Technical Note No. 3 – Power Supply and Rolling Stock

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1. Purpose

The purpose of this Technical Note is to provide analysis and commentary on the technical aspects around future power supply options and wider rolling stock considerations. Background
Tram networks generally obtain their power from overhead electric lines. Overhead lines require the installation of appropriate infrastructure along the route to provide the trams with motive power. This infrastructure includes:

- substations;
- transformers;
- masts; and
- overhead line equipment (OLE).

Trams draw down power through pantographs from the overhead equipment, which then powers the vehicle, with the track providing the return path to the substation; completing the circuit. Direct current (DC) is typically used due to the lower voltages involved (compared with the mainline railway network 25kV AC); posing less of a risk to the public in urban areas.

The current Edinburgh Tram network is powered by overhead lines operating at 750V DC; a common standard for tram networks across Europe. The current rolling stock is detailed in the table below.

Element	Specification
Manufacturer / Model	CAF / Urbos 3
Constructed / In Service	2009-2011 / since 2014
Fleet Size	27
Formation	7-articulated units per tram
Length	~43m
Passenger capacity	78 seated, 2 wheelchair spaces, 170 standing. 250 total
Floor height	Low floor (~350mm)
Maximum speed / acceleration	70km/h / $1.2ms^{-1}$
Track gauge	1435mm (standard)

2. Technical Considerations

As well as overall considerations of achieving value-for-money and minimising embedded and operational carbon, there are a number of technical challenges that could be resolved by the consideration of alternative traction technologies. Specifically, the removal of the need for sections of overhead line equipment could provide a number of benefits, including:

- Visual impact
  - Roseburn corridor – part of this corridor runs through the Coltbridge and Wester Coates conservation area. Specific note is made of the recognised environmental amenity provided on the current cycle route/path.
  - Orchard Brae corridor – part of this corridor runs through the UNESCO World Heritage Site (New Town), New Town and Inverleith conservation areas, and is adjacent to a number of listed buildings. Specific note is made of Dean Bridge (‘A’ listed).

  - North Bridge / South Bridge corridor – this corridor runs through the UNESCO World Heritage Site (Old Town), the Old Town conservation area and is adjacent to a number of listed buildings. The corridor extends south into other conservation areas.
  - Note that in relation to these issues, further diagrams and analysis are contained in Report 5 (Landscape, Streetscape and Heritage).
- Carbon
  - The provision of overhead line equipment involves significant embedded carbon relating to materials, construction and maintenance. Adopting a solution that minimises or removes the need for overhead line equipment would significantly reduce the embedded carbon of the project. Acting against this would be the need to install battery/capacitor technology in the rolling stock, which would increase their carbon footprint. Notwithstanding this, and that an assessment of project lifecycle carbon will be required at the outline business case stage, it is generally considered that there would remain a significant net benefit from being able to reduce the embedded carbon.
- Cost
  - Cost reductions can be accrued through:
    - Removing the requirement for overhead line equipment and associated infrastructure (CAPEX)
    - Reducing the stray current / corrosion protection requirements (CAPEX/OPEX)
    - Eliminating overhead line maintenance requirements (OPEX)
  - Cost increases can be accrued through:
    - Increased cost of hybrid rolling stock including energy management systems
    - Battery replacement charges, charging infrastructure or other hybrid fuel systems
  - The net cost position depends on the geographical extent over which infrastructure savings can be made; and the relative complexity of those, in comparison to the additional costs.

3. Future Power Supply Options

There are three broad options for future power supply:

1) Continue with conventional approach, i.e. overhead power supply only;
2) Adopt a 'hybrid' solution where conventional compatibility is augmented with on-board battery/capacitor storage; or
3) Adopt emerging hydrogen power technology; either on its own or hybrid using the conventional compatibility on legacy parts of the network.

Option 1 would involve installing overhead power system installations per the existing route infrastructure on all new sections of route.

Option 2 would enable parts or all of the new track route to be delivered without overhead power systems along the route. This would involve charging on-board power storage systems via (i) existing overhead catenary sections, (ii) limited sections of new overhead catenary, and/or (iii) fast-charge systems at tram stops. Examples in operation are:

- West Midlands Metro, UK – CAF Urbos trams retro-fitted with batteries to allow for operation through the city centre.
- Newcastle Light Rail, Australia – CAF Urbos system using at-stop overhead recharging for the full route.
- Nice, France – Alstom Citadis using at-stop ground charging strips/supercapacitors in much of the city centre and outer suburban areas.
- Florence, Italy – Hitachi Sirio system using at-stop charging and allowing legacy overhead system to be removed from historic areas.

It is also important to note that both Option 1 and Option 2 would require the provision of power supply across some or all of the new network, which may in turn require strengthening/upgrades to the local power supply grid to ensure adequate power is available. For Option 1 this would involve the installation of power supply equipment at strategic locations along the route to energise the overhead line. Given the potential number of additional unit movements, strengthening of supply on shared parts of the existing network may also be required. For Option 2, this could involve fewer installation but potentially more concentrated supply.

Nice: At Stop Ground Charging

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Newcastle, NSW: Overhead Charging

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Option 3 could enable the whole new route to be delivered without new overhead power systems but would require the installation of hydrogen fuelling facilities. Hydrogen trams are at the early stages of development and deployment with Hyundai-Rotem delivering units in 2026 to Daejon in South Korea. Similarly, a demonstration project in Goerlitz, Germany is planned to be in operation by 2026 using units developed by HeiterBlick. Operational systems include:

- The 14 km light rail line in Tangshan, China utilises a vehicle with a range of 40 km on a single 12kg hydrogen fill-up (refuelling takes around 15 minutes to complete). The three-section vehicle is listed as having a top speed of 70 km/h and a capacity of 336 passengers, with 66 seated.
- The Foshan tram in Guangdong Provence, China operates on a 17 km long line, using tram vehicles with 20kg hydrogen tanks that will power the trams for 125 km, again taking 15 minutes to refuel at the depot.

Self-powered units are by nature heavier than conventional vehicles but, depending on energy storage/management and power output, can achieve comparable operating performance to conventional vehicles. It is also noted that Options 2 and 3 have the potential to provide greater operational resilience to overhead line failures by providing self-powered capability to individual trams. To give some context, over 80% of systems worldwide use conventional overhead line technology, between 5% and 10% use battery/supercapacitor only, with a similar proportion using hybrid (usually battery with overhead line). Less than 1% use hydrogen, and a handful of systems use other power such as diesel/electric traction. A set of example systems that cover the current range of power systems is giving below.

Tram System	Rolling Stock	Power System
West Midlands Metro, UK	CAF Urbos 3	Hybrid overhead line (750v DC) and battery
Blackpool, UK	Bombardier Flexity 2	Overhead Line 600V DC
Manchester Metrolink, UK	Bombardier M5000	Overhead Line 750V DC
Dublin, Ireland	Alstom Citadis 401 and 502	Overhead Line 750V DC
Prague, Czechia	Skoda 15T	Overhead Line 600V DC
Newcastle Light Rail, Australia	CAF Urbos 100	ACR supercapacitor battery
Nice, France	Alstom Citadis 402	Overhead Line 750V DC
	Alstom Citadis 405	Hybrid overhead line (750V DC) and APS ground supply
Florence, Italy	Hitachi Sirio	Hybrid overhead line (750V DC) and battery
Amsterdam, The Netherlands	Siemens Combino & CAF Urbos 100	Overhead Line 600V DC
Seville, Spain	CAF Urbos 3	ACR supercapacitor battery
Foshan, China (suspended)	CRRC Qingdao Sifang / Ballard Power Systems	Hydrogen
Tangshan, China	CRRC Tangshan Co., Ltd	Hydrogen
Daejeon, South Korea (under construction)	Hyundai Rotem	Hydrogen

4. Rolling Stock

Although the current rolling stock has been operating for around 11-years, vehicle deliveries commenced in 2010, making them approximately 15 years old. Based on industry norms, it can be anticipated that a major refurbishment will be required within the next five years. The lead time for new tram deliveries is also five years; assuming a vehicle lifespan of approximately 25-30 years, this means that a plan for rolling stock replacement needs to be considered in the near future.

The size of fleet originally ordered was in line with the then service expectations for the full delivery of Tram Lines 1 and 2 (as per the Acts). This could allow the existing fleet to service the current network plus the proposed north-west arm (linking the existing network to Granton), but would not be sufficient to cope with the addition of the south-east arm (linking the existing network with Bioquarter and beyond). In practice, it is expected that a small number of additional tram vehicles is required (up to 5), although journey time improvements on the existing network could reduce this requirement.

The vehicle type (CAF Urbos 3) is the same as utilised by West Midlands metro where retrofitting with battery technology has been possible.

It is also important to note that the provision of the north-south route allows for a network-level operational response that is led by passenger demand. In practical terms, the optimisation of this can be broken down into three core areas:

- The provision of more complex routes to provide direct routes across the network:
  - Airport to Newhaven (existing);
  - Airport to Bioquarter and Beyond;
  - Airport to Granton[1];
  - Granton to Bioquarter and Beyond;
  - Granton to Newhaven; and
  - Newhaven to Bioquarter and Beyond.
- The provision of changed/enhanced service frequencies to better match with future demand requirements; and

[1] Direct service only possible via Roseburn Options not via Orchard Brae Option.

- The potential to enhance operating hours to better serve potential demand (e.g. hospital late shift)

There will be a need to optimise these aspects as planning and development of the scheme is taken forward; starting with an initial modelling-based optimisation process for service patterns to feed into the finalised Strategic Business Case (SBC).

The development of the SBC is based on passenger operations only. This is not to preclude future use of the network by tram-freight operations, but (i) such operations are generally commercial and building in reliance on this within the SBC would introduce a level of risk, uncertainty and complexity that would be unwise at this stage, and (ii) even in highly developed city tram networks across Europe, there are few examples of successful operation, and where this has occurred it has generally been a particular use case (e.g. VW CarGoTram in Dresden).

5. Technical Design Assumptions at Strategic Business Case Stage (SBC)

The development of the SBC requires a working assumption to be made at this stage on the best practical option. This is based around:

- Make best use of the existing legacy infrastructure;
- Leverage technology improvements to help address/mitigate design constraints but focussing on operationally proven systems; and
- Providing greater resilience to weather/incidents by incorporating capacity for self-powered operation.

It is not considered appropriate to assume hydrogen powered systems at this time due to the lack of maturity of the solutions, and the need for hydrogen infrastructure.

The potential visual and environmental impact issues on a number of route sections means that there is significant value in being able to dispense with overhead power systems in these locations.

It is therefore recommended that the working assumption for SBC is that the rolling stock fleet will be hybrid with on-board battery/capacitor storage that could be recharged via legacy overhead power systems plus new overhead power systems/fast charge at stops. This would involve either retro-fitting of the existing fleet or fleet renewal; depending on the most economically advantageous position when considering this project in conjunction with Edinburgh Trams own renewals strategy.