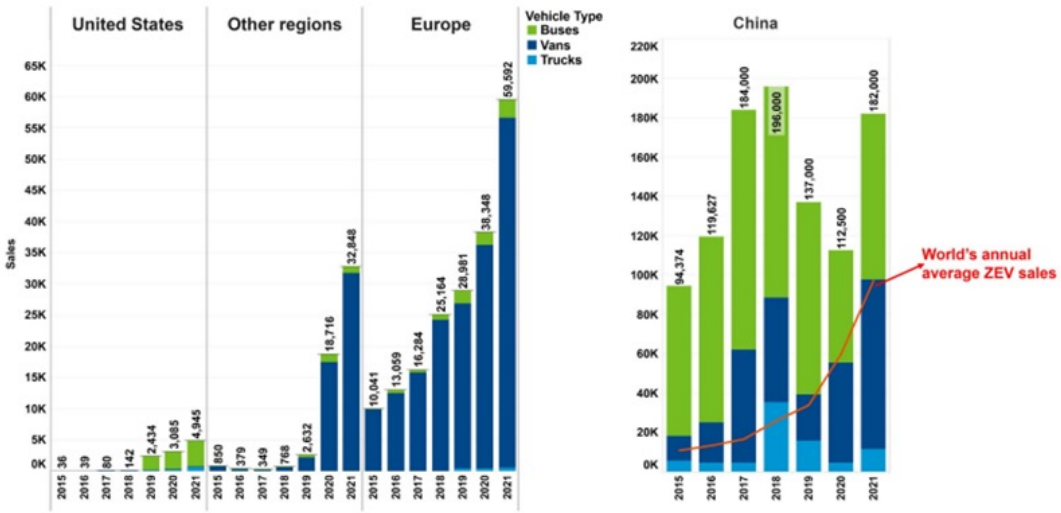


Figure 3 : Volume of zero-emission medium and heavy-duty vehicle sales, by vehicle type, per region, 2015 to 2021[4]

[2] ICCT. 2020. Race to zero: How manufacturers are positioned for zero emission commercial trucks and buses in North America. https://theicct.org/wp-content/uploads/2021/06/Canada-race-to-zero-EN-oct2020.pdf

[3] Ibid

[4] Global Drive to Zero. 2023. Zero-emission truck and bus market update: June 2023. https://globaldrivetozero.org/site/wp-content/uploads/2023/06/Final_ZETI-Report-June-2023_Final.pdf

Figure 3 illustrates whilst zero-emission medium and heavy-duty vehicle sales rose consistently, this was driven primarily by the bus and van segment in the US and China, whilst the sales of vans dominated in Europe – this indicates how small the global market for zero-emissions trucks is. Global Drive to Zero (2023)[5] notes that a total of 163 927 zero-emission heavy-duty trucks were sold in 2021, with China being responsible for 114 898 units (70,1%); Europe being responsible for 1 756 units (1,07%), the US responsible for 704 units (0,42%) and Other Regions responsible for 46 569 units (28,4%).

In terms of FCEV trucks specifically, Statista (2023)[6] reports total global FCEV truck sales of 11 040 units in 2023 and forecasts exponential growth to 1 million units by 2030, as seen in Figure 4 below.

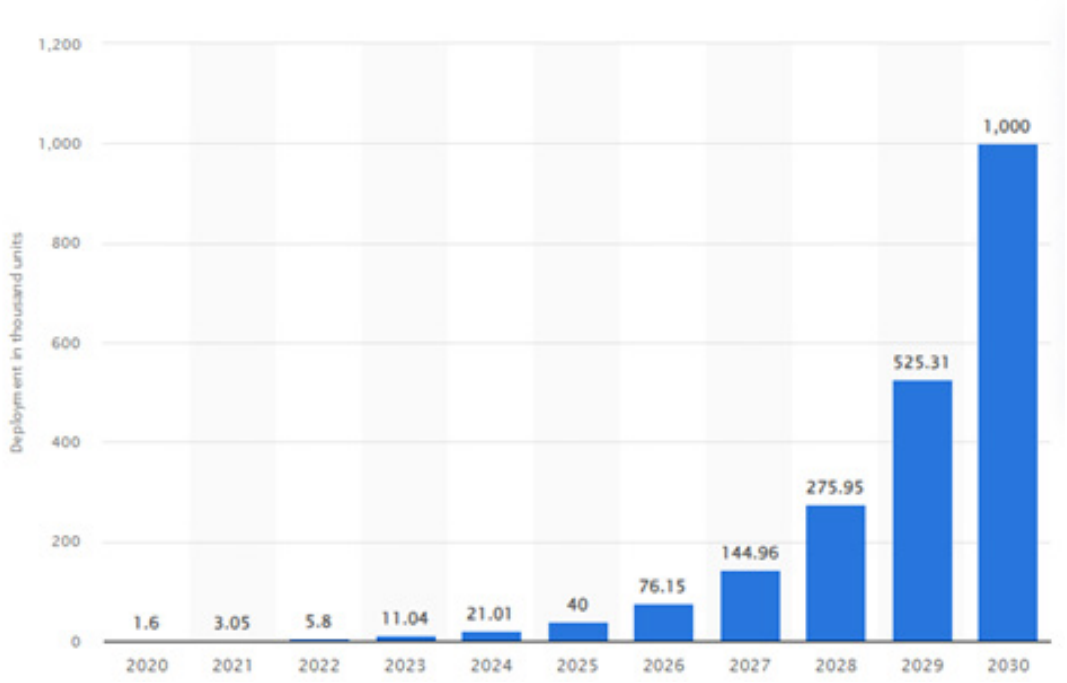


Figure 4 : Global projected fuel cell electric truck deployment between 2020 and 2030 (in 1,000s).[7]

2.1.2 South African Trends and Developments

The South African HCV sub-sector is typically low volume compared to the passenger and LCV segments, with 13 OEMs and 105 model derivatives for HCVs and 18 OEMs and 374 model derivatives for XHCVs. In terms of annual growth, the HCV segment grew by 21.8% and the XHCV segment by 24.2%, as seen in Table 1. In terms of OEM dominance, the leading HCV OEM was Isuzu, whilst Daimler Trucks and Buses was the highest performer in the XHCV segment (AIEC, 2023)[8].

[5] Ibid
[6] Statista. 2023. Global projected fuel cell electric truck deployment between 2020 and 2030 (in 1,000s). https://www.statista.com/statistics/1272558/fuel-cell-electric-commercial-vehicle-global-deployment/
[7] Statista. 2023. Global projected fuel cell electric truck deployment between 2020 and 2030 (in 1,000s). https://www.statista.com/statistics/1272558/fuel-cell-electric-commercial-vehicle-global-deployment/
[8] Automotive Industry Export Council (AIEC). 2023. Automotive Export Manual – 2022 – South Africa. https://naamsa.net/wp-content/uploads/2022/05/Automotive-Export-Manual-2022.pdf

Table 1: South African annual truck sales; and HCV truck sales as a percentage of total MCV and HCV sales[9]

Year	HCV truck sales (units)	XHCV truck sales (units)	Total HCV and XHCV truck sales (units)	% of total MCV and HCV sales
2017	5 306	11 978	17 284	66%
2018	5 374	13 126	18 500	67%
2019	5 041	13 350	18 391	66%
2020	4 091	11 200	15 291	67%
2021	4 982	13 908	18 890	70%

In terms of the NBI's TCO calculations, the TCO for FCEVs in South Africa is calculated on a cost-per-kilometre basis. The National Business Initiative (2023)[10] finds that in the absence of tariffs on FCEV trucks, price parity between ICE and FCEV trucks could be reached by 2030 to 2032, as seen in Figure 5 . Should both ICE and FCEV trucks be subject to a 12% import tariff, there are no significant differences to the 'no tariff' scenario and price parity remains from 2030 to 2032. If ICE trucks are subject to a 12% import tariff and FCEV trucks are subject to a 20% import tariff, price parity is pushed out one year to 2031 to 2033 (NBI, 2023)[11]

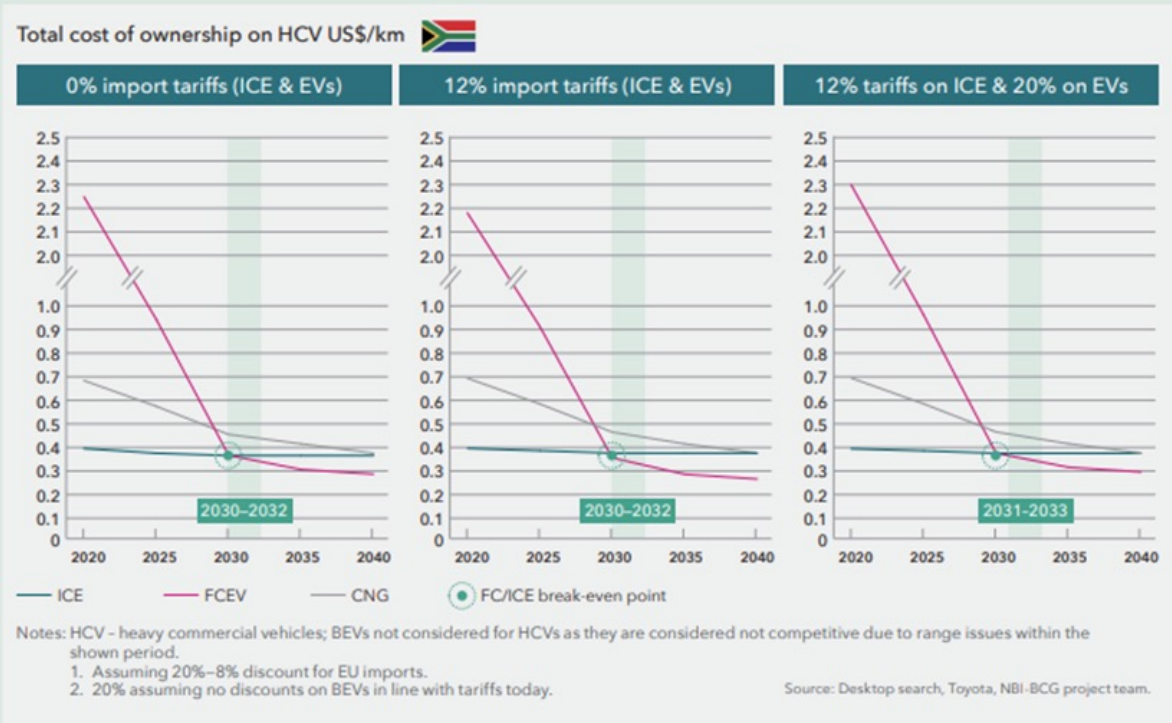


Figure 5: Total cost of ownership of HCVs in South Africa, US$/km [12]

Shoprite has acquired an electric heavy-duty electric truck from Scania to support domestic deliveries. The truck which is refrigerated and can carry up to 16 pallets, has an estimated range of 350km but has averaged about 250km on one charge since implemented. The vehicle has on-board solar panels and is powered by nine batteries. It is currently being charged by Shoprite's existing solar PV infrastructure (Business Day, 2023)[13].

[9] Ibid
[10] National Business Initiative (NBI). 2023. Decarbonising the South African Transport Sector: Just transition and climate pathways study for South Africa. https://www.nbi.org.za/wp-content/uploads/2023/08/Decarbonising-the-South-African-Transport-Sector_Final_17March2023.pdf
[11] Ibid
[12] Ibid
[13] Business Day. 2023. Electric truck takes to SA roads in Scania and Shoprite pilot. https://www.businesslive.co.za/bd/life/motoring/2023-02-23-electric-truck-takes-to-sa-roads-in-scania-and-shoprite-pilot/

In June 2023, Volvo South Africa delivered its first electric truck to logistics company, KDG Logistics, where it will be used to move passenger vehicles at the Durban Port. The truck, fitted with six battery packs (each weighing about 500 kg) has sufficient range for most regional logistics applications, has 378 kWh of power and will be charged on a 120 kWh DC charger, which Volvo has installed at key sites. The lithium-ion batteries for the trucks will be produced at Volvo's Belgian battery assembly plant. The trucks only require one service per year, which ensures that minimal downtime is required per vehicle. As the vehicles do not produce any noise during use, they are well-suited to night-time operations (Cleantechnica, 2023)[14].

In November 2023, at the Smarter Mobility Africa Summit, Toyota South Africa Motors, Sasol and Air Products South Africa demonstrated a hydrogen mobility ecosystem 'proof of concept'. While the project focused on a passenger vehicle, the Toyota Mirai, the establishment of the hydrogen re-fuel infrastructure is of relevance to this study. About the project, Sasol announced that they had produced their first green hydrogen at their Sasolburg Operations, which was supported by the installation of a 3 MW solar farm. In addition, the green hydrogen production will also be supported by 69 MW of wind energy from the Eastern Cape, to increase production to 3 500 tonnes per day, in 2024 (CBN, 2023)[15].

In October 2023, online retailer, Takealot, in partnership with renewable energy company Aversa and fleet management company, Avis, partnered to acquire BEV trucks and set up the largest fast-charging station in the Western Cape. Aversa, through the use of strategic charging solutions, has extended the normal 200 km range of the JAC N75EV to 400 km per charge, which will be supported by a 240 kWh charging station (Hako, 2023)[16].

2.1.3 Truck Electrification

Three infrastructure-related challenges exist that will impact truck electrification:

- **Electricity supply and demand**: To supply the required amount of energy to the trucking industry, utilities will have to expand infrastructure to generate more electricity and transmit and distribute that electricity to locations where trucks need to charge. With a shift toward electrification, trucking will be one of many new consumers of electricity, competing with passenger vehicle owners for access to low-cost, reliable electricity. This new energy consumption is set against the backdrop of an ageing electricity infrastructure and instances where peak-period demand has exceeded available supply. Additionally, some provinces such as Gauteng and the Western Cape are better equipped to implement electrification than others due to urbanisation, high population density, supporting government policies and incentives as well as economic development. Since trucking operates across all provinces and in both rural and urban settings, the industry will need affordable and reliable access to electricity in thousands of locations throughout the country[17].
- **Electric vehicle production**: There are 505 000 heavy-duty trucks in SA which are all equipped with diesel engines. A move toward industry electrification requires the replacement of ICE trucks with BEV trucks. This requires a major ramp-up of lithium-ion battery production or a new and improved form of electric battery. Suppliers of the raw materials utilised in batteries, for instance, will need to expand mining operations to meet demand and battery manufacturers will likewise need to grow. The ability of trucking companies to switch from ICE to BEV is dependent on reasonably priced and easily accessible BEV truck materials – without expanded mining and processing infrastructure to support battery demand, prices will likely increase[18].

[14] Cleantechnica. 2023. 1st Volvo electric FM 4×2 truck in South Africa delivered to KDG Logistics. https://cleantechnica.com/2023/06/09/1st-volvo-electric-fm-4x2-truck-in-south-africa-delivered-to-kdg-logistics/
[15] CBN. 2023. Hydrogen ecosystem Proof-of-Concept demonstrated. https://www.cbn.co.za/industry-news/renewable-energy-solar-power/hydrogen-ecosystem-proof-of-concept-demonstrated/
[16] Hako, N. 2023. Takealot takes on electric trucks and largest fast-charging station in WC. https://www.esi-africa.com/business-and-markets/takealot-takes-on-electric-trucks-and-largest-fast-charging-station-in-wc/
[17] ATRI, Charging Infrastructure Challenges for the US Electric Vehicle Fleet (2022)
[18] Ibid

- **Truck charging requirements**: Vehicle re-fuelling is accomplished today through a relatively quick transfer of diesel that is sourced from well-established private fuelling facilities. This model would change substantially through vehicle electrification due to recharging times, vehicle trip ranges and the varying loads the trucks must carry. At the very least, an entirely new set of infrastructure – in the form of vehicle charging stations – will be required. The scale of this network as well as implementation costs will depend on various factors such as the future projected number of NEV trucks in South Africa, as well as their operating hours and distances travelled[19].

2.1.4 Global best practice

Whilst the economic analyses indicate that BEVs and FCEVs will eventually reach price parity with ICE vehicles, the initial investment cost of swapping a fleet to BEVs or FCEVs is still a significant barrier to their wider adoption, particularly in South Africa. This challenge is often compounded in the logistics industry, which is already relatively capital-intensive and operates on 'thin' profit margins (Ragon and Rodriguez, 2022). Government incentives and funding support can drive the initial adoption of NEVs, but these tools are often not sustainable in a fiscally constrained environment.

Table 2: Examples of alternate ownership and operational models for BEVs and FCEVs[20]

	Truck ownership	Infrastructure ownership	Operational expenses	Payment
Traditional ownership	Carrier	Carrier	Carrier	One-off upfront payment
Leasing	Carrier/manufacturer	Carrier	Carrier	Fixed monthly payment
Trucking-as-a-service (TaaS)	Service provider	Service provider	Carrier	Fixed monthly payment
Pay as you drive	Service provider	Service provider	Carrier	Monthly fee based on usage
Charging-as-a-service (CaaS)	Carrier	Service provider	Carrier	Fixed monthly payment

Table 2 provides an outline of ownership models for BEVs and FCEVs. Leasing has been a common ownership strategy for fleet owners in South Africa and will likely continue to be a business model for the purchase of BEVs and FCEVs. However, new business models are likely to gain more prominence in the coming years:

- "*Trucking-as-a-service*" (TaaS) requires less of an upfront capital investment, whilst supporting a vehicle over its full lifetime. It may be provided by the OEM or a third-party service provider who is responsible for the purchase of the vehicle, maintenance, insurance and all costs associated with charging or refuelling and the fleet owner/carrier would pay a fixed monthly fee for the service.
- "*Pay-as-you-drive*" supports fleet owners/carriers by allowing them to only pay for the energy/fuel used and the related maintenance for that distance. This provides some relief, as the operational expenses of a fleet often constitute the biggest portion of its TCO.
- When the fleet owner/carrier wants to retain ownership of their vehicles, "*Charging as a service*" is a useful model as a third party is responsible for the deployment, building, operation and maintenance of charging or refuelling stations and the fleet owner/carrier pays a fixed monthly fee.

Trucks, unlike passenger vehicles, often form part of a large fleet (e.g. municipal mixed-use fleet; or a private sector long-haul logistics company) and the decision to purchase one of these vehicles differs from personal ownership decision-making for a passenger or LCV.

[19] ATRI, Charging Infrastructure Challenges for the US Electric Vehicle Fleet (2022)
[20] Ragon, P. and Rodriguez, F. 2022. Road freight decarbonisation in Europe: readiness of the European fleets for zero-emission trucking. https://theicct.org/publication/road-freight-decarbonization-europe-sep22/

There are usually four key decision points to consider, as outlined by the Zero Emissions Transition (ZEV) Transition Council (2023)[21] below in Table 3.

Table 3: Key decision points for fleet owners and operators[22]

Planning ahead and grid challenges • While battery electric vehicle (BEV) orders can often be fulfilled within a few months, charging infrastructure setup can take months or even years. It is thus important that fleet operators consider charging infrastructure before or at least at the same time as vehicle procurement. • Grid upgrades take time and can take up to 10 years if transmission upgrades are needed. Electricity utilities thus need to be proactive in upgrading the grid instead of reacting to demand from fleets; this will prevent utilities from being a bottleneck in the process. • Most of the time, challenges appear at the distribution stage rather than at the generation or transmission stages and alternative solutions should be envisaged that would allow BEVs to operate while existing electricity is brought to the right place.	**Collaboration and expertise** • Collaboration is needed between transport, environment, economics and energy departments in government to develop long-term plans, design policies and incentives and enable new opportunities such as vehicle-to-grid (V2G). • Fleet operators are historically more knowledgeable about transport than they are about the energy sector and cannot often develop this expertise. They can struggle with unclear or non-existent permitting procedures for grid connection or charger installation. Conversely, electricity utilities are historically less knowledgeable about transportation and fleet needs for charging infrastructure.
Public charging infrastructure • Small fleets generally lack the resources to build a centralized private charging infrastructure hub and thus depend on public charging infrastructure. • Long-haul trucks that do not return to the same location every night need reliable charging infrastructure along freight corridors. • Regional fast-charging hubs give confidence to fleet operators to switch to ZEVs. • Deploying public charging infrastructure requires land.	**Cost** • Charging infrastructure deployment is capital-intensive. • Due to high upfront costs and their lack of expertise, many fleet owners are adding a few BEVs to their fleet at a time and installing a small number of chargers at a time. This is the most expensive way to electrify a fleet and install the charging infrastructure needed.

[21] ZEV Transition Council. 2023. Accelerating ZEV adoption in fleets to decarbonise road transportation. Briefing paper, May 2023. https://theicct.org/wp-content/uploads/2023/05/ZEVTC_fleets-briefing_final.pdf
[22] Ibid

The Chinese government allows for extensive incentives and financial support to be offered on a city level, to promote the adoption of FCEV and BEV trucks[23]. Niu et al (2023) provide an overview of the Guangdong province, below in Table 4.

Table 4: Financial support provided at the city level to promote FCEV and BEV truck adoption in China.[24]

City	Timeline	Target	Financial support[25]	Non-financial support
Shenzhen	2018 - 2025	1 million NEVs on the road by 2025	BEV: R 2 030 805,60 to purchase a new BEV dump truck. R 203 080,56 to R 360 467,99 to replace a diesel dump truck with a BEV dump truck (determined by vehicle specifications). FCEV: R 307 159,35 to R 558 471,54 to replace a diesel dump truck with an FCEV dump truck (determined by vehicle specifications).	Road privileges for NEVs during the daytime. Free parking for NEV vehicles.
Foshan	2018 - 2035	18 000 FCEVs; 80 hydrogen stations and hydrogen production capacity of 50t per day by 2035	BEV: Commencing in 2023, R 76 155,21 to purchase a new BEV truck. FCEV: R 7,6 billion industry funding to provide subsidies for FCEVs and hydrogen stations. R 177 695,49 to replace diesel trucks with FCEV trucks, specific to the Nanhai district. Commencing in 2023, R 291 928,30 to purchase a new FCEV truck.	Road privileges for FCEVs specifically. 50% reduction in toll fees for FCEVs specifically.

The state of California has been a global leader in legislation regarding the transition of HCVs with the Advanced Clean Trucks (ACT) regulation – the first legislation of its kind which requires manufacturers to sell increasing numbers of zero emissions HCVs in the state will commence in 2024. As a result of this legislation, it is expected that 94% of HCVs in the state in 2050 will be zero-emissions vehicles.[26]

Another trend observed in the HCV transition is the implementation of fleet procurement targets and emissions targets. These targets or quotas for zero-emissions vehicles are often utilised by governments to promote the increased adoption of NEVs in the HCV segment. If generous targets are set and implemented

[23] Niu, T., Ma, Y. and Zhang, Y. 2023. Real-world use cases for zero-emission trucks: Market review and policy suggestions for Guangdong province. https://theicct.org/publication/real-world-zet-guangdong-oct23/
[24] Ibid
[25] Utilising November 2023 Yaun/Rand exchange rate
[26] ZEV Transition Council. 2023. Accelerating ZEV adoption in fleets to decarbonise road transportation. Briefing paper, May 2023. https://theicct.org/wp-content/uploads/2023/05/ZEVTC_fleets-briefing_final.pdf

by the government, it starts to create a critical mass for the manufacture, operation and maintenance of these vehicles which will encourage the private sector to follow suit. The ZEV Transition Council[27] in 2023 notes the following international developments in Table 5 below.

Table 5: Select examples of global developments in fleet procurement and emissions targets for the truck sector[28]

- The United States government has implemented a 100% zero-emissions vehicle target for all small trucks purchased by 2027 and has extended this to other vehicle classes in fleets which include at least 600 000 vehicles
- The UK government will ensure that all government passenger and truck fleet vehicles will have zero emissions by 2027
- The South Korean government has committed that all new government vehicles must be at least 80% BEV or FCEV by 2022

2.1.5 Technology Development: Emissions and Range

The transition to NEVs is often conflated with a move from ICE to BEV vehicles only. In determining the transitional path for a mode of transport, it is important to consider the functional requirements of the vehicle, with the most important being the expected range to be driven.

The DOT (2018)[29] in its Green Transport Strategy 2018 – 2050, notes that BEV batteries have a low energy density per weight (estimated at 0.6 MJ per kg) making BEVs suitable for lighter vehicles (passenger and LCVs) over short ranges.

FCEVs are effectively BEVs which are also powered by hydrogen, stored in an on-board pressurised tank and fuel cell. FCEVs like BEVs make use of regenerative braking to re-charge the on-board battery. However, as hydrogen has a higher energy density per weight (estimated at 2.3 MJ per kg)[30], FCEVs can travel longer distances and have improved performance for HCVs where batteries are impractical (from a charge time and the anticipated roll-out of charging stations over long distances)

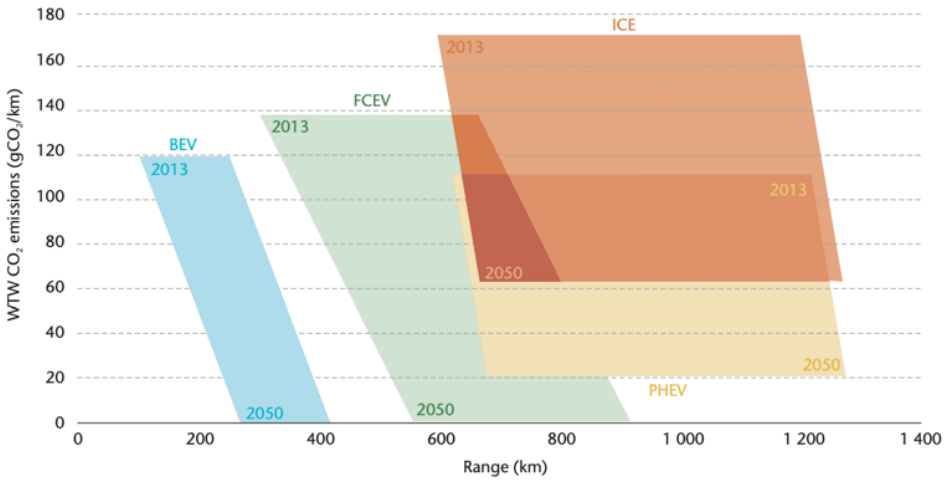


Figure 6: A comparison of indicative well-to-wheel emissions and vehicle ranges[31]

[27] Ibid
[28] ZEV Transition Council. 2023. Accelerating ZEV adoption in fleets to decarbonise road transportation. Briefing paper, May 2023. https://theicct.org/wp-content/uploads/2023/05/ZEVTC_fleets-briefing_final.pdf
[29] Department of Transport. 2018. Green Transport Strategy 2018 – 2050. https://www.transport.gov.za/documents/11623/89294/Green_Transport_Strategy_2018_2050_onlineversion.pdf/71e19f1d-259e-4c55-9b27-30db418f105a
[30] Ibid
[31] International Energy Agency (IEA). 2015. Technology Roadmap: Hydrogen and fuel cells. https://iea.blob.core.windows.net/assets/e669e0b6-148c-4d5c-816b-a7661301fa96/TechnologyRoadmapHydrogenandFuelCells.pdf

Figure 6 illustrates that while ICE and PHEVs have a greater range compared to BEVs and FCEVs, FCEVs have a marked improvement in range compared to BEVs. Whilst the emissions on the BEVs are lower than FCEVs initially, it must be noted that this assumes that all electricity generated for the BEV to charge, originates from green/clean sources, which is not the case in South Africa. Additionally, by 2050, the emissions of BEVs and FCEVs will be on par.

The success of an FCEV truck for a long-distance route is determined by the range the FCEV can achieve versus a traditional diesel-powered ICE truck. The factor which has the most bearing on an FCEV truck being able to ensure improved range is the volume of hydrogen which may be stored onboard the truck. The physical layout of the truck has a bearing on the location of the onboard hydrogen storage system – it is usually expected that the hydrogen tank will be located behind the driver's cabin and its size (typically 2 000 litres) is constrained by the dimensions of the truck. Figure 7 provides a simplified schematic of the onboard hydrogen storage system for a long-distance truck.

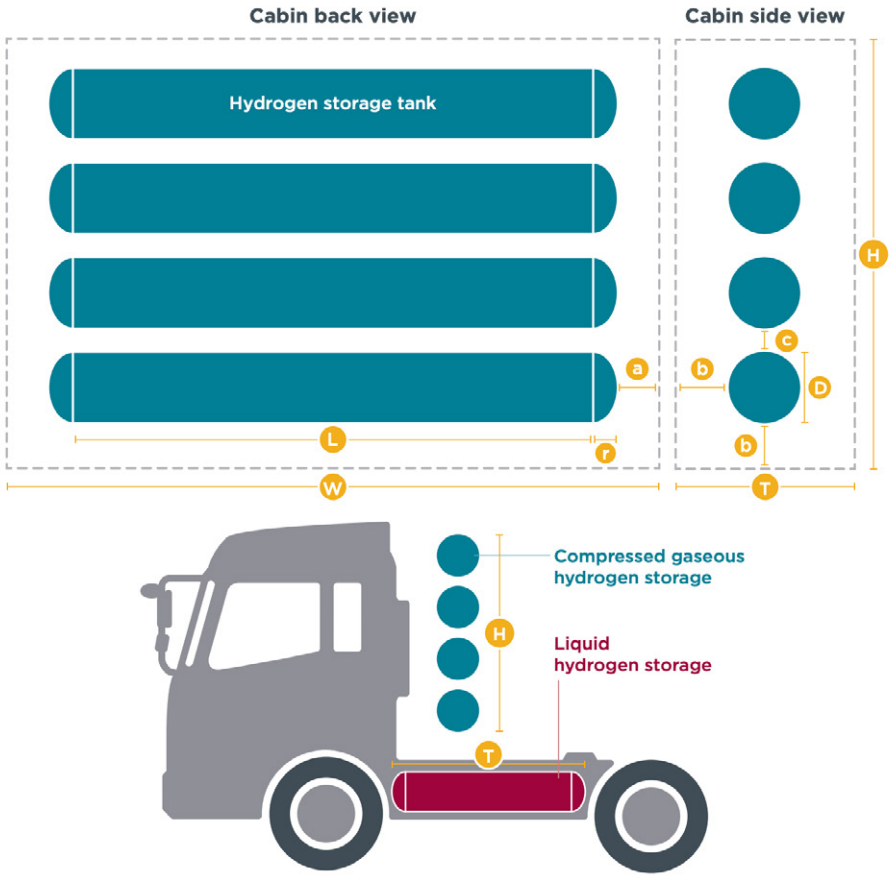


Figure 7: Schematic of an onboard hydrogen storage system for a long-distance truck[32]

While the onboard storage capacity is 2 000 litres, the storage technology selected will have a role in determining the driving range of the truck. Hydrogen tanks compressed to 350 bars may have a current driving range of 370km, which with future technologies could be extended to 500km. Increased volumetric density to 700 bar may deliver a range under current technology of 600km, which could be extended to 800km with future technologies. On the other type of storage technologies, liquid and cryo-compressed storage, the highest range under current technologies is estimated to be 800 to 900km, which could breach the 1000km threshold by 2023, as illustrated in Figure 8 below (Basma and Rodriguez, 2022).

[32] Basma, H. and Rodriguez, F. 2022. Fuel cell electric tractor-trailers: technology overview and fuel economy. https://theicct.org/publication/fuel-cell-tractor-trailer-tech-fuel-jul22/

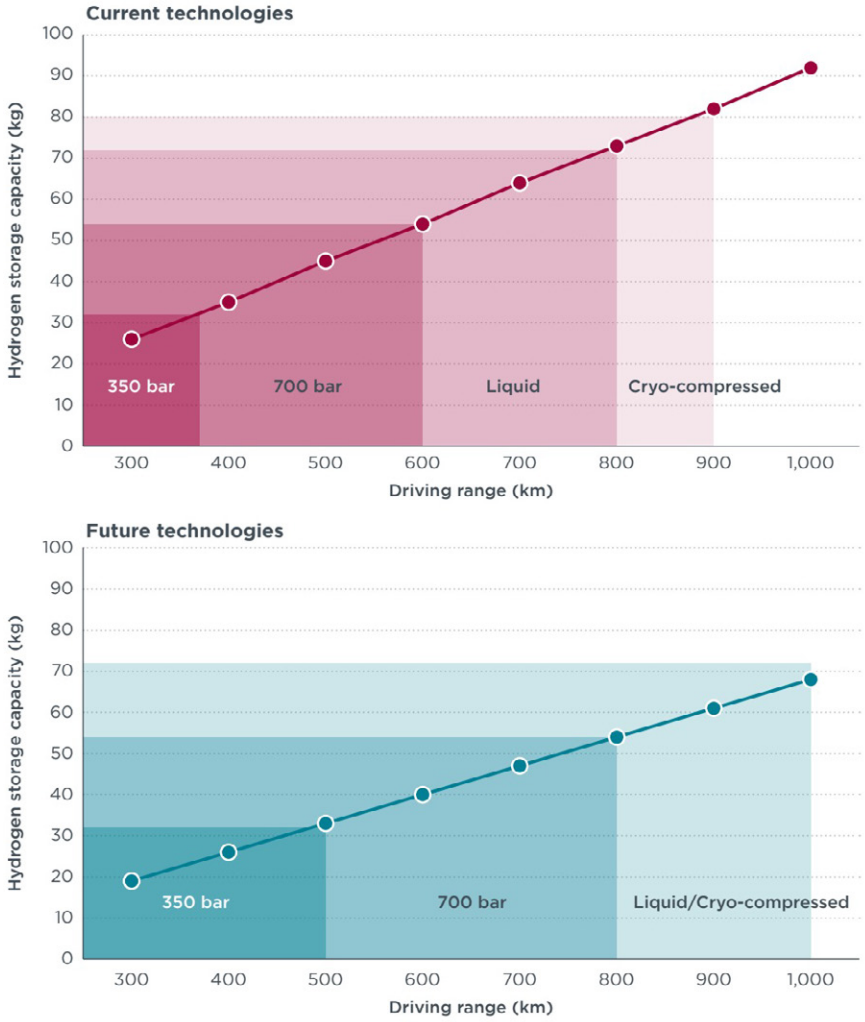


Figure 8: Maximum range achieved by FCEV trucks, per hydrogen storage scenario and comparing current and future technologies[33]

A key determinant when considering the change-over from ICE to FCEVs is the TCO – the total cost of ownership. It is only once an ICE and NEV vehicle reach TCO parity, that it makes economic sense to switch to the adoption of the NEV. The DSI (2021) suggests that nearly 25% of the total hydrogen demand for the Durban hub, will be driven by the HCV truck sector and that by 2040, between 20 and 25% of all HCV trucks in the Hydrogen Valley will be FCEV.

2.1.6 Global performance

Globally, mining companies are increasing their net-zero commitments, in line with the Paris Agreement to limit GHG emissions. GlobalData (2022) analysed the company filings of these companies and found a three-fold increase between 2020 and 2021 in terms of references to key phrases "decarbonisation", "net zero" and "carbon neutral" and a nine-fold increase compared to 2018[34].

[33] Basma, H. and Rodriguez, F. 2022. Fuel cell electric tractor-trailers: technology overview and fuel economy. https://theicct.org/publication/fuel-cell-tractor-trailer-tech-fuel-jul22/

[34] GlobalData. 2022. Decarbonisation strategies and progress in mining, March 2022. Available on request

Whilst most mining companies have made their commitments to achieve net zero Scope 1 and 2 GHG emissions before 2050, notable leaders include De Beers and Fortescue which have committed to 2030 and Anglo American, Sibanye Stillwater and The Mosaic Company committing to 2040, as seen in Figure 9 .

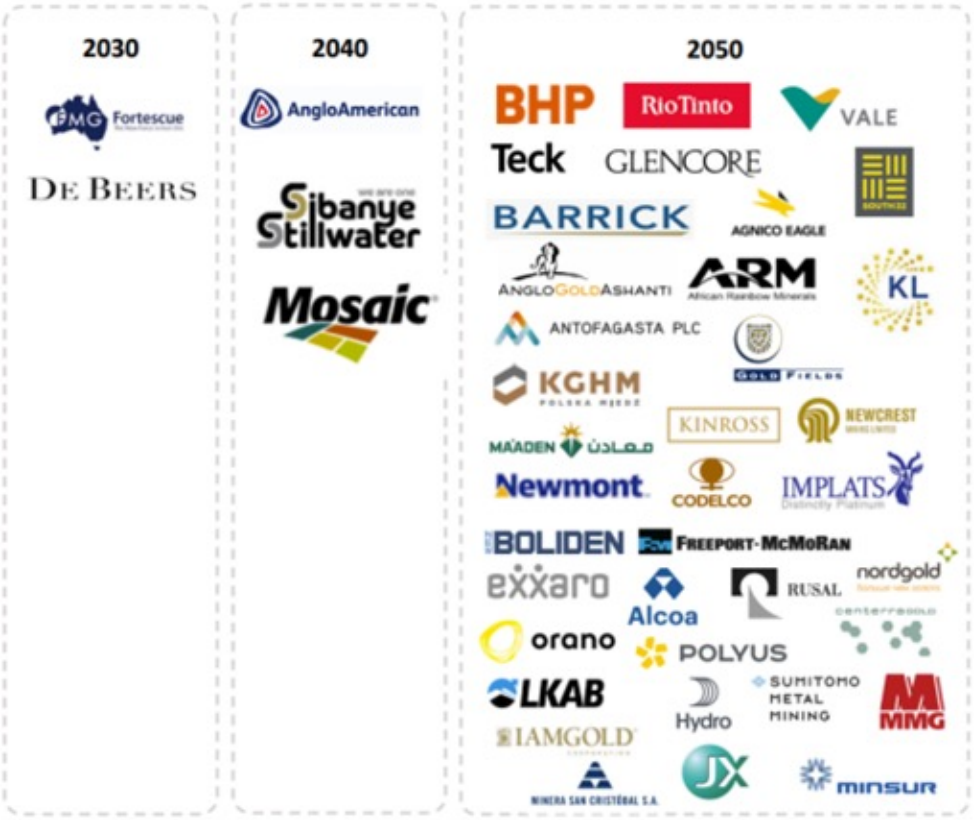


Figure 9: Major global mining companies and phasing-in of carbon commitments[35]

Typically, the short-term activities to support this transition are a combination of increasing the use of renewable power (either through on-site generation or power purchase agreements) as well as a reduction in the use of diesel fuel and increased adoption of BEVs and FCEVs for mining vehicles. The challenge for South African mines, is that about 80% of power generated in the country comes from coal sources, estimated at 176.6 TWh per annum[36].

While there's a noticeable global shift from diesel-powered mining vehicles to BEVs, mining companies must also transition to renewable energy sources to charge their BEVs and achieve their net zero emission targets. Encouragingly, within the South African mining sector, there's a rising inclination towards investing in solar power plants for electricity generation. This shift is presented in Figure 10. Examples of this are: Sibanye-Stillwater – 175 MW solar farms across three locations, Seriti Resources – 155 MW wind farm in Mpumalanga, Anglo American Platinum – 100 MW solar farm in Limpopo and Harmony Gold – 30MW solar farm in Free State.

[35] GlobalData. 2022. Decarbonisation strategies and progress in mining, March 2022. Available on request
[36] CSIR. 2023. Statistics of utility-scale power generation in South Africa. https://www.csir.co.za/sites/default/files/Documents/Statistics%20of%20power%20in%20SA%202022-CSIR-%5BFINAL%5D.pdf

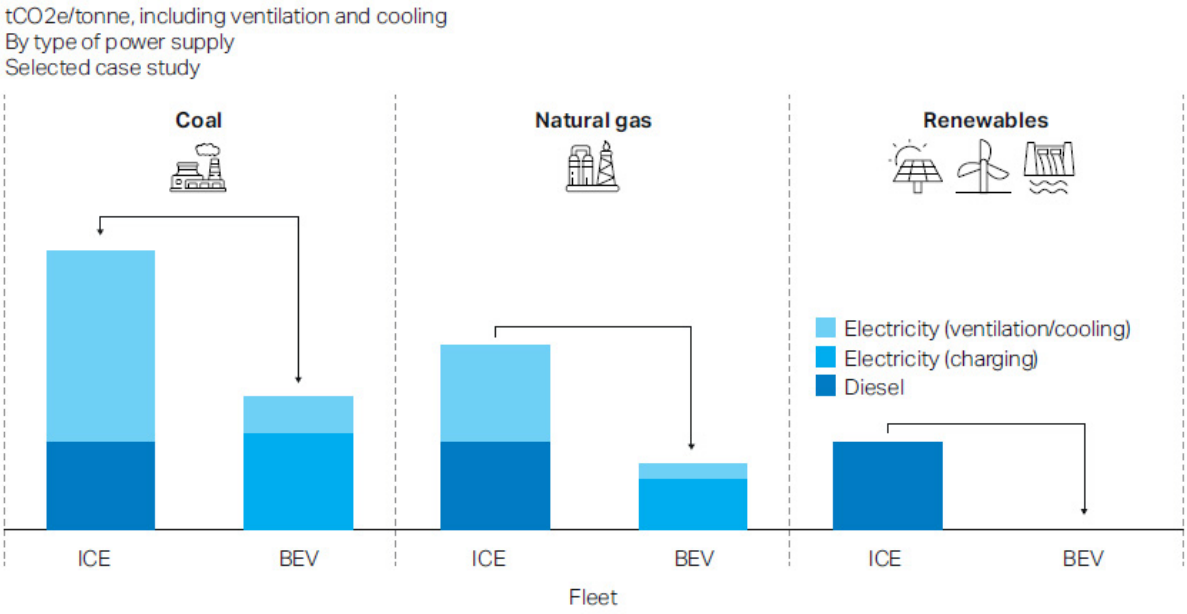


Figure 10: Mining Emission Intensity by Power Supply Type[37]

2.1.7 Current Trends

The global mining sector is increasingly prioritising the shift toward achieving net zero emissions. Surface mines primarily rely on truck and shovel operations for transportation, with mining dump trucks constituting a significant portion of equipment fleets. These trucks are primarily tasked with transporting broken rock from one point to another, with distances varying widely between different mines. Consequently, the ratio of dump trucks to shovels/loaders also varies significantly. Shovels, typically stationed strategically around areas of broken rock, are predominantly stationary.

Given the relatively low proportion of shovels compared to dump trucks, their stationary nature and the operational hours of mines, the widespread trend of converting shovels to battery electric vehicles (BEVs) is not currently feasible. Nevertheless, electric-powered shovels connected to power grids are increasingly common in surface mining operations worldwide. Overall, the adoption of electric-powered shovels in surface mines represents a significant step towards achieving sustainability goals while simultaneously improving operational efficiency, safety and environmental stewardship in the mining industry. As technology continues to advance, electric-powered equipment is expected to play an increasingly vital role in shaping the future of mining.

Table 6 below shows the current NEV adoption trends in the mining industry across the world.

[37] Sandvik, Power at the End of the Tunnel: Electrifying Underground Mining (2023)

Table 6: Examples of global mining equipment projects associated with a net zero transition

Country	Tech	Partners	Description	No. of Vehicles	Timeline
Chile[38]	BEV	Mine: BHP (Escondida mine) Mobility partners: Caterpillar and Finning	BHP's full fleet of mining vehicles will be replaced with Caterpillar's low/zero-emission BEV powertrain trucks.	160 mining trucks	End-2023
Sweden and Finland[39]	BEV	Mine: Bolidan (Sweden - Aitik mine) and (Finland – Kevitsa mine) Mobility partners: Caterpillar and Komatsu	Bolidan's fleet of trolley-assisted haul trucks will be substituting diesel power with electricity from overhead cables during the most demanding part of the truck work cycle	27 trolley-assisted haul trucks	End-2023
Australia and USA[40]	BEV	Mine: Newmont (Australia – Tanami mine) and USA (Cripple Creek and Victor mines) Mobility partner: Caterpillar	Newmont is investing US$ 100 million in acquiring BEVs for surface and underground mining	26 mining trucks	End-2026
Canada[41]	BEV	Mine: Teck (Elk Valley mine) Mobility partner: Caterpillar	Teck will deploy BEV mining trucks, which will be powered by a 95% clean electricity grid	30 mining trucks	2027
Canada[42]	BEV	Mine: Glencore (Sudbury Integrated Nickel Operations) Mobility partner: Epiroc	Glencore will acquire an all-electric fleet for the Onaping Depth Project, which will be one of the first fully electric mining fleets in the world	23 haul trucks and mobile equipment	2024
Australia	BEV	Mine: Rio Tinto (Gudai-Darri) Mobility partner: Caterpillar	Rio Tinto will develop a fleet of autonomous BEV trucks	35 mining trucks	Not disclosed

[38] BHP. 2022. BHP, Caterpillar and Finning announce an agreement to replace entire haul truck fleet at Escondida Mine in Chile
[39] International Mining. 2022. Boliden's trolley journey continues to evolve with Kevitsa line launch.
[40] Newmont. 2021. Newmont and Caterpillar Announce Revolutionary Strategic Alliance to Achieve Zero Emissions Mining.
[41] Teck. 2022. Teck And Caterpillar To Advance Zero-Emissions Mining Haul Trucks.
[42] Epiroc. 2022. Epiroc wins large battery-electric equipment order for new all-electric mine in Canada.

The synergy between the South African mining sector and FCEVs is a natural one due to platinum mining being required as a critical component for electrolysers and fuel cells; the position of South Africa as one of the top 10 gold suppliers in the world; as well as the prominence of diamond, copper and titanium mining.

The DSI (2021) suggests that due to intensive commitment from Anglo American to convert all their diesel-powered ultra-class mine haul trucks to green hydrogen, the prominence of mining truck FCEVs is expected to expand significantly by 2030. By 2040, it is expected that the Hydrogen Valley could have an expected mining truck fleet size composed of between 40% to 60% hydrogen FCEVs, as diesel and FCEV mining trucks also reach TCO parity by 2030, as seen in Figure 11 below.

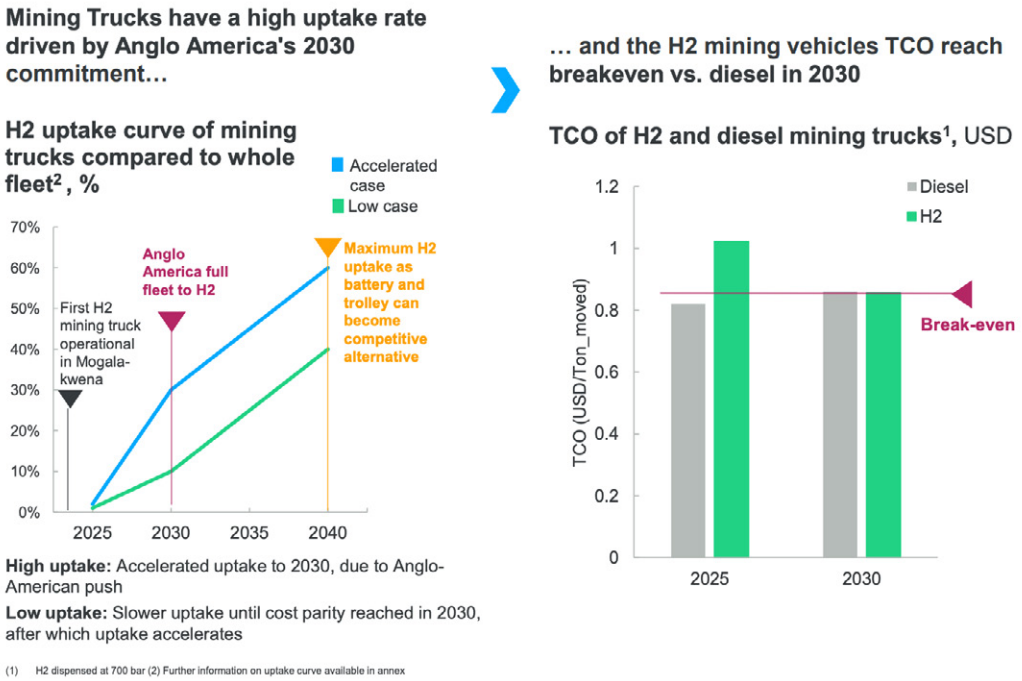


Figure 11: South African heavy-duty truck total cost of ownership – diesel versus FCEV; and FCEV uptake[43]

The integration of Battery Electric Vehicles (BEVs) into underground mining operations carries multifaceted implications. Within established mines, infrastructure has been intricately tailored to accommodate conventional mining methodologies and equipment. The transition to BEVs necessitates more than just considering the costs associated with acquiring new equipment and implementing charging systems. It requires a comprehensive revaluation of the mine layout and design to accommodate the installation of charging infrastructure or battery swapping stations. This redesign process involves optimising spatial arrangements to ensure efficient charging access while maintaining operational effectiveness and safety standards. Table 7 shows the total cost of ownership benefits between BEVs and ICE in an underground mine environment.

[43] Department of Science and Innovation (DSI). 2021. South African Hydrogen Valley Final Report. https://www.dst.gov.za/images/2021/Hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf

Table 7: Direct and Indirect Benefits/Costs for BEV vs ICE in an Underground Mine Environment[44]

		Direct benefits/costs	Indirect benefits/costs
Total Cost of Ownership BEV vs ICE	Production	- Lower cycle times: higher acceleration and speeds - Potential for higher availability due to fewer moving parts and less time in service	- Crew productivity gains from improved air quality, lower temperature, and noise levels
	Capital	- Opportunity to reduce fleet size through higher productivity (can also reduce congestion) - Higher capital costs for BEVs + batteries	- Mine development cost optimization - Reduced ventilation and cooling infra-structure - No need for diesel handling infrastructure - Electrical infrastructure upgrades
	Operating	- Mechanical routine and rebuild maintenance costs (parts and labor) given fewer moving parts - Lower maintenance labor costs with simpler driveline maintenance - No diesel costs - Regenerative braking recovers electrical energy - Electricity energy costs to charge batteries - Battery service costs - Battery charging infrastructure and technicians	- Reduced ventilation, cooling and heating energy requirements and operating costs (brownfields and greenfields) - No diesel logistics - Reduced carbon costs when applicable

Green refers to benefits of selecting BEV instead of ICE i.e., regarding productivity and maintenance.
Black refers to added costs of selecting BEV vs ICE i.e., battery charging infrastructure and capital investment of batteries.

Moreover, the introduction of BEVs prompts a reassessment of ventilation, power distribution and logistical workflows to support the seamless integration of electric mobility solutions. These adaptations reflect a broader paradigm shift towards sustainable and technologically advanced mining practices, underscoring the importance of strategic planning and investment in navigating the transition towards electrified mining operations. Some positive outcomes will be zero diesel emissions and less heat generation for underground BEVs, which ultimately will reduce the ventilation requirements for underground mine operations. An ICE fleet typically represents 30–50% of heat generation in an underground mine. Converting to an electric fleet will reduce heat emissions by up to 80–90%. Together with the reduction in air particle emissions, ventilation requirements can be substantially relaxed.[45] There will also be significant energy savings from lower ventilation requirements.

2.2 Forklifts

2.2.1 Global market[46]

The global forklift industry expects strong growth and increased competition to fuel forklift industry innovation and development, with the market expanding by 50% between 2022-32.

The global forklift market is seeing shipments catch up with orders as demand dips, but growth of 4-5% is still forecast out to 2032.

The global market share of Li-ion models is anticipated to surpass 50% in 2030.

[44] Sandvik, Power at the End of the Tunnel: Electrifying Underground Mining (2023)
[45] Sandvik, Power at the End of the Tunnel: Electrifying Underground Mining (2023)
[46] Interact Analysis – Forklift Market to be 50% bigger by 2032 (2023)

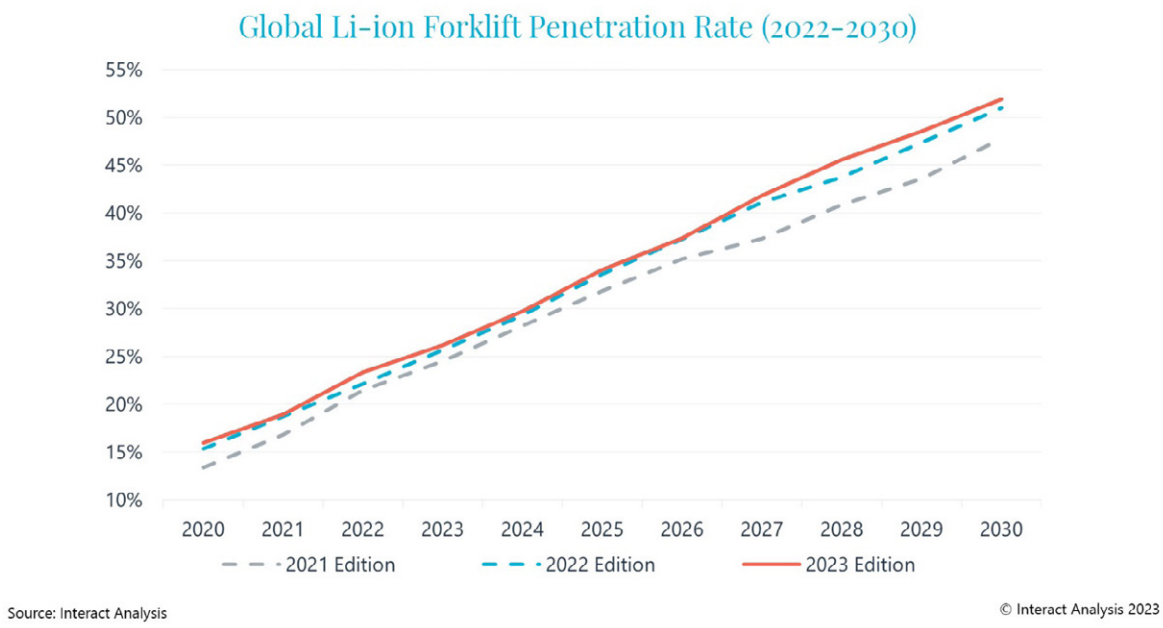


Figure 12: Global Electric Forklift Adoption for 2020-2030[47]

2.2.2 South African trends and development

South African lifting equipment market size is estimated to be at $207 million in 2022 and is expected to grow at a CAGR of 3% until 2026, as per Beroe's estimate. The forecasted market size in 2026 is expected to be $233 million. The manufacturing sectors such as Food & Beverage, Steel and Metal Working and Plastics are expected to drive the South African Forklift market during the forecasted period. Electric walk-in (Class I) warehouse forklift is the main type used in warehousing operations with a share of about 60%. Figure 13 below shows the capital cost comparison between ICE and BEV forklifts in South Africa.

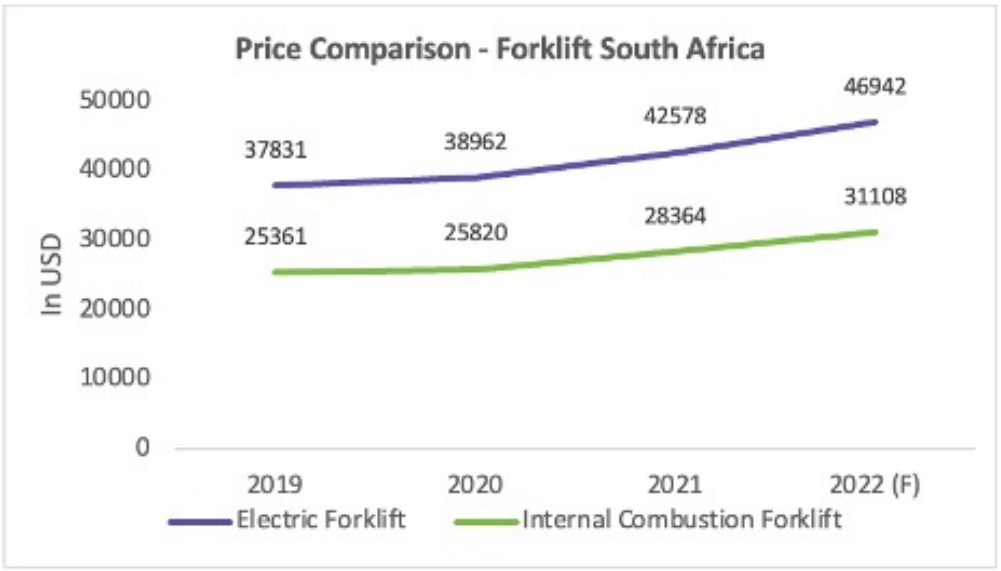


Figure 13: Price Comparison - EV vs ICE Forklifts in South Africa[48]

South Africa's industrial equipment and material handling industry recorded its largest markets in history, with 10,724 units imported into the country in 2021 and 9 828 units in 2022. This is in a market that historically averaged about 7 000 units a year. Between 2021 and 2022, we noted steady growth from

[47] Ibid
[48] Vignesh Venugopal, Inflation trends on Forklift Equipment and Forklift Maintenance Services- South Africa (2022)

45% to 57% in electric versus IC orders. This increase in the market shows that businesses are utilising and maximising their operational space to the fullest.

National sales manager for Toyota Material Handling, Vuyokazi Bangazi, says greater demand for electric, counterbalance and electric low- and high-level warehouse equipment has shown the country is moving towards electric, warehousing and high stacking, most likely due to the increased cost of space.

Lithium-ion battery-powered electric forklifts offer the South African warehouse industry the opportunity to enjoy the benefits of electric forklifts without concerning themselves with energy efficiency. The fast-charging lithium-ion batteries ensure that your electric forklift charges from 0%-50% in about 30 minutes, with a full charge taking as little as two hours and lasting up to eight hours. These energy-dense batteries charge faster and withstand longer load cycles while constantly maximising power precision and ensuring reliability and safety.

SITS[49] is the first South African-based Forklift Assembly Plant that will manufacture (assemble) 100% of all forklifts within the country, with clients based in South Africa as well as southern Africa, SADC (export market).

- Manufacturing of forklift components – SITS manufactures a variety of forklift components including cabs, carriages, forks, overhead guards, counterweights and other essential forklift components. Parts to manufacture these components are all sourced locally, tested and approved by all relevant bureaus of standards.
- Assembling of diesel forklifts
- Assembling of electric / battery forklift

2.3 Agriculture

2.3.1 Global performance

Agricultural vehicles and equipment are a niche transport equipment market and are dominated by tractors. The DOE (2021)[50] estimates that there has been growth in the global market, which was estimated to be worth US$ 41.5 billion in 2020 and is forecast to reach US$ 50.5 billion by 2025. The market is dominated by ICE vehicles with some developments in fuel-swopping to biofuels and methane. The DOE (2021) notes that there are currently no FCEV tractors available for commercial purchase and the handful in existence are retrofitted for research and development.

Globally, the power source of combine harvesters used is mainly internal combustion engines such as diesel engines. There is little global adoption in the conversion to battery electric combine harvesters.

New vehicle sales in the agricultural environment are driven by crop yields and commodity prices. It is evident in the tractor new vehicle sales that the market in South Africa is buoyant, as opposed to the steep incline in combine harvester sales, as shown in Figure 14 below.

[49] https://sitsgroup.co.za/
[50] US Department of Energy (DoE). 2021. Hydrogen fuel cells in farm equipment: Market research study. https://science.osti.gov/-/media/sbir/pdf/Market-Research/HFCT---Hydrogen-Fuel-Cells-in-Farm-Equipment-June-2021-Public.pdf

Tractor Sales	
2020	6042
2021	7868
2022	9175
2023	8374

Combine Harvesters	
2020	187
2021	270
2022	373
2023	505

Figure 14: New Vehicle Sales for Tractors and Combine Harvesters in South Africa[51]

Figure 15 provides an indication of the number of tractors on US farms and the split across power segments. Whilst the American tractor 'vehicle parc' is relatively large, at over 4 million tractors in 2017, it must be noted that all these tractors are diesel-powered.

Tractor Horsepower Segment	Number of Tractors on U.S. Farms (2017)
Less than 40 horsepower	995,918 tractors
40-99 horsepower	1,795,589 tractors
100 horsepower	1,246,592 tractors
Total number of tractors	**4,038,099 tractors**

Figure 15: Number of tractors on US farms, per horsepower segment.[52]

2.3.2 Global best practice

Whilst data on the carbon emissions stemming from the burning of fossil fuels for agricultural transport is limited in South Africa, in Europe, CEMA(2022)[53] estimates that fossil fuel combustion specifically for agricultural and forestry transportation, accounts for roughly 1% of total European GHG emissions. 'Greening' of agricultural transport is difficult as both BEV and HCEV solutions increase the weight of the vehicles significantly and reduce the range and cooling efficiencies of NEVs. CEMA (2022) notes that even though the weight and volume of hydrogen storage systems are often lower than BEVs, both BEVs and FCEVs have a lower range compared with diesel-powered ICE vehicles. Additionally, farms are traditionally in outlying areas and the challenges with hydrogen storage and logistics present a significant barrier to adoption. CEMA (2022) suggests that agricultural transport equipment is often better predisposed to biogas and methane conversions for ICE vehicles, as these alternate fuels can often be generated on-site.

Table 8 and Table 9 discusses examples of countries transitioning to net-zero agricultural equipment.

[51] South African Agricultural Machinery Association
[52] US Department of Energy (DoE). 2021. Hydrogen fuel cells in farm equipment: Market research study. https://science.osti.gov/-/media/sbir/pdf/Market-Research/HFCT---Hydrogen-Fuel-Cells-in-Farm-Equipment-June-2021-Public.pdf
[53] CEMA. 2022. The role of agricultural machinery in decarbonising agriculture. https://www.cema-agri.org/publications/17-position-papers-publications/916-the-role-of-agricultural-machinery-in-decarbonising-agriculture

Table 8: Global examples of countries transitioning to net zero agricultural equipment

Country	Tech	Partners	Description	No. of Vehicles	Timeline
USA[54]	BEV	OEM: Monarch Tractors Agriculture partner: Constellation Brands (wine and spirits)	Monarch Tractors, at their manufacturing facility in California, manufactures fully electric, driver-optional tractors. If charged with 'clean' electricity, the tractors are zero-emissions vehicles. The tractor is a multi-functional vehicle, which serves as a tractor, utility vehicle and electric generator when in the field.	6	2022
Australia[55]	BEV	OEM: John Deere Mobility partner: Kreisel Electric	John Deere, after acquiring majority ownership of Kreisel Electric to accelerate the adoption of BEV technology, will bring the first BEV tractor to Australia for prototype testing on Australian farms. This project is supported by John Deere's recent investment in a battery manufacturing facility in North Carolina, USA.	Not disclosed	2026
Germany[56]	BEV	OEM: Fendt	To research the usability and performance of hydrogen in the agricultural sector, Fendt will test hydrogen-powered prototype tractors in real-world farm environments.	2	The trial commenced April 2023

[54] Future Farming. 2022. Series production of Monarch MK-V electric, driver-optional tractors started.
[55] Afgri Equipment Australia. 2023. John Deere has announced the first battery-powered electric tractor will be launched in Australia in 2026, labelling the announcement a 'monumental shift' in primary production.
[56] Green Car Congress. 2023. Fendt shows prototype hydrogen tractor at German Hydrogen Summit.

Table 9: Case study: India's transition to electric tractors

Case study: India's electric tractors[57]

Prevailing context

India is a leading global tractor manufacturer, having produced nearly 1 000 000 tractors in 2021, of which 125 000 were exported. As the bulk were utilised domestically, they play a significant role in contributing to India's GHG emissions, as they utilise about 60% of India's total agricultural fuel.

Many of India's tractor manufacturers have begun manufacturing zero emissions tractors, with Sonalika launching India's first electric tractor in 2020, with Escorts, Celestial and KAMCO all planning to launch BEV tractors shortly.

Total cost of ownership (TCO) comparison

Assuming a 10-year ownership of both the electric and diesel tractors and assuming both require a 20% down-payment on purchasing, Shao and Anup (2022) find that the TCO of electric and diesel tractors are almost comparable (with the diesel tractor costing 30.2 INR Lakh and the electric tractor costing INR 31.1 Lakh. For both tractors, the fuel remains the largest cost component, whilst the tractor purchasing and financing costs are also notable for both tractors, with the electric tractors being significantly higher. The authors find that this high vehicle purchasing and finance cost associated with the BEV tractor may be negated if the electricity costs are assumed to be on the upper bound.

Policy and incentive suggestions

The authors suggest a basket of policy and incentive support suggestions which can be used to drive the adoption of electric tractors:

1. **Central government-funded upfront purchase incentives**
   - In 2015, the Indian government launched the Faster Adoption and Manufacturing of Electric and Hybrid (FAME) scheme to disincentivise the use of ICE vehicles and promote the development of NEVs. At present, the scheme offers a subsidy based on the size of the battery capacity (INR 15 000/kWh) or up to 40% of the total cost of the vehicle.
   - At present, the FAME scheme does not apply to agricultural vehicles, but the authors suggest that its extension to this sector is fiscally prudent.
2. **Reduction in VAT/GST**
   - Tractors in India are currently subjected to 12% Goods and Services Tax (GST) – a successor to VAT. The authors suggest a reduction from 12% to 5% which could support the electric tractor reaching price parity with the BEV tractor.
3. **Reduction in electricity tariffs for the agricultural sector**
   - India has historically subsidised electricity tariffs for the agricultural sector – initially in the 1960s to promote the use of irrigation. It is suggested that discounted tariffs be applied, to reduce the TCO of BEV tractors.

[57] Shao, Z. and Anup, S. 2022. Incentives for electrifying agricultural tractors in India.

2.3.3 Technology development

In November 2023, MAN Engines launched a hydrogen combustion engine, specifically for off-road applications in agriculture. The new MAN H4576 is based on the engine base for the D3876 diesel engine, with an output of 368 kW. Building the hydrogen engine in line with the existing diesel engine, allows MAN to use nearly 80% of the same components (including crankshaft, crankcase, connecting rods and cooling circuits) across both engine types. The similar componentry allows assemblers to integrate them more easily into the final assembly. Although the hydrogen engine is yet to be commercialised, a key advantage of the MAN H4576 is that it may still be run off traditional diesel, if required.[58]

On 20th November 2023, Caterpillar announced the launch of a multi-year programme to demonstrate a hybrid-hydrogen power solution developed on the new Cat® C13D engine platform. The engine is suited to agricultural vehicles such as tractors and harvesters due to their unique duty cycles and lifetime demands. Caterpillar expects that the hybrid-hydrogen engine will meet and possibly exceed the power density and transient performance of existing diesel engines. The project which kick-off in 2024, with support of the US Department of Energy and Office of Energy Efficiency and Renewable Energy, will see Caterpillar hone the functionality of the Cat® C13D's engine platform which will offer eight power ratings (between 340 and 515 kW) and which will provide up to 20% more power than diesel engines in the same power class. It is expected that OEMs will be able to commence pilot deployment in 2025 and series production will commence in 2026[59].

2.4 Electrification of machinery and equipment: Case studies for Africa

There have been several NEV-related developments in Africa in recent years, with significant developments in the policy sphere.

2.4.1 Case study: Kenya (Trucks)

Ronn, currently a global HCV FCEV solutions provider has announced its ambitions to support truck FCEV applications due to the segment's unique requirements including re-fuel time constraints, range extension and large payload and cargo volume sizes. In May 2023, it was announced that Ronn will collaborate with the Nairobi Group to launch a pilot FCEV delivery truck programme, which will be supported by the establishment of a hydrogen refuel hub. The programme will be one of the first in Africa to focus on both mobile and stationary hydrogen solutions.[60]

The first phase of the project, expected to kick off in the first quarter of 2024 will include the deployment of up to 6 FCEV trucks, which will be followed by additional strategic purchases by municipalities and fleet operators in Nairobi and the rest of Kenya.

The programme which will operate under a MoU between private and public sector stakeholders, will involve unlocking specific incentives for land acquisition, tax rebates and additional support to minimise "red tape".

[58] Hydrogen Central (MAN Engines). 2023. MAN Engines presents groundbreaking hydrogen combustion engine for off-road applications. https://hydrogen-central.com/man-engines-presents-groundbreaking-hydrogen-combustion-engine-for-off-road-applications/

[59] Caterpillar. 2023. Caterpillar to Develop Hydrogen-Hybrid Power Solution for Off-Highway Vehicles. https://www.cat.com/en_US/news/engine-press-releases/caterpillar-to-develop-hydrogen-hybrid-power-solution-for-off-highway-vehicles.html

[60] Hydrogen Central (Ronn). 2023. Ronn, Inc begins formal discussions with a Nairobi Group for a hydrogen electric delivery truck pilot program and potential hydrogen hub in support of the New Africa Hydrogen Alliance. https://hydrogen-central.com/ronn-inc-begins-formal-discussions-nairobi-group-hydrogen-electric-delivery-truck-pilot-program-and-potential-hydrogen-hub-in-support-of-the-new-africa-hydrogen-alliance/

2.4.2 Case study: South Africa (Mining)

Anglo American in South Africa is leading the transition in terms of utilising FCEV mining equipment. The company is an active participant in the Hydrogen Valley project and in May 2022 launched the world's largest hydrogen-powered mine truck for its Mogalakwena PGM in Limpopo[61]. The project forms part of Anglo's nuGen™ Zero Emission Haulage Solution (ZEHS) – "a fully integrated green hydrogen system, consisting of production, fuelling and haulage system, with green hydrogen to be produced at the mine site" (Anglo American, 2022).

Anglo American estimates that emissions from diesel-powered mining vehicles are responsible for up to 15% of the organisation's total Scope 1 emissions and were a priority area to consider if they are to meet their 2040 carbon neutrality target. It is expected that if their current fleet of diesel-powered vehicles could be converted or replaced with green hydrogen, it could reduce their diesel emissions by up to 80% (Anglo American, 2022). Table 10 refers to a case study on Anglo American's nuGen Zero Emission Haulage Solution.

[61] Anglo American. 2022. Anglo American unveils a prototype of the world's largest hydrogen-powered mine haul truck - a vital step towards reducing carbon emissions over time. https://www.angloamerican.com/media/press-releases/2022/06-05-2022

Table 10: Case Study: Anglo American nuGen Zero Emission Haulage Solution

Case study: Anglo American nuGen™ Zero Emission Haulage Solution[62]

Overview:

The nuGen™ Zero Emission Haulage Solution is a hydrogen-powered ultra-class mine haul truck – a 220t truck with a load capacity of 290t = a total laden weight of 510t, which has been converted to run on hydrogen, that will be produced on-site in hybrid combination with a battery.

Project details:

- The hydrogen FCEV truck will be retrofitted from an ICE diesel-powered truck, with hydrogen providing half the fuel requirements and the onboard battery (re-charged from regenerative braking from travelling downhill) providing the other half.
- The 2-megawatt hybrid battery/hydrogen fuel cell powerplant replaces the diesel engine and has been designed by Anglo American and their mobility partner, First Mode.
- Management of the power and energy exchanges between the fuel cells, batteries and vehicle drivetrain will be supported by a specific software solution, designed and implemented by Anglo American.

Supporting infrastructure:

- To improve e-fuelling efficiencies and in line with the recommendations of the Hydogren Valley (2021) feasibility study, Anglo American has built a hydrogen 'complex' at Mogalakwena/Limpopo which supports hydrogen production, storage and re-fuelling.
- This complex houses the largest electrolyser in Africa and is supported by renewable energy via a solar PV installation.

Key advantages:

- As hydrogen from the fuel tank enters the fuel cell, it combines with oxygen through a chemical reaction, which is catalysed by platinum. This reaction generates electricity which powers the vehicle's motor and batteries and the only emission created through this process is water vapour.
- The energy derived from regenerative braking extends the range of the vehicle and increases the proportion of operational time (in a BEV, significant reductions in operational times are experienced as the vehicle is 'offline' to re-charge)
- The purpose-built software solution will ensure the safe transmission and monitoring of power and energy exchanges.

Proof of concept:

- After a year of operational trials, several favourable outcomes were achieved. The vehicle was introduced into the fleet alongside diesel vehicles and following operator training, logged a total of 1 245 hours and consistently delivered a peak power output of two megawatts.
- In terms of parity with diesel vehicles, the vehicle achieved a full payload capacity of 300 tonnes during pit runs and increased efficiency allowed for high operational speeds with the same power, indicating performance parity with diesel vehicles.

[62] Anglo American. 2022. Anglo American unveils a prototype of the world's largest hydrogen-powered mine haul truck - a vital step towards reducing carbon emissions over time. https://www.angloamerican.com/media/press-releases/2022/06-05-2022

2.4.3 Case study: Rwanda (Agricultural tractors)

Following VW's launch of an electric tractor at its Wolfsburg plant, the e-Tractor was launched in November 2021 in Rwanda. Through collaboration with the University of Rwanda and Deutsche Gesellschaft Für Internationale Zusammenarbeit (GIZ) GmbH and VW, a trial was completed in September 2022, to confirm the feasibility of the equipment for local conditions. The long-term objective of the project is to replace diesel-powered ICE tractors, with electric tractors that contain 'swappable' batteries, which will allow the tractors to operate continuously.

In July 2023, a memorandum of understanding (MoU) was signed by the Rwandan Agriculture and Animal Resources Ministry; Volkswagen Mobility Solutions Rwanda; and Volkswagen Group South Africa (VWSA). As part of the MoU, the government of Rwanda has agreed to provide land for the project, as well as to assist with the permitting and licensing requirements of the project, while VW will support the roll-out of electric tractors.

To overcome the TCO challenges often incurred when pivoting to NEVs, the electric tractors in Rwanda will be purchased by communities, rather than individual farmers and will be managed co-operatively. Through a 'share scheme' farmers can block book the use of the tractor, which is shared amongst several farms in an area.

2.5 Further Opportunities

2.5.1 Trucks

Table 11: FCEV heavy-duty trucks operating between Johannesburg and Durban[63]

Project detail	Rationale	Estimated costs[64]	Required LCOH for breakeven
• Replacement of diesel ICE heavy-duty trucks, with operate on the N3 between Johannesburg and Durban, with green hydrogen FCEV trucks • Core project components include: – 100 FCEV heavy-duty trucks – 4 re-fuel stations (2 in DBN; 2 in JHB) – 2 17 MW electrolysers to be installed in DBN and JB (2kTon H2/year) – 4 tube trailers to transport hydrogen from the electrolyser to re-fuel stations	Hydrogen-powered heavy-duty trucks will become cost-competitive with ICE alternatives soon and offer several benefits: • Lower maintenance costs compared to ICE trucks • The FCEV battery system is more efficient than the ICE system • Regenerative braking allows the battery to re-charge	• R 591,6 million for hydrogen FCEV heavy-duty trucks • R 1,27 billion for hydrogen infrastructure	

[63] Department of Science and Innovation (DSI). 2021. South African Hydrogen Valley Final Report. https://www.dst.gov.za/images/2021/Hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf
[64] Estimated costs are calculated by utilising the average 2021 USUS$ /Rand exchange rate of R 14,79

Existing initiatives	Potential partners/collaborators	How does this project support a Just Transition?
• Rhynbow project of Anglo American, Bambili Energy and ENGIE aiming for 50 hydrogen city buses by 2025 • Toyota South Africa Motors and SASOL form a green hydrogen mobility partnership	Truck producers: Hyzon, Toyota, Hyundai, Daimler Logistics companies: Imperial Logistics, Transnet, CHEP, Interlogix	• Direct job creation within electrolyser plant/s and re-fuelling stations • Development of expertise on hydrogen and possible production of hydrogen trucks within South Africa • Hydrogen re-fuelling stations can kickstart other hydrogen mobility solutions (vans, pickups, taxis, etc.) and become the backbone of South Africa's hydrogen infrastructure • Employment creation

2.5.2 Mining

Table 12: FCEV mining trucks for open pit copper/PGM/diamond mines[65]

Project detail	Rationale	Estimated costs[66]	Required LCOH for breakeven
• Mining houses to replace the fleet of diesel mining trucks with hydrogen FCEV mining trucks – those with a payload larger than 200 tonnes for select mine types: open pit mining; PGM and diamonds • As demand for hydrogen will be significant, on-site green hydrogen production to be utilised • Core project components include: – 10 to 50 FCEV trucks for application in open pit mines (powertrain of 2MW) – 30 to 160 MW on-site electrolysers to be installed (2 to 10kTon H2/year) – 60 to 320 MW solar farms to provide green H2.	Mining trucks powered by green hydrogen will become cost-competitive with ICE alternatives soon and offer several benefits: • Lower maintenance costs compared to ICE mining trucks • The FCEV battery system is more efficient than the ICE system • Regenerative braking allows the battery to re-charge whilst moving in the mine pit • Mining trucks are required to operate 24/7 so BEVs are often not suitable due to the long charge times required during operational hours	• R 961 million for mining trucks • R 1,14 million for hydrogen infrastructure *2021 US$ estimate	

[65] Department of Science and Innovation (DSI). 2021. South African Hydrogen Valley Final Report. https://www.dst.gov.za/images/2021/Hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf
[66] Average 2021 US$ /Rand exchange rate of R 14,79

Existing initiatives	Potential partners/collaborators	How does this project support a Just Transition?
• Anglo American has initiated a pilot in 2021 in Mogalakwena, by building the world's first hydrogen mining truck • Anglo American projecting to switch their entire mine truck fleet to hydrogen by 2030 • Liebherr announcing green mining truck program	Truck producers: Komatsu, Caterpillar and Liebherr Mining companies: Anglo American, Sibanye Glencore, Ivanhoe, Impala, De Beers, etc.	• Many mining houses have committed to comprehensive decarbonisation targets, with many aiming to achieve net zero between 2040 and 2050 • With mining trucks being significant emitters of carbon, the switch to green hydrogen will support South Africa in becoming a provider of green minerals • Flagship mining projects may kick-start smaller regional hydrogen projects • Employment creation

2.5.3 Agriculture

Table 13: FCEV agricultural vehicles for operation on commercial farms along the Johannesburg and Durban hydrogen corridor[67]

Project detail	Rationale	Estimated costs[68]	LCOH
• De-carbonising current agricultural diesel machinery (tractors, reach stackers, etc.) by retrofitting to hydrogen-diesel dual combustion engines • Core project components include: – 20 tractors and 20 reach stackers – 1 re-fuel station – 1,5 MW electrolyser to be installed (0,2 KTon H2/Year) – 1 tube trailer to transport hydrogen from electrolyser to re-fuel station	Retrofitting current ICE agricultural machinery will become cost-competitive soon and offers several benefits: • Retrofitting allows a portion of emissions to be mitigated, at a relatively lower investment cost (more suitable over a small volume of vehicles) • Lower maintenance costs compared to pure ICE • Whilst the full efficiency of a hydrogen transition is not realised, the lower investment requirement should encourage more rapid adoption	• R 33 million for tractors/reach stackers, etc. • R 73 million for hydrogen infrastructure	

Existing initiatives	Potential partners/collaborators	How does this project support a Just Transition?
• None locally	Hydrogen dual-fuel retrofit: Ulemco, Alset, etc. Farms: Large commercial farms to be identified (preferred location: across the Hydrogen Valley spatial priorities)	• Large commercial farms will become hydrogen hubs within the Hydrogen Valley and this project can kickstart hydrogen acceptance with the first hydrogen production project • Employment creation

[67] Department of Science and Innovation (DSI). 2021. South African Hydrogen Valley Final Report. https://www.dst.gov.za/images/2021/Hydrogen_Valley_Feasibility_Study_Report_Final_Version.pdf
[68] Average 2021 US$ /Rand exchange rate of R 14,79

2.6 Identification of role players and stakeholders

It is important to understand the developments in the regional behaviour of OEMs in terms of their increased presence per region, plus the number of new NEV models which they introduce – this provides a useful indicator of their future market development plans and provides visualisation of their priority markets.

The total availability of zero-emission medium and heavy-duty vehicles has increased from 621 models in 2021 to 856 models in 2023 (a total increase of 38%). While electric buses remain the dominant vehicle category, zero-emission heavy-duty truck models have doubled between 2021 and 2023, with nearly 50 OEMs introducing new truck models[69].

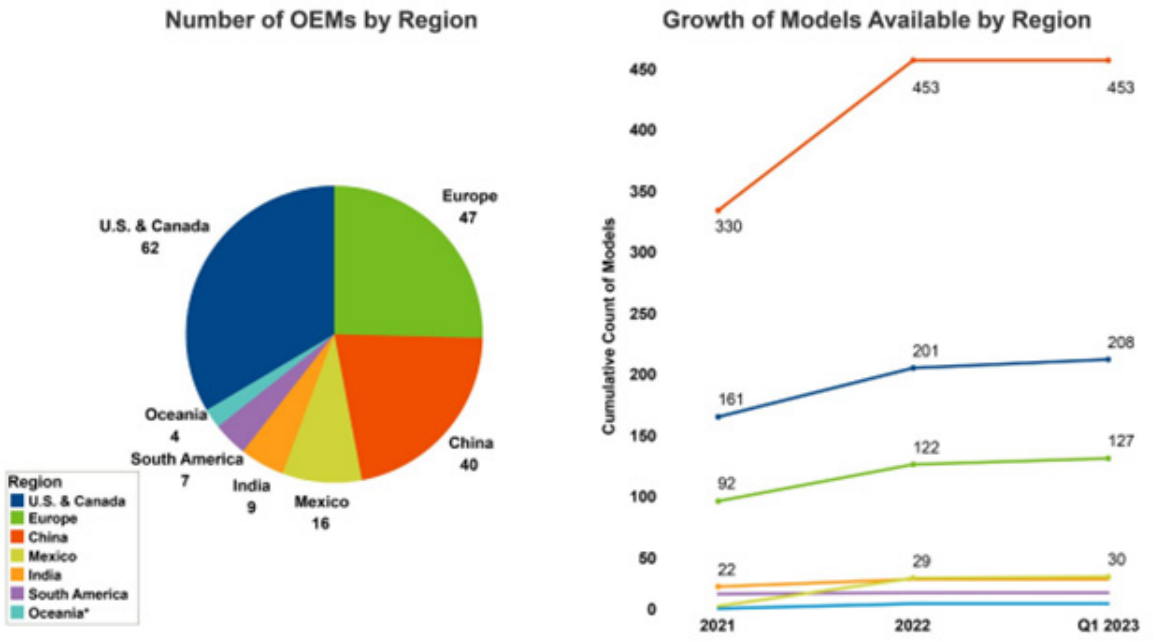


Figure 16: Global MCV and HCV zero emissions vehicle OEMs and models per region (2021 to Q1 2023).[70]

****Oceania includes only Australia and New Zealand***

The Global Drive to Zero (2023) reports that 59 new zero-emission medium and heavy-duty vehicles have been introduced since Q4 of 2022. In terms of heavy-duty vehicles, this includes seven heavy-duty trucks and 27 buses. 147 individual OEMs are operating in this sector across the US, Canada, Europe China, Mexico, India and South America. Whilst the US and Canada alone represent 62 'active' OEMs, China represents 40 OEMs with a greater number of models available, illustrated in Figure 16. A key development from emerging markets is found in Mexico, where; in 2021 only five OEMs and five models were recorded in 2021. By the end of Q1 2023, Mexico has recorded 16 OEMs and 30 available zero-emission medium and heavy-duty vehicles (Global Drive to Zero, 2023)[71].

[69] Global Drive to Zero. 2023. Zero-emission truck and bus market update: June 2023. https://globaldrivetozero.org/site/wp-content/uploads/2023/06/Final_ZETI-Report-June-2023_Final.pdf
[70] Ibid
[71] Global Drive to Zero. 2023. Zero-emission truck and bus market update: June 2023. https://globaldrivetozero.org/site/wp-content/uploads/2023/06/Final_ZETI-Report-June-2023_Final.pdf

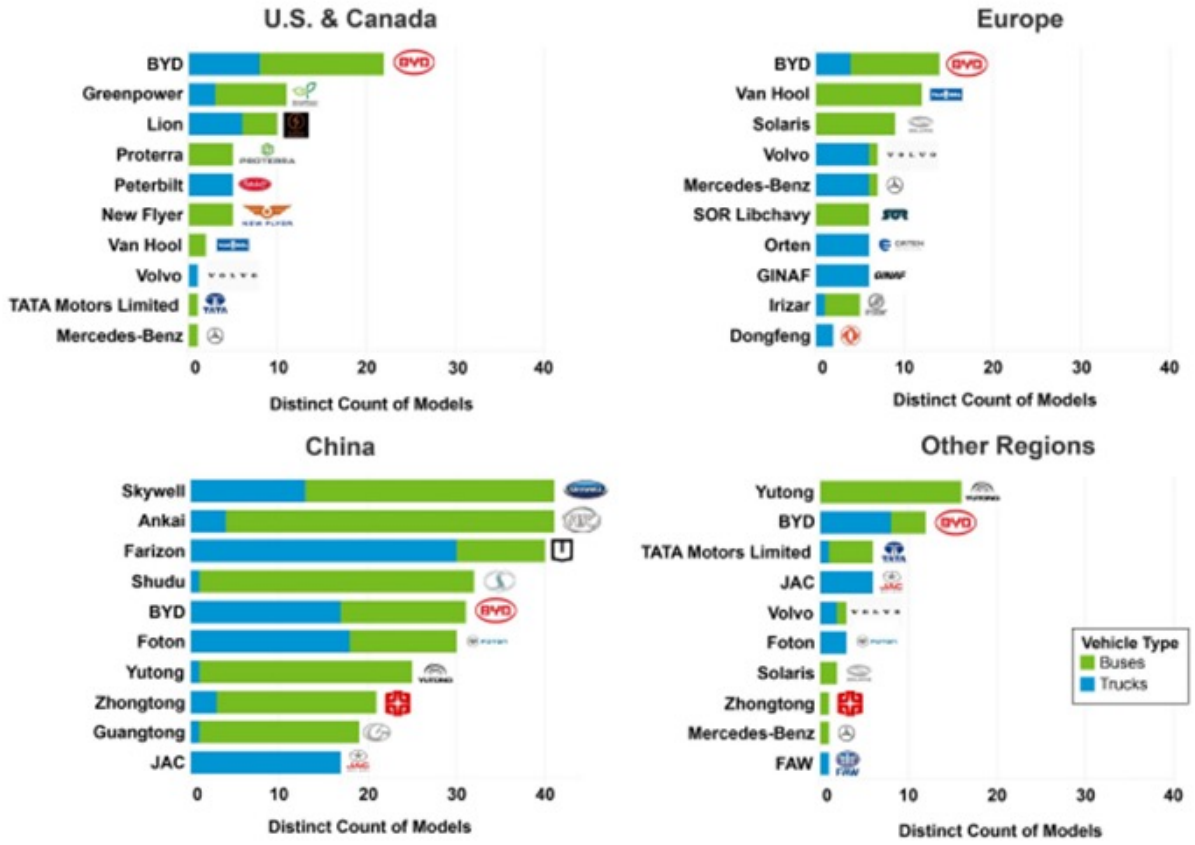


Figure 17: Top 10 Zero emission heavy-duty vehicle OEMs per region, Q1 2023.[72]

As seen in Figure 17, the Chinese domestic OEM, BYD is a significant role player in buses and trucks across multiple regions, having supplied 22 models to the US and Canada in 2023. In China, the largest players are Skywell and Ankai, cumulatively supplying 41 models.

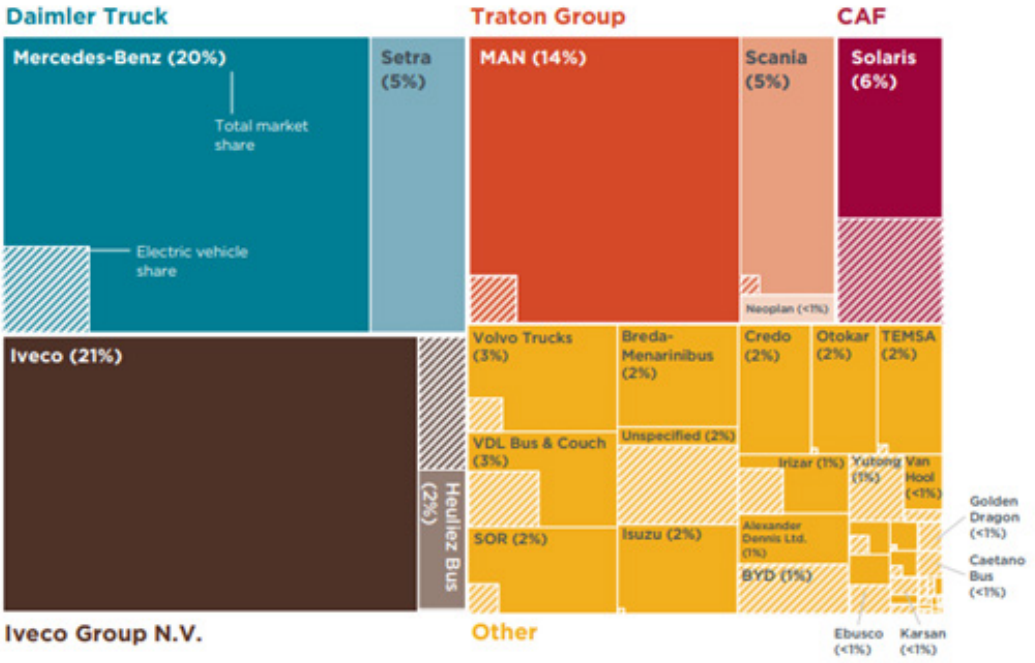


Figure 18: Market share of bus sales by OEM manufacturer in 2021 (Overall market share shown in brackets. Cross hatched areas represent a share of sales which are EVs).[73]

[72] Ibid
[73] International Council on Clean Transportation (ICCT). 2022. The rapid deployment of zero-emission buses in Europe. https://theicct.org/wp-content/uploads/2022/09/zero-emission-buses-europe-sept22.pdf

Bus sales globally are dominated by four OEM groups (parent companies) – Daimler Truck, Traton Group, Iveco N.V. and CAF - who combined were responsible for 75% of all bus sales in 2021[74], as seen in Figure 18 . These groups, whilst mostly legacy manufacturers of ICE vehicles, all have prominence in the EV space too. They have made the following commitments as shown in Table *14*.

Table 14: OEM bus manufacturers and their recent commitments to electric buses.[75]

OEM bus manufacturer	Electric bus commitment
Traton Group	MAN has committed that by 2025, half of their buses sold will include an electric drive train (this may include hybrid and FCEVs) Scania will ensure that at least 10% of their sales are EVs
Daimler Trucks	No further investments will be made for ICE buses to comply with the Euro VII emissions standards and will phase out ICE engines from city buses by 2030. The company will only offer battery or hydrogen bus technology.
Iveco	A range of fully electric buses will be introduced by 2024.

In terms of mining equipment, Figure 19 illustrates that yard tractors are an extremely small portion of zero emissions available – those included in this schematic, are all BEVs.

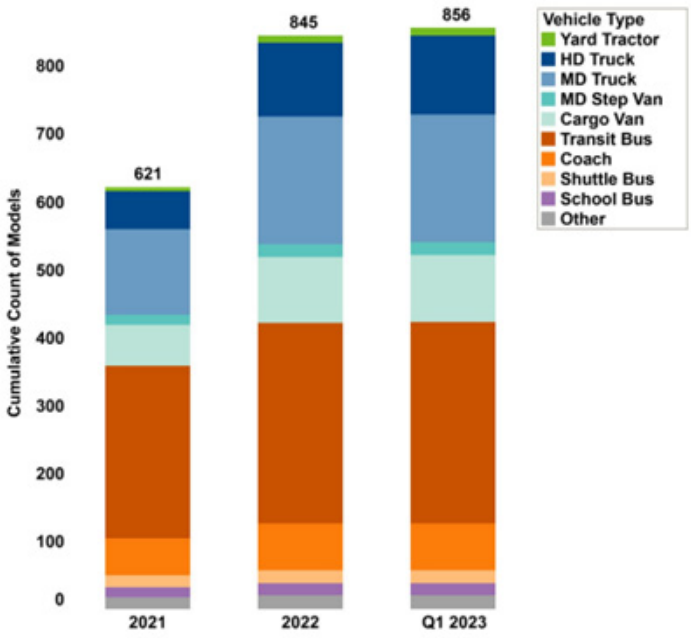


Figure 19: Global zero emissions vehicle model availability, per vehicle type (2021 to 2023)[76]

[74] Ibid
[75] Ibid
[76] Global Drive to Zero. 2023. Zero-emission truck and bus market update: June 2023. https://globaldrivetozero.org/site/wp-content/uploads/2023/06/Final_ZETI-Report-June-2023_Final.pdf

The global agricultural equipment market is dominated by tractors, with five key OEMs being responsible for nearly 80% of the total market share – John Deere; CNH; Kubota; AGCO; and Yanmar[77]. This is indicated in Figure 20 and Table 15 below:

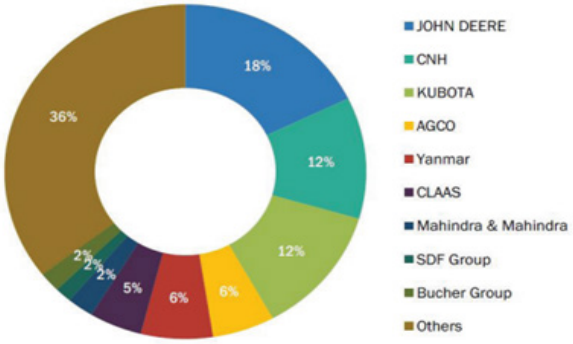


Figure 20: Global farm equipment market share analysis, by main OEM[78]

Table 15: Main agricultural tractor OEMs; their product offerings; and description of their NEV-related developments.[79]

OEM	Description	NEV developments
JOHN DEERE	• Large, medium and utility tractors • Tractor loaders • Combines • Cotton pickers and strippers • Harvesting front-end equipment	John Deere has expressed a greater interest in transitioning to fully electric agricultural equipment. In 2019, they announced the development of a fully electric, autonomous tractor using a cable connection on the field border to power the tractor.
CNH INDUSTRIAL	Represents Case IH and New Hollande agricultural brands and includes: • Traditional tractors • Crawler tractors • Hay and forage equipment • Soil preparation and cultivation equipment	Whilst Case IH focuses on improving engine efficiency for diesel-powered tractors, New Hollande has launched an FCEV tractor based on an existing tractor model. The tractor features two electric motors (one for the power train and one for traction) and has an operation time of up to two hours on one hydrogen tank re-fuel.
Kubota	• Tractors • Combine harvesters • Rice transplanters • Soil preparation implements	The company has committed to organisation-wide net carbon neutrality by 2050 and is developing several electric and hydrogen-powered versions of its agricultural equipment.

[77] US Department of Energy (DoE). 2021. Hydrogen fuel cells in farm equipment: Market research study. https://science.osti.gov/-/media/sbir/pdf/Market-Research/HFCT---Hydrogen-Fuel-Cells-in-Farm-Equipment-June-2021-Public.pdf
[78] IBID
[79] Ibid

OEM	Description	NEV developments
AGCO	• Tractors • Combine harvesters • Hay and forage equipment • Seeding and tillage implements • Grounds care	The company's strategy involves upgrading existing models to improve engine efficiencies to reduce emissions, whilst also investing in BEV technology. The company is piloting a BEV compact tractor which has an operational time of roughly five hours.
YANMAR	• Compact tractors • Diesel engines and generators • Gas heat pump energy storage systems	As the company specialises in compact tractors for small farms and has institutional knowledge of power generation, the approach to supporting NEVs is to support BEV compact tractors.

2.7 Regional and global partnerships

There are several existing global and regional partnerships to support specifically emerging markets, to accelerate the adoption of zero-emissions vehicles. Khan and Yang (2022)[80] highlight some key partnerships in Table *16*.

Table 16: Select examples of regional and global partnerships to support e-mobility transition.[81]

Partnership	Segment	Partners	Description
Zero Emission Bus Rapid-deployment Accelerator (ZEBRA)	Buses	Funding: Partnering for Green Growth and the Global Goals Supporting partners: C40 cities and the ICCT	A regional partnership for Latin American countries to support the adoption of EV buses in key cities. The partnership has secured commitments from **10 bus OEMs and distributors** to make EV buses available in Latin America. In 2021, ZEBRA secured US$ 1 billion to deploy EV buses and focus on the following work areas: • Through a regional working group, share best practices and technical skills amongst cities; • Secure commitments from bus OEMs and industry to support new technology development; • Support the procurement of 3600 EV buses in the region, through supporting fleet deployment strategies; and • Provide financial support to maintain a pipeline of active investment projects
United Nations Environment Programme's (UNEP) Global Electric Mobility Programme	Buses	Funding: Global Environment Facility (GEF) and the SOLUTIONSplus project Investment platform: UNEP	A programme to support 50 emerging and developing nations' transition to the adoption of zero-emission vehicles, with a core focus on driving the electrification of buses. Key objectives include: • Convene a global platform to support the development of EV technologies and a supportive policy framework; • Support capacity building and technical skills development The UNEP serves as an investment platform for this partnership to mobilise investment funding and drive coordination between OEMs, financial institutions and governments. To date, the UNEP has supported a clean bus fleet programme for 20 cities and has rolled out pilot projects for EV buses.

[80] Khan, T. and Yang, Z. 2022. Electrification of heavy-duty vehicles in emerging markets. https://theicct.org/wp-content/uploads/2022/09/global-hvs-evs-zev-electrif-hdv-emerg-mkts-sep22.pdf
[81] Ibid

Partnership	Segment	Partners	Description
GEF Electric Mobility Programme	Buses and trucks	Funding: European Bank for Reconstruction and Development and the Asian Development Bank Implementation: UNEP and the International Energy Agency	The partnership focuses on providing financial and technical support to 27 countries to support the increased deployment of zero-emission buses and trucks. Areas of support include: • The development of national e-mobility roadmaps, targets and enabling policy frameworks; and • The development of business models and financial mechanisms to accelerate the transition.
Transformative Urban Mobility Initiative (TUMI) E-Bus Mission	Buses	Funding: German Ministry for Economic Cooperation and Development	The partnership supports 20 Global South countries to accelerate the deployment of electric buses, replicate activities and scale deployment to 100 000 buses by 2025, in 500 cities. Areas of support include: • The convening of private and public sector stakeholders to promote mass adoption of EV buses; • The development of electrification roadmaps and provision of technical assistance; • Knowledge-sharing on topics related to planning, procurement and operation of EV buses.

2.8 Map FCEV components value chain and identify opportunities at a Bill of Materials (BOM) level

2.8.1 FCEV-specific components value chain and opportunities at a BOM level

A fuel cell electric vehicle is powered by two main energy sources – batteries and hydrogen stored in tanks. There are two main ways in which the FCEV powertrain may be oriented – with load-follower or range-extended powertrains. With the load-follower powertrain a large hydrogen-fuel stack producing most of the power couples with small batteries to support consistent power during peak loads. With the range-extended powertrain, the primary power source is the battery, supported by a smaller fuel stack to extend the vehicle's driving range, as illustrated in Figure 21 below. Several fuel cell technologies depend on the application of the fuel cell, with the most common application for transport equipment being the polymer electrolyte membrane (PEM)[82]

[82] US Department of Energy (DoE). 2021. Hydrogen fuel cells in farm equipment: Market research study. https://science.osti.gov/-/media/sbir/pdf/Market-Research/HFCT---Hydrogen-Fuel-Cells-in-Farm-Equipment-June-2021-Public.pdf

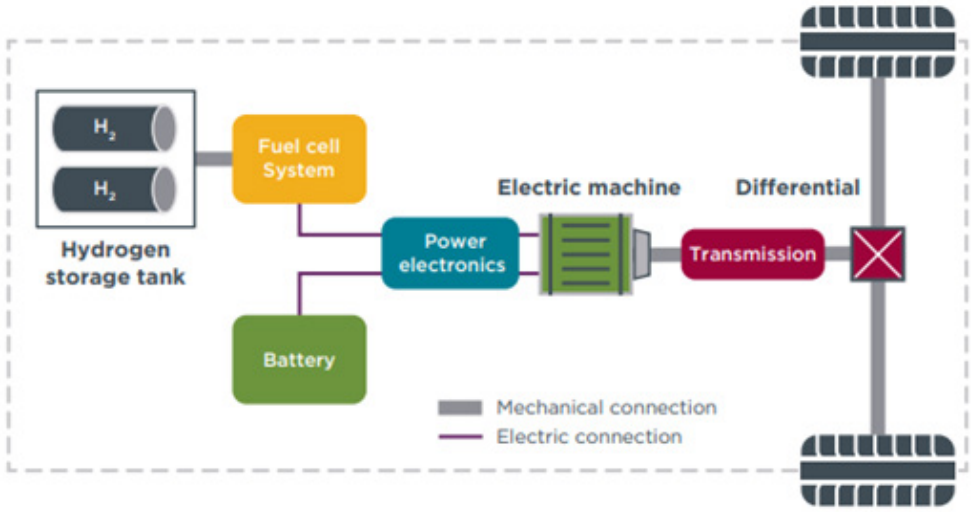


Figure 21: Basic fuel cell electric vehicle architecture[83]

The main raw materials associated with FCEVs are outlined below, in Figure 22 below.

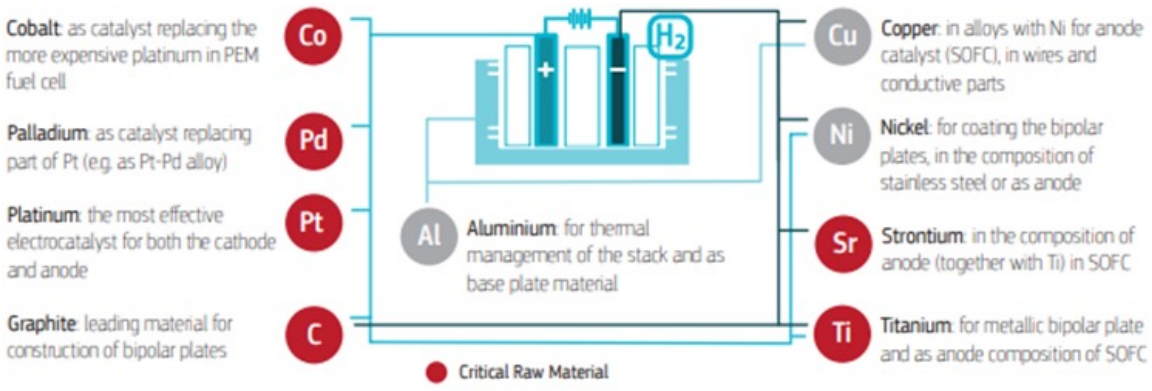


Figure 22: Relevant raw materials used in fuel cells, with items in red indicating critical raw materials[84]

FCEVs make extensive use of PGMs in their production, catalysing the fuel cell stack. Bobba et al (2020) note that an FCEV used roughly ten-fold more PGM than an ICE vehicle, however, the high price of platinum (estimated to be about 50% of the cost of the fuel stack) may be prohibitive to adopting the technology.

The raw material supply chain for FCEVs is relatively diverse across several suppliers. As seen in Figure 23, nearly half of all raw materials for FCEVs originate in Africa, with South Africa being responsible for 71% of global production of platinum, followed by Russia (16%) and Zimbabwe (6%). Other critical raw materials for FCEVs are palladium, rhodium and ruthenium, originating from the same three locations.

[83] Basma, H. and Rodriguez, F. 2022. Fuel cell electric tractor-trailers: technology overview and fuel economy. https://theicct.org/publication/fuel-cell-tractor-trailer-tech-fuel-jul22/

[84] Bobba, S., Carrara, S., Huisman, J., Mathieux, F., Pavel, C. 2020. Critical raw materials for strategic technologies and sectors in the EU: A foresight study. https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

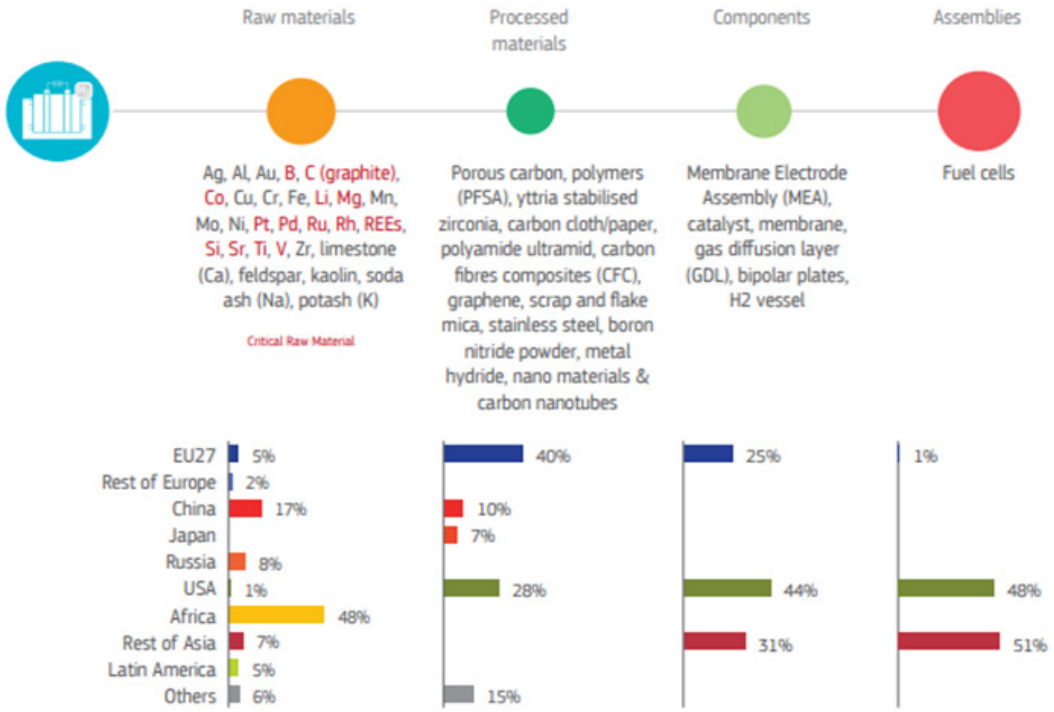


Figure 23: FCEVs: Overview of key suppliers along the value chain.[85]

In terms of processed raw materials, there are 12 materials relevant to FCEVs and the related hydrogen value chain and a basket of carbon-related materials required for electrode manufacturing, with European and American suppliers dominating these categories respectively (cumulatively supply 68% of processed materials and 69% of components. Lastly, Asian and US suppliers are responsible for 99% of all FCEV assemblies, as seen in Figure 23 above.

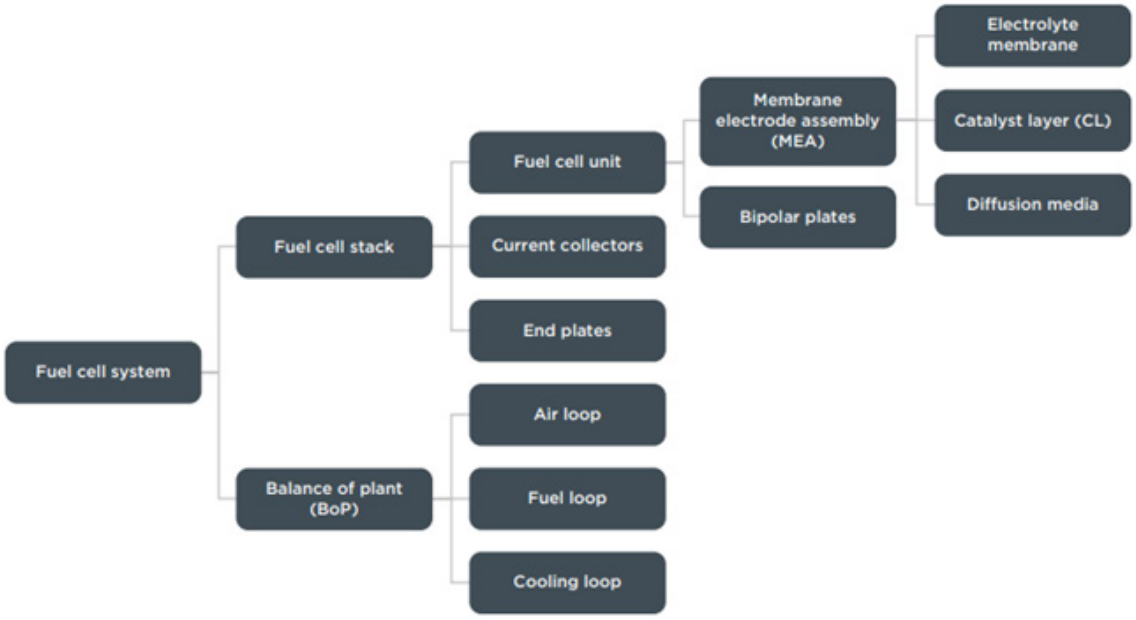


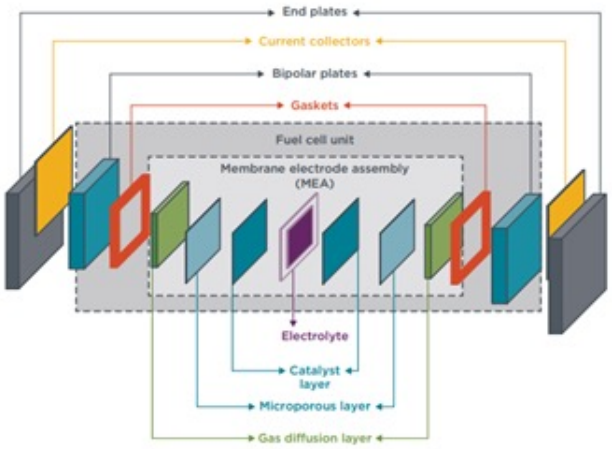
Figure 24: Fuel system components[86]

As seen in Figure 24, a fuel cell system is comprised of two main sub-systems: a fuel cell stack and a Balance of Plant (BoP).

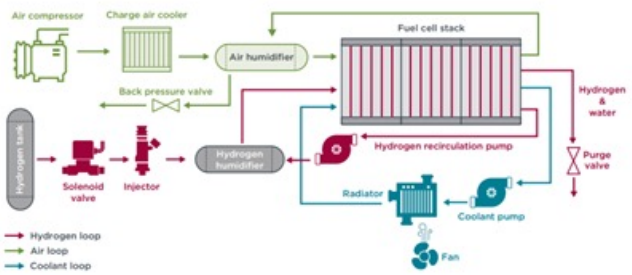
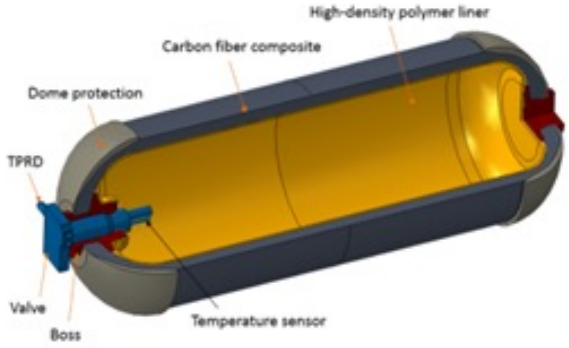
[85] Bobba, S., Carrara, S., Huisman, J., Mathieux, F., Pavel, C. 2020. Critical raw materials for strategic technologies and sectors in the EU: A foresight study. https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

[86] Basma, H. and Rodriguez, F. 2022. Fuel cell electric tractor-trailers: technology overview and fuel economy. https://theicct.org/publication/fuel-cell-tractor-trailer-tech-fuel-jul22/

Table 17: Description of fuel cell system sub-systems[87]

FCEV sub-systems	Schematic	Description
Fuel cell stack		Fuel cell stacks are composed of two main components: Membrane Electrode Assembly (MEA) and bipolar plates, both of which are comprised of several sub-components 1. Membrane Electrode Assembly (MEA) 1.1 The electrolyte membrane is mainly involved in separating the reactant gases – hydrogen and oxygen – and transporting the electric charges between the anode and cathode. 1.2 The catalyst layer is where the electrode's reactions take place. Whilst several metal technologies may be used in this layer, platinum is often utilised due to its high catalytic activity and stability, however, due to scarcity, may sometimes be cost-prohibitive. 1.3 The diffusion media is comprised of two layers – the Gas Diffusion Layer (GDL) and the Microporous Layer (MPL). The GDL is made of carbon fibre papers and is responsible for supporting electrical conductivity; structural support; removal of heat; and preventing corrosion. The MPL serves to separate the GDL from the catalyst layer, to minimise the loss of catalyst to the GDL. 2. Bipolar plates The bipolar plates serve a largely mechanical function in the fuel cell and separate the fuel cell units using gaskets to prevent MEA leakage. They also aid in heat removal and the collection of electrical currents. The boiler plates also distribute gases stemming from the reaction and assist in removing reaction byproducts.

[87] Basma, H. and Rodriguez, F. 2022. Fuel cell electric tractor-trailers: technology overview and fuel economy. https://theicct.org/publication/fuel-cell-tractor-trailer-tech-fuel-jul22/

FCEV sub-systems	Schematic	Description
Balance of Plant		The Balance of Plant (BoP) provides three auxiliary systems: air loop; fuel/hydrogen loop; and coolant loop. 1. The air loop (which consumes 15% of the fuel stack power) serves the primary function of supplying oxygen to the cathode (as a function of the required load). As the oxygen pressure has a direct bearing on the performance of the fuel cell, an air compressor regulates intake air pressure. An air cooler is used to control temperature to prevent degradation of the fuel cell, due to the high reactive temperatures. At the same time, a humidifier is required to prevent the membrane from drying out and ensure that there is proton conductivity. 2. The fuel/hydrogen loop supplies hydrogen to the anode. An injector is used to regulate the flow rate of the hydrogen, as the combination of water and nitrogen gas may reduce the pressure of the hydrogen which negatively affects the performance of the fuel stack. Additionally, a purge valve is used to reduce excess water or hydrogen from the system. Hydrogen is fed back into the anode to reduce fuel loss via a hydrogen recirculation pump. 3. The cooling loop serves to remove excess heat produced by the fuel cell unit, which prevents degradation of the membrane. Traditionally, liquid coolants are used in FCEVs, however, but there is also noted usage of active air cooling.
Hydrogen tank		The hydrogen storage system, or tank, which sits onboard a vehicle is an important component of a FCEV. The gas is pressurised within the tank (at either 350 or 700 bar) and this differs across types of vehicles as the rate of pressurisation may affect the power output, i.e. the distance achieved. E.g. while 350 bar is traditional for FCEV buses, in long-distance FCEV trucks, this rate of pressurisation would result in a driving range of less than 400km

2.8.2 Key components of FCEVs and opportunities

After an analysis of the fuel cell value chain certain of the FCEV opportunities can be identified.

Table 18 provides an overview of the key components in FCEVs and provides an overview of potential manufacturing capability and capacity which may exist domestically, as well as suggesting existing automotive suppliers. Those with at least 51% black ownership, are highlighted. Battery components and the related value chain are covered elsewhere in the study.

Table 18: FCEV components; existing manufacturing capability and capacity; and list of prospective domestic suppliers

FCEV sub-component	Description	Does the current FCEV manufacturing capacity exist in South Africa?	Prospective existing automotive suppliers in South Africa. Companies with at least 51% black ownership are bold and underlined
Catalyst	As part of the Membrane Electrode Assembly (MEA), the catalyst is a chemical compound/substance which can increase the rate of a chemical reaction, without being consumed	No	BASF South Africa Corning Products South Africa Heraeus South Africa (Pty) Ltd Johnson Matthey South Africa Umicore Automotive Catalysts
Plates	As part of the Membrane Electrode Assembly (MEA), the plates may be made of metal, to provide structural support and conduct liquids, gases and electricity.	No	Metal plates: Bosal Afrika BraceAble Manufacturing CRH – Africa MA Automotive Tool and Die Naicker Toolmakers Ramsay Engineering Selago Industries Technique Manufacturing WRC Automotive Components

FCEV sub-component	Description	Does the current FCEV manufacturing capacity exist in South Africa?	Prospective existing automotive suppliers in South Africa. Companies with at least 51% black ownership are bold and underlined
Gas Diffusion Layers (GDL)	Primarily used in platinum-based MEAs and are often made of carbon paper or woven carbon materials and are responsible for supporting electrical conductivity; structural support; removal of heat; and preventing corrosion.	No	None Note: A leading global supplier of GDLs is 3M – which does have a non-automotive component manufacturing presence in South Africa.
Membrane Electrode Assembly (MEA)	Mainly involved in separating the reactant gases—hydrogen and oxygen—and transporting the electric charges between the anode and cathode	Yes	Isondo Precious Metals (existing FCEV supplier)
Gaskets	Used in MEA assembly, it is a shaped piece of rubber or metal that seals a junction between two surfaces	No	Bosal Afrika Dynafoam Converters Hudson Rubber John Moffat Prolock Natal Gaskets Tenneco
Sensors	Have multiple applications in an FCEV, including supporting flow management, pressure control, leak detection, etc. These sensors are not only used in the FCEV but also in hydrogen production, storage, distribution and re-fuel stations	No	Sensor bosses Bentler South Africa Eberpacher Microfinish Wekaba Engineering

FCEV sub-component	Description	Does the current FCEV manufacturing capacity exist in South Africa?	Prospective existing automotive suppliers in South Africa. Companies with at least 51% black ownership are bold and underlined
Thermal management systems	Removes excess heat produced by the fuel cell unit, which prevents degradation of the membrane	No	MAHLE Behr South Africa Smiths Manufacturing
Power electronics	Control and convert energy from one form to another including inverters, converters, motor drives	No	Jendamark Automation Hesto Harnesses Lear Corporation Pasdec (Delta Automotive) Robert Bosch Wabco South Africa
Fuel tank	Plastic container which holds and stores hydrogen fuel source	No	Plastic Omnium

3. PROJECT TEAM

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