OTSI Office of Transport Safety Investigations

BUS SAFETY INVESTIGATION REPORT

FIRE INVOLVING STA BUS MO4878

HILLSDALE, NSW

29 JULY 2011

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THE OFFICE OF TRANSPORT SAFETY INVESTIGATIONS

The Office of Transport Safety Investigations (OTSI) is an independent NSW agency whose purpose is to improve transport safety through the investigation of accidents and incidents in the rail, bus and ferry industries. OTSI investigations are independent of regulatory, operator or other external entities.

Established on 1 January 2004 by the *Transport Administration Act 1988*, and confirmed by amending legislation as an independent statutory office on 1 July 2005, OTSI is responsible for determining the causes and contributing factors of accidents and to make recommendations for the implementation of remedial safety action to prevent recurrence. Importantly, however, OTSI does not confine itself to the consideration of just those matters that caused or contributed to a particular accident; it also seeks to identify any transport safety matters which, if left unaddressed, might contribute to other accidents.

OTSI's investigations are conducted under powers conferred by the *Rail Safety Act 2008* and the *Passenger Transport Act 1990*. OTSI investigators normally seek to obtain information cooperatively when conducting an accident investigation. However, where it is necessary to do so, OTSI investigators may exercise statutory powers to interview persons, enter premises and examine and retain physical and documentary evidence.

It is not within OTSI's jurisdiction, nor an object of its investigations, to apportion blame or determine liability. At all times, OTSI's investigation reports strive to reflect a "Just Culture" approach to the investigative process by balancing the presentation of potentially judgemental material in a manner that properly explains what happened, and why, in a fair and unbiased manner.

Once OTSI has completed an investigation, its report is provided to the NSW Minister for Transport for tabling in Parliament. The Minister is required to table the report in both Houses of the NSW Parliament within seven days of receiving it. Following tabling, the report is published on OTSI's website at www.otsi.nsw.gov.au.

OTSI cannot compel any party to implement its recommendations and its investigative responsibilities do not extend to overseeing the implementation of recommendations it makes in its investigation reports. However, OTSI takes a close interest in the extent to which its recommendations have been accepted and acted upon. In addition, a mechanism exists through which OTSI is provided with formal advice by the independent transport safety regulator (ITSR) in relation to the status of actions taken by those parties to whom its recommendations are directed.

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ACRONYMS AND ABBREVIATIONS

ADR ....Australian Design Rule
CNG ....Compressed Natural Gas
DIP ....Directly Involved Party
ITSR ....Independent Transport Safety Regulator
OTSI ....Office of Transport Safety Investigations
PTIPS ....Public Transport Information and Priority System
RTA ....Roads and Traffic Authority of NSW[1]
STA ....State Transit Authority

1 The operational elements of the Roads and Traffic Authority (RTA) were integrated with elements of both NSW Maritime and NSW Transport and Infrastructure to form Roads and Maritime Services NSW, with effect 1 November 2011.

EXECUTIVE SUMMARY

Shortly after 7.38pm on Friday 29 July 2011, a State Transit Authority (STA) bus powered by compressed natural gas (CNG) caught fire when returning empty to the Port Botany Depot. The driver, after being alerted to the fire by a motorist travelling behind, stopped the bus and attempted to extinguish the fire with the only equipment onboard, a small capacity portable extinguisher. His efforts were to no avail and the bus was destroyed.

The investigation found that the most likely cause of the fire was coolant being sprayed onto the engine from a split hose connection on the turbocharger coolant return line to the compressor. The water content of the coolant evaporated on the hot surface of the engine, allowing the residual ethylene glycol to crystallise and ignite. As the fire intensified, it burnt through the rear floor hatch and ignited the seating and other combustible interior materials.

Some 19 minutes after the fire was initially detected, a connection in the CNG line at the engine succumbed to the intense temperature and resultant increase in pressure, and vented a jet of flame. This secondary event occurred because the driver did not shut off the CNG supply before leaving the bus.

The investigation found there were deficiencies in the training of drivers to handle a vehicle fire. However, it was identified that Network Control personnel could assist in emergencies involving gas powered buses by reminding drivers to shut off fuel supplies, and by forewarning emergency services personnel of any known additional hazards at the fire site.

The STA has implemented a range of appropriate remedial actions, the nature and extent of which preclude the need for recommendations for further action by the Authority. This action has included:

- the replacement of the return coolant line and connecting hose fitting on all their Mercedes Benz OC500 LE CNG model buses;
- the calling of tenders for the retrofitting of fire suppression systems on all their Mercedes Benz OC500 LE CNG model buses; and

- the provision of training and instructions to drivers and Network Control personnel concerning actions to be taken when a bus experiences a fire or 'thermal incident'.

As a result of the number of bus and coach fires that have occurred in NSW since the beginning of 2010, OTSI is undertaking a review of the results of the investigations it has completed with a view to identifying and further examining any systemic safety issues that become apparent.

PART 1 CIRCUMSTANCES OF THE INCIDENT

Incident Synopsis

1.1 At about 7.38pm[2] on Friday 29 July 2011, a State Transit Authority (STA) bus (MO4878) caught fire on Beachamps Road at Hillsdale when returning empty to the Port Botany STA Depot. Despite attempts by the driver and Fire and Rescue NSW units, the bus was destroyed (see *Photograph 1*).

Photograph 1: Bus interior

The Bus

1.2 The bus was one of a fleet of 255 compressed natural gas (CNG) powered Mercedes-Benz model OC500 LE buses owned and operated by the STA. It was imported by Mercedes-Benz Australia in buggy format in January 2007. Completion of the body work and fit-out by Custom Coaches, Villawood, NSW, commenced on 31 July 2007. MO4878 was first registered with the

2 All times in this report are Australian Eastern Standard Time (UTC+10 hours).

Roads and Traffic Authority (RTA) in December 2008 and last re-registered on 24 January 2011, with Inspection Report AZ1129219 recording no defects.

1.3 Initially the RTA would not register these buses because they were approximately 500kg overweight. However, modifications were made to the buses to facilitate compliance with RTA requirements, although this resulted in a delay of about 18 months before the buses could enter service. Included in the work was some modification to the frames, rearrangement of passenger distribution and the replacement of steel wheel rims with aluminium rims. The 255 CNG buses, as well as 200 diesel powered Mercedes-Benz model 0500 buses, were registered between 26 May 2008 and 6 June 2011.

1.4 The body of the bus was constructed of welded stainless steel frames with fibreglass side and roof panelling. The internal linings were predominantly of composite plastic materials. Noise reduction was provided by polystyrene infill between inner and outer panels on the sides and roof. The flooring consisted of rot-resistant treated plywood with a covering of non-slip recycled cork granules with a rubber binder. The seating consisted of plywood bases and back supports mounted on stainless steel frames with foam filled seat padding covered with cloth material. Although complying with clause 17 of ADR 58 *Requirements for Omnibuses Designed for Hire and Reward – Interior Fittings/Materials*, the material used in the interior fit-out was consumed rapidly once the fire breached the interior of the bus.

1.5 The bus had two doors, both of two leaf inward opening design, one at the front opposite the driver’s position and one on the nearside midway along the length of the bus. There was provision for wheelchair passengers with flip up seating in the front half of the bus. Emergency exit windows were located on both sides of the bus above the wheelchair spaces.

1.6 The engine bay area, except for the floor-mounted inspection hatches, was sheathed with stainless steel to protect the passenger area from heat from the engine. The plywood floor service hatches at the rear of the passenger area were not similarly sheathed with any such lining.[3]

[3] These hatches are in place to provide maintenance staff with access to bus driveline components. As the hatches are regularly removed and refitted, the weight of a hatch is an OH&S consideration.

1.7 The bus was fitted with the Public Transport Information and Priority System (PTIPS)[4], closed circuit television (CCTV) and STA radio communications. None of the OC500 LE CNG buses were fitted with a fire suppression system, heat detectors, smoke detectors or alarms.

1.8 The bus had travelled more than 91,412km at the time of the fire.[5] It was refuelled at the Botany Depot the previous day at 10.50pm and had travelled 97km before catching fire.[6]

1.9 The bus was powered by a Mercedes-Benz OM 447 hLAG TYPE CNG-fuelled six cylinder engine of 12 litres displacement. The engine had a lean burn turbocharger with intercooler and a power rating of 185kW at 2000rpm. The CNG fuel was stored in seven cylinders. The cylinder set is rated at 1055 litres of CNG when measured at a standard atmospheric pressure of 101.325kPa, but occupying 240m^3 when compressed to 200 bar (20mPa), the operating pressure of the storage cylinders.

1.10 The CNG storage cylinders were installed by Custom Coaches in a fibreglass pod on the roof towards the front of the bus with the gas supply line running along the roof to the rear mounted engine. The supply line had two emergency isolation (shut-off) valves: one on the offside of the roof-mounted pod assembly which could be activated by a remote mounted emergency pull handle located behind the driver's position and the other at the rear offside corner of the bus which was accessible for operation only from outside the bus. Both valves required a quarter turn between the open and closed positions. The mounting of the CNG Pod and cylinder set was installed by Custom Coaches. CNG installation and compliance was certified by RFD Pty Ltd, which was a contractor to Mercedes Benz.

1.11 The CNG cylinders were constructed of ferritic chromium-molybdenum steel[7] wrapped with carbon fibre. They had a maximum fill pressure of 260 bar (less temperature compensation), settling to the operational pressure of 200 bar.

4 PTIPS employs global positioning systems and radio data communications to deliver information about buses and their location that is then used to give priority to buses at traffic signals by altering the sequencing and timing of the signals.

5 The odometer was destroyed in the fire. The distance quoted is that recorded at its last service on 13 July 2011.

6 This distance was obtained from PTIPS data.

7 A stainless steel highly resistant to oxidation, corrosion and stress corrosion cracking.

Each CNG cylinder was fitted with a Ceodeux 'burst disc' pressure valve wherein the disc breaks if the pressure in an individual cylinder reaches 300 bar. The cylinders were also fitted with a thermal release valve that would allow the gas to vent if the temperature of the cylinder exceeded 110°C (±10°). These valves operated independently on each storage cylinder and would release CNG to the atmosphere in a lateral direction when activated.

The Fire

1.12 The driver was travelling along Denison Road, Hillsdale, returning empty to STA's Botany Depot at the end of a shift when he was alerted to a problem by a motorist travelling behind the bus. He stopped the bus and was informed that there was a fire in the rear of the bus. He then drove approximately 150 metres across the intersection with Beauchamp Road to the first available safe area and stopped alongside the roadside kerbing. He left the engine running and went to the rear nearside wheel arch of the bus where he observed what he described as an "*orange glow*" emanating from the area above the rear mounted engine. He returned to the driver's console and radioed the STA's Network Control Centre to alert them to the fire, although he was unsure of his exact location at this time. He then turned off the ignition. The time was then 7.38 pm.[8]

1.13 The driver took the portable 2.5kg dry chemical (powder) extinguisher from its bracket near the driving position and returned to the rear nearside of the bus. Another STA driver, who had stopped to assist after overhearing the radio call, discharged the extinguisher on behalf of the driver under the nearside wheel arch and towards the engine bay and then departed the scene. (A number of drivers who were interviewed were of the understanding that they were not to open the side engine bay hatch for personal safety reasons.)

1.14 The driver returned to the front of the bus where he noticed the interior was rapidly filling with smoke. Realising that the fire had escalated and spread, he grabbed his personal bag and moved along the road to a safer position away from the fire, about 10 metres in front of the bus. Using his mobile phone, he

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8 As recorded by the PTIPS. The exact location was determined by the Network Control Centre also using the PTIPS.

called Network Control again to report the escalation of the fire, and then proceeded to video record the fire on the phone's camera.

1.15 When interviewed, the driver stated that he had turned off the ignition but did not activate either of the emergency gas isolation valves.

Emergency Services Response

1.16 Fire and Rescue NSW was notified by STA Radio and units from Matraville and Maroubra attended. NSW Police also attended. The first notification was received by the Matraville Fire Station at 7.44pm and Unit 56 was despatched immediately. Unit 70 from the Maroubra Fire Station responded at 7.51pm. At 7.52pm, shortly after the first Fire and Rescue unit arrived, the CNG line at the rear of the bus ruptured and the CNG ignited. This caused a jet of flame to extend from the offside of the engine bay out across the road for a distance of over four metres. Several passing motorists and a motorcyclist narrowly avoided being injured before traffic movement was stopped.

1.17 Because the CNG was escaping, Fire and Rescue personnel considered it prudent to evacuate the ORICA Chemical Plant located on the other side of Beauchamp Road adjacent to the bus. Additional assistance was requested and Unit 38 responded. The evacuation of the ORICA Plant was completed at 8.06pm. The fire was declared completely extinguished at 9.15pm. See *Table 1* for a timed event summary.

7.33pm	Passing motorist informs Driver of the fire.
7.37pm	Bus stopped at kerb. Driver inspects the rear of the bus.
7.38pm	PTIPS identifies bus ignition off.
7.40pm	Driver makes initial call advising Network Control Centre of the fire.
7.42pm	Driver leaves the bus with an extinguisher.
7.43pm	Another STA bus driver following discharges extinguisher then departs.
7.44pm	Fire & Rescue units receive call out.
7.46pm	Driver has left bus with bag and phones Network Control Centre. Fire now inside the bus.

7.47pm	PTIPS ceases to function.
7.52pm	Fire units in attendance. CNG vents.
8.06pm	ORICA chemical factory evacuated.
9.15pm	Fire extinguished but bus destroyed.

Table 1: Timed event summary

1.18 Fire and Rescue units responded expeditiously to the notification and dealt effectively with the fire and surrounding environs. While the fire fighters completed their task efficiently and without sustaining any injuries, they were not initially informed that the bus was fuelled by CNG.[9] Such prior knowledge would have been advantageous from a risk management perspective in preparing them for the potential hazards of venting CNG and exploding CNG cylinders.

Damage

1.19 The roof, windows, all interior fit-out and most of the side panels were destroyed by the fire. The stainless steel welded frame remained substantially intact but the sections supporting the roof in the middle of the bus were severely distorted. The flooring and inspection hatches at and towards the rear of the bus sustained significant fire damage but the tyres, wheels and chassis remained intact. The air-conditioning unit housed in a fibreglass pod and mounted on the roof at the rear of the bus was destroyed. The driver's console, including steering wheel and dashboard, and the driver's separation shield were all destroyed as was all internal electrical wiring, the CCTV cameras and the PTIPS unit.

1.20 The seven CNG storage cylinders housed in the fibreglass pod on the roof remained intact although the pod itself was destroyed. The CNG cylinders sustained some minor fire damage to the carbon fibre sheathing but the individual safety pressure and temperature valves were not damaged and remained operational. The emergency gas isolation valve mounted on the roof was not damaged but its activation cable and handle located at the rear of the driver's position were destroyed.

9 The operator at STA Radio was not in a position to know from its call sign that the bus was powered by CNG.

1.21 The power steering hydraulic fluid and coolant reservoirs and the engine fan and housing, being constructed predominantly of plastic material, were destroyed. The electrical system was totally burnt out with electrical shielding and cable ties melted, allowing remnants of wiring to fall away. Most of the copper electrical wiring was melted.

1.22 The engine, gear box and turbocharger remained intact although all supporting hoses, wiring and sensors were destroyed.

PART 2: ANALYSIS

Bus Inspections

2.1 An OTSI investigator inspected the bus at the STA's Leichhardt Depot holding yard on 30 July 2011. Based on the results of this inspection the Chief Investigator determined that a formal investigation under *Section 46BA (1)* of the *Passenger Transport Act 1990 (NSW)* was warranted. The bus was then quarantined pending further examination.

2.2 Further inspections of MO4878 were made by OTSI investigators on 1 and 4 August 2011. On these occasions undamaged OC500 LE CNG buses were also inspected to assist with the identification of systems and parts of the burnt-out bus. (Four buses were inspected as there are minor variations between buses of the same model.) On 11 August 2011 two technical representatives of Mercedes-Benz Australia/Pacific, accompanied by an engineer from Ingenieurbüro Gottwald, a German company engaged by Mercedes-Benz to determine the cause of the fire, met STA representatives and OTSI investigators to examine the bus.

2.3 Additional examinations were undertaken on 21 and 22 September 2011 when OTSI investigators requested the engine be removed to enable a more comprehensive inspection. The engine was removed on 12 October 2011 and samples of coolant and hose connections were removed for analysis. A Fire and Rescue NSW fire investigator attended the bus on 20 October 2011 in company with STA and OTSI investigators. Following this inspection the engine was cleaned and a final inspection made on 28 October 2011.

Possible Causes

2.4 The most likely ignition sources of the fire were determined to be:

- electrical - shorting of 24 volt wiring;
- gas fuel - leak of gas from the supply line or associated components;
- oil - leak resulting in oil coming into contact with hot engine components; or

- coolant - leak with residual ethylene glycol impregnated into rubber, plastic or other material and being ignited through contact with hot engine components.

Electrical

2.5 The bus had two 28 volt / 140amp alternators and a 24 volt / 6.2kW starter motor. Two 12 volt batteries were located at the offside front of the bus and were wired in series to provide a 24 volt supply.

2.6 The main wiring loom between the batteries and the starter motor and alternators was examined for faults. The battery power supply cable had come into contact with a section of copper piping and short-circuited, burning through the wall of the pipe. However, this was in front of the gear box housing and away from the seat of the fire so was determined to be a consequence of the fire, not the cause.

2.7 The main electrical loom from the batteries was burnt through with the remnants resting on the drive shaft (see *Photograph 2*). However, there were no markings on the drive shaft to indicate this cabling had come into contact with the shaft while the bus was moving. It was concluded, therefore, that the fire melted the plastic cable ties holding the wiring harness clear of the engine thereby allowing the harness to fall onto the drive shaft. Examination of several other undamaged buses of the same model and age showed the wiring harness was firmly secured and well clear of the drive shaft.

2.8 Although part of the offside alternator casing had melted, there was no indication of electrical shorting or of any other problem with the alternator. Examination of the starter motor revealed only signs of secondary heat damage and fire exposure; its wiring was mostly intact. The fire could not be attributed to faults in either of the alternators or the starter motor.

2.9 The PTIPS tracking unit was functioning for some 14 minutes after the fire started (until 7.47pm) and five minutes before the CNG line vented at 7.52pm. (This allowed the Network Control Centre to determine the exact position of the bus.) Examination of the videos of the fire showed that the headlights remained on until the fire reached the front section of the bus. This confirmed that the electrical power was still being supplied from the batteries located at the front offside of the bus after the fire was well underway.

Photograph 2: Electrical loom on tail shaft

2.10 All ancillary wiring in the engine bay and throughout the interior of the bus, including the driver's console and the dashboard, was either destroyed or badly damaged.

2.11 From the available video evidence, the driver's interview and inspection of all electrical components, electrical short circuiting could be discounted as being the cause of the fire.

CNG Fuel Leak

2.12 CNG differs from Liquid Petroleum Gas (LPG) in that it is lighter than air and so, when released, will immediately rise and dissipate quickly in the atmosphere. The bus had seven storage cylinders each fitted with two relief valves, one thermal and one pressure. In the event of the cylinders being subjected to excessive heating or experiencing excess pressure build up within, gas will vent through one or other of the relief valves. Any gas venting near a naked flame will ignite.

2.13 Examination of the bus found that the CNG fuel line was intact between the supply cylinders and the engine high pressure solenoid valve where a male threaded fitting manufactured from stainless steel had been torn out of a brass female fitting, stripping the internal brass thread. This component failure can be attributed to the combined effect of pressure in the gas supply line and heat from the fire, given that brass has a higher coefficient of thermal expansion than stainless steel.[10] The fuel line, with the stainless steel fitting attached, was bent well away from the brass fitting indicating that the line had been under considerable pressure when the fitting failed (see *Photograph 3).*

Photograph 3: Ruptured CNG line-compared with an undamaged line

10 Coefficient of expansion for brass is 18.5 x 10^{-6}m/m K while stainless steel is 16 x 10^{-6}m/m K. (Information sourced from http://www.engineeringtoolbox.com/linear-expansion-coefficients-d_95.html)

2.14 When the fitting failed, CNG vented through the ruptured line and was ignited by the fire. This caused a jet of flame to shoot out from the bus and partially across the roadway. The event was captured on the video recorded by the driver on his mobile phone and similarly by nearby witnesses who subsequently posted their video footage on YouTube. All videos show the back of the bus alight along with the interior and engine bay before the gas ignited.

2.15 The venting through the ruptured line at the solenoid valve occurred 19 minutes after the fire was reported to the driver by the motorist following the bus. Fire and Rescue NSW units arrived on scene just before the venting occurred.

2.16 As the videos showed no venting to be occurring from the relief valves on the gas storage cylinders and all cylinders were empty when inspected, it is concluded that all the gas was consumed through the ruptured line at the solenoid valve. Had the emergency gas isolation valve been activated, the cylinders would have vented separately through their relief valves and to the sides of the cylinders when the pressure and/or temperature rose to critical levels. Based on the fact that the bus had travelled 97 km since being refuelled the previous day, it is estimated the pressure in the CNG cylinders would have been approximately 188 bar when the fire started.

2.17 The driver did not notice any loss of power or misfiring of the engine prior to the incident which might have indicated a leak in the gas supply to the engine. A report of the bus misfiring at low speeds and being sluggish was made on 27 April 2011. This was identified as being due to a gas leak at the gas filter on the high pressure inlet side of the supply which was duly repaired at the Botany workshop.[11]

2.18 Any excess gas not used by the engine is vented unpressurised to the atmosphere above the roof line on the offside rear of the bus through a stainless steel pipe. A fitting on this pipe, after the main relief valve, was found to be loose by one complete turn. A gas leak from this fitting is only likely to have occurred intermittently, if at all, during normal operation, and

11 Work Order PC 7309 dated 27 April 2011.

only if there was an excess of CNG not required by the engine. Additionally, there was no potential ignition source in the immediate area of the fitting. It was concluded, therefore, to be most unlikely that this loose fitting contributed to the cause of the fire.

2.19 In its report, Ingenieurbüro Gottwald concluded that, when the solenoid valve was replaced, the high pressure line fitting was screwed in at an angle (cross-threaded) eventually loosening such that gas could escape and ignite on contact with a spark or hot components in the engine bay.[12] Evidence supporting a contrary view would appear to be:

- the time that had elapsed since the solenoid valve was replaced - 16 January 2008;
- that a leak would have become apparent by adversely affecting the engine's performance;
- that no leak or fault was detected in the annual gas system inspections;
- the fire pattern;
- the driver's observations; and
- the progress of the fire as recorded on videos.

Oil leak

2.20 There was no oil residue or obvious effects from fire on the underside of the engine. The engine block, sump and cylinder heads survived intact and showed no signs of oil loss. The lines to the oil filters were undamaged and the plastic covers on the filter housing, located higher on the engine, were only partially burnt.

2.21 The hydraulic reservoir for the power steering was destroyed in the fire. However, there was a residue of hydraulic oil present on the offside of the engine which had come from the hydraulic steering pump inlet connection. This hydraulic oil had flowed vertically downwards and not trailed towards the rear of the engine, indicating it was deposited after the bus had caught fire and stopped. It is considered most likely that heat from the fire caused the washer at the pump inlet connection to fail thus allowing oil to leak out.

12 Ingenieurbüro Gottwald, Fire damage, EXPERT REPORT E 0811098, 17 October 2011 [Translation]

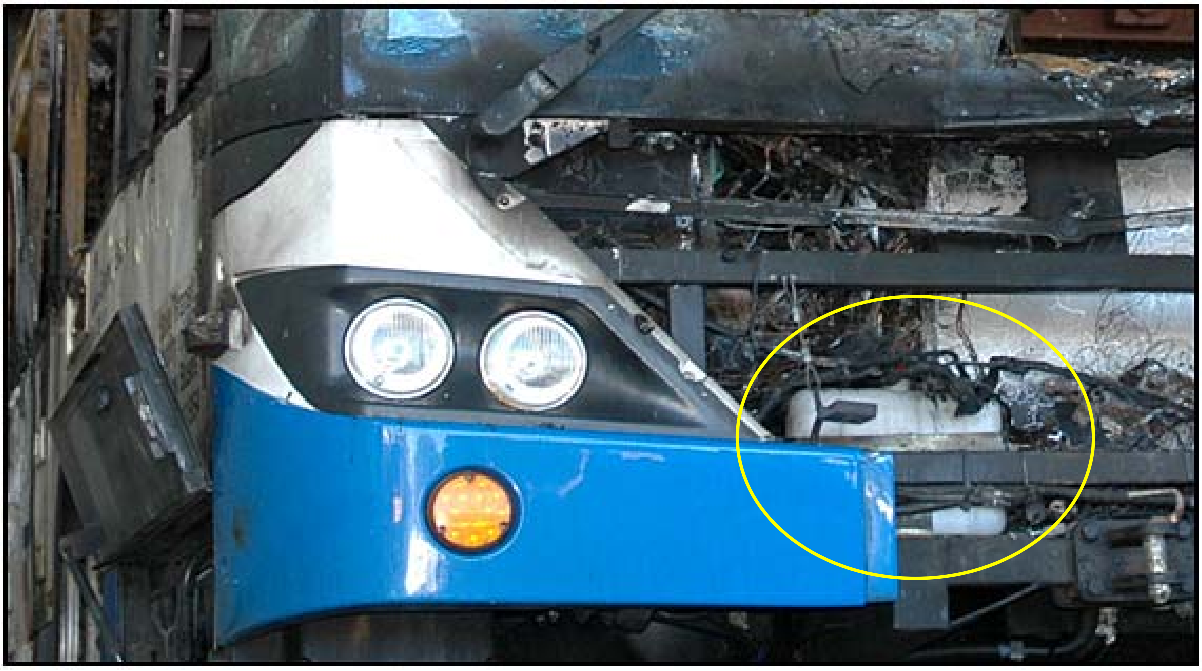
2.22 The engine sump was drained and the 33 litres of oil obtained was found to be clean and of the correct volume in accordance with the manufacturer's specifications. Examination of the incident site indicated there had been no major oil leak onto the bitumen road surface at, or leading up to that location.

2.23 The oil supply pipe to the turbocharger was removed and examined by an independent metallurgist contracted by the STA. This examination found no evidence of fractures or pin holes in the oil supply pipe which would have allowed oil to spray out onto a hot surface.

2.24 The rubber air inlet hose to the turbocharger was burnt on the top surface only. The hose was removed to permit an examination of the turbocharger fan blades. They were found to be intact and the rotor could be spun easily with finger pressure. This indicated that there had not been any substantial interruption to either coolant supply or oil lubrication which would have resulted in the turbocharger rotor seizing or being damaged. It was concluded, therefore, that the turbocharger could be eliminated as being the source of the fire.

Coolant

2.25 Examination of the interior section of the heat exchanger on the offside of the bus showed a clear line where the lower section had not melted, indicating that the coolant in the lower section had prevented it from melting. The coolant header tank mounted at the rear of the bus had completely melted indicating that the reservoir was empty prior to the fire. In contrast, the plastic windscreen washer bottle located in the front of the bus remained intact and was full of water, although all other components around it had been destroyed (see *Photograph 4*). The conditions as described are indicative of the possible loss of coolant in the heat exchanger and coolant reservoir before the fire commenced. A significant loss of coolant would result in a substantial rise in the operating temperature of the engine.



Photograph 4: Windscreen washer bottle

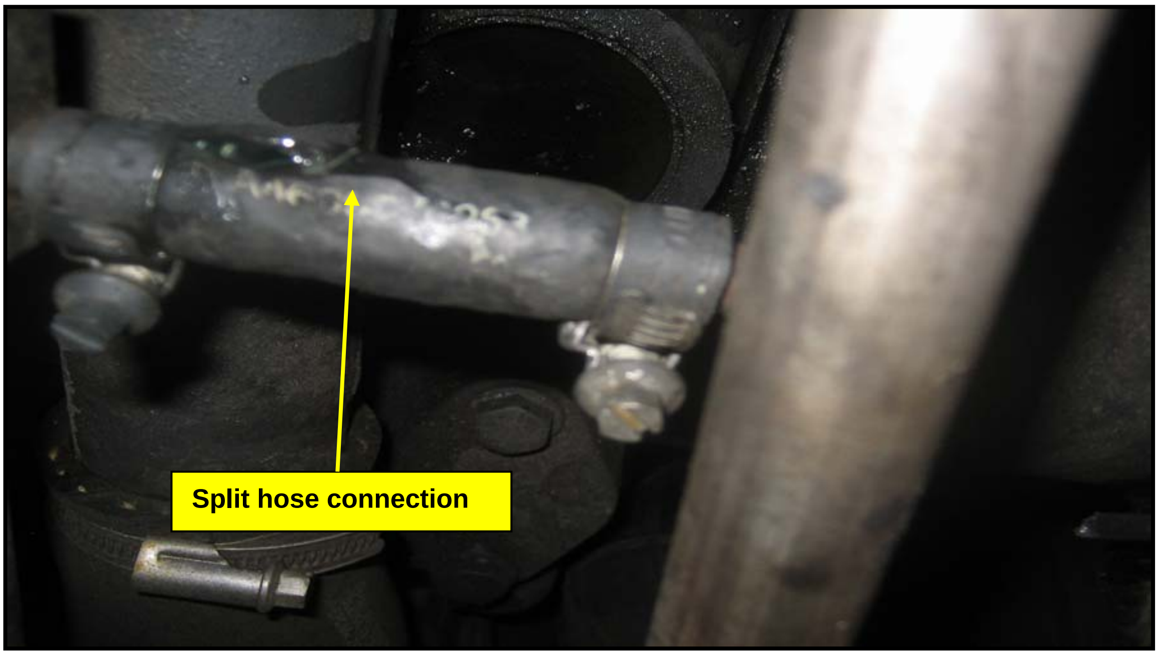
2.26 With the engine removed from the bus, a more detailed inspection was made to determine the cause of the fire. Examination of the coolant system showed the flexible rubber connection between the coolant return line from the turbocharger and a 'T' fitting was destroyed by the fire (see *Photograph 5*). The steel piping from the turbocharger was 18mm out of alignment with the 'T' fitting to which it was connected. This misalignment would have placed additional stress on the rubber hose, exacerbated by engine vibration. The coolant return line was supposed to have been replaced on 14 December 2010 but was not (see Servicing and Maintenance).

2.27 There was also a split and fire damage to the flexible rubber reduction fitting on the main coolant supply pipe running along the top of the engine block, near the engine compressor (see *Photograph 6*). The main coolant reduction hose had also been severely damaged by fire on the top surface. It could not be determined if coolant leaking from the split in this hose was the cause of the fire or was a consequence of the fire.

Photograph 5: Coolant return hose fitting misalignment

Photograph 6: Main coolant line reduction hose

2.28 On 11 August 2011, the flexible rubber connection between the coolant return line from the turbocharger and a 'T' fitting was found to have split on another OC500 LE CNG bus. This split in the hose resulted in a considerable amount of coolant being sprayed onto the engine (see *Photograph 7*). On this occasion the driver received a low coolant alarm and responded immediately by turning off the engine's ignition. He reported observing a large amount of steam emanating from the top of the engine. It is believed this steam was caused by the water content in the coolant boiling off on coming into contact with the hot surface of the engine.



Photograph 7: Split coolant return rubber connection

2.29 After the coolant leak had been examined by OTSI and the Mercedes-Benz investigators, the bus was left standing for several hours before being restarted and driven a short distance (about 200 metres) from the holding area to the depot workshop. On arrival at the workshop, it was found that the residual ethylene glycol from the coolant had pooled on the engine and had ignited while the bus was being moved. The turbocharger coolant return line hose on this bus was identical to the one on MO4878, having also not yet been replaced.

2.30 The recommended coolant for use on OC500 LE CNG model buses was a mixture of 50% water and 50% ethylene glycol. A sample of the coolant was taken from MO4878 on 12 October 2011 and subjected to chemical analysis at the University of NSW (UNSW) Chemical Consulting Laboratory, Mark Wainwright Analytical Centre. It was determined that the specific gravity of the coolant was approximately 1.08 with a water content of 66%. There is no plausible explanation as to why the water content of the sample was higher than 50% other than that the header tank may have been topped up at some stage with fresh water rather than coolant mixture.

2.31 The Western Australia Public Transport Authority commissioned a consulting engineer's report into a fire which destroyed a Transperth Mercedes-Benz OC500 LE CNG bus on 15 December 2009. This report concluded: "*The fairly high probability that there was a glycol leak and the somewhat makeshift nature of the modified 'T' piece gives rise to the possibility that this pipe may be implicated in this fire"*.[13] The circumstantial evidence supporting the conclusion was a low coolant level alarm, a trail on the road leading to the bus, judged to be most probably coolant, and the driver's report of "'*whitish' smoke*" billowing from under the nearside of the engine compartment.

2.32 An analysis of the characteristics of ethylene glycol-based coolants indicates that under certain conditions coolant can ignite.[14] This occurs when the water content of the coolant is evaporated off leaving pooling of the residual ethylene glycol. It can also ignite in circumstances where the glycol impregnates other materials such as lagging or shielding and is then exposed to a heat source and air.

2.33 With the engine removed from MO4878, investigators were able to determine that the initial seat of the fire was located on top of the engine near where the compressor is mounted. This is immediately below the rear floor hatch. The initial seat of the fire was also in the immediate proximity of the small hose connection on the coolant return line from the turbocharger.

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13 Martin E Simms & Associates Pty Ltd, *Report on a Fire in CNG Bus TP1854*, Report Reference 4328-MES-02, dated 1 February 2010.

14 Hull WC et al, "Analysis of Ethylene Glycol-based Engine Coolant as a Vehicle Fire Fuel', International Symposium *on Fire Investigation Science and Technology*, 2008.

Servicing and Maintenance

2.34 In July 2010 Mercedes-Benz ordered the upgrade of a number of M447 hLAG engine components.[15] The work involved included the replacement of:

- the turbocharger heat shield,
- the oil feed lines to the turbocharger,
- the manifold heat shield,
- the air compressor oil feed line, and
- the coolant return line from the turbocharger to the compressor.

2.35 Mercedes-Benz issued a Technical Information Bulletin (TS-CV-20-11) in July 2010 advising that the coolant hose secured to the 'T' piece from the compressor coolant pipe and the associated hose clamps had been superseded. The replacement of these parts was incorporated with other work to be completed under Vehicle Safety Recall RC 832 *Turbocharger and Air Compressor Modifications* which was dated 20 July 2010.

2.36 On 19 September 2011, Mercedes-Benz Australia/Pacific Pty Ltd advised Mercedes-Benz Huntingwood that "*it would appear that there was some confusion during the initial release of this Recall* [RC 832] *and it may not have been completed on all vehicles"*. On 23 September 2011, Mercedes-Benz advised the STA that Mercedes-Benz had instructed their dealership to complete the work on STA buses. The STA states it was not aware of the requirement until then. Mercedes-Benz explained that STA buses were not included in the original list of vehicles to have the coolant pipe replaced. Mercedes-Benz further explained that *"further research has shown that TS-CV-20-11 is applicable to the STA busses"* which would have included MO 4878 if it had survived the fire.

2.37 An examination of the service records for MO4878 since its introduction into service showed that all regular servicing and maintenance had been carried out as recommended by the manufacturer, other than the changeover of the coolant connecting hose as indicated in RC 832. There was no indication from the service records that a lack of maintenance or servicing could have contributed to creating a potential fire risk.

15 Recall Notices - 0C500 LE CNG – M447 hLAG RC722, RC766 and RC832.

Development of the Fire

2.38 Examination of the fire pattern on the top of the engine, the sub-frame and under floor areas with the engine removed, established that the seat of the fire was located under the rear floor inspection hatch. This was the area of most severe damage and greatest heat effect on the engine metal. Hoses in the area that were not destroyed were damaged on the surfaces exposed to the fire. Also in this area was a considerable amount of electrical wiring to the electronic control management unit, all of which had been wrapped in plastic binding, which was consumed in the fire.

2.39 The turbocharger coolant return line connecting hose and connecting reduction hose on the main coolant line were located in the area immediately below the hatch. If a coolant leak were to occur in this area, the fluid could pool on top of the engine block as was the case with the bus that suffered a split connecting hose on 11 August 2011.

2.40 There was no corresponding fire pattern to the rear of the bus hatch, especially near the CNG lines or on the sill between the engine bay and the rear window, which would indicate that the initial seat of the fire was in this area. The damage to various fittings and hoses attached to the engine was consistent with the effect of a fire commencing in the area under the rear floor hatch.

2.41 Analysis of the fire pattern on the underneath of the floor of the bus and on the engine indicated that the fire initially entered the inside of the bus through the small rearmost floor hatch which had completely burnt through (see *Photograph 8*). The second last floor hatch had also been severely damaged by fire although not burnt through completely. The hatch under the rear passenger bench seat was also severely damaged although there was a section of stainless steel shielding under the hatch.

2.42 As evidenced by the fire pattern radiating from the small hatch, the fire spread into the interior of the bus around the hatch then along both sides of the rear passenger seat, to both sides of the bus and towards the roof. This is consistent with the video evidence, the driver's statement and there being comparatively limited damage to fibreglass side panelling.

Photograph 8: Rear floor hatches

2.43 The floor hatches were not protected with stainless steel shielding like the other areas of the engine bay except for the rear seat hatch which, despite having some shielding, was still severely damaged. Also, the floor hatches are made of much thinner plywood than the rest of the floor; 12mm compared to 16.2mm. These bus floor hatches provided the area of least resistance to the fire and allowed the flames into the interior of the bus.

Mercedes-Benz 0C500 LE CNG Bus Fire in Australia

2.44 STA experienced one other fire in its fleet of 255 Mercedes-Benz OC500 LE CNG buses between June 2008 and July 2011.[16] The only other known operator currently using this model of bus in Australia is Transperth which has 480 operating in the Perth metropolitan area. Transperth has experienced 11 fires in this model bus since the commencement of their introduction into service in 2005, although all these fires occurred in 2008 and 2009. Four buses were destroyed while fires on six were extinguished by the bus driver before major damage was caused. The remaining bus was saved by a

16 STA bus MO1813 experienced a fire on 27 August 2008.

recently fitted fire suppression unit.[17] Of the buses destroyed, three fires were attributed to faulty oil supply pipes to the turbocharger and the fourth to a coolant leak.

Other Safety Issues

Driver Training

2.45 At no stage did the driver shut off the CNG supply which could have been done either internally from behind his seat or externally at the rear of the bus. Depriving the fire of this major source of fuel may have impeded its rate of development, thus giving fire fighters greater opportunity to contain and extinguish it.

2.46 Although the bus was equipped with a portable fire extinguisher, it appears that instructions to drivers on how to respond to a bus fire were unclear. Some drivers indicated that they were told not to open side or rear engine hatches for the sake of their own safety. Some said they did not have a key to open the engine bay. Yet others indicated that they thought they should open the engine bay and had the appropriate key.

2.47 The effectiveness of a dry powder extinguisher relies on the powder blanketing the fire from above. Without opening the engine bay hatches, drivers are unable to accurately direct the dry powder at the seat of a fire. An alternative is to discharge the extinguisher under the sides and generally towards the location of the engine area. This is unlikely to be effective as is evidenced in this instance.

2.48 Residue of the powder from the extinguisher remained evident on areas of the chassis and other components indicating that the discharge of powder was not effective in blanketing the fire source on top of the motor. The engine, chassis, sub-frame and engine appendages blocked the powder from its target.

2.49 The investigation found that there were deficiencies in the training of drivers in handling this type of incident. They had not received clear instructions or, in some cases, any instructions to isolate the CNG supply and evacuate

17 Transperth has fitted all buses in the fleet with fire suppression units as a result.

passengers immediately before attempting to fight the fire. Additionally, they had no basic training in first attack fire fighting procedures, especially instruction in the use and effectiveness of dry powder extinguishers.

2.50 A structured training programme in emergency procedures for drivers on each type of bus was lacking. Long term employees had received their initial training on other bus models which ran on different fuel but no subsequent refresher training. Comprehensive conversion training in emergency procedures was not provided at all STA depots when the CNG buses entered service.

Network Control

2.51 At no time during radio communications between the Network Control and the driver did the operator ask the driver if the bus was CNG fuelled, nor did he remind him to isolate the gas supply. Although radio operators cannot be expected to know by bus registration the make and fuel type of every bus in the fleet, it would be advantageous in the case of fire if they could establish if the bus is CNG powered and, if so, remind the driver to isolate the gas supply.

2.52 It could be critical for emergency services to be forewarned of particular hazards they are likely to encounter when deployed. With CNG fuelled bus fires, there is the danger of jets of venting gas igniting or storage cylinders exploding. The danger template is therefore larger and may require greater and more diverse resources to protect lives and property.

Dangers of CNG Fuel in Fire Incidents

2.53 The use of CNG has been growing in transit and other fleet vehicles in response to increasingly stringent emissions standards. While CNG has some benefits relating to reduced emissions compared with other fuels, its use also introduces different fire safety risks than those associated with more conventionally powered vehicles. A study published in 2004 concluded that CNG school buses could be expected to be significantly "*more prone to fire fatality*" than diesel powered buses.[18]

[18] Chamberlain, S *Development of a Physics of Failure Model and Quantitative Assessment of the Fire Fatality Risks of Compressed Natural Gas Bus Cylinders*", PhD Dissertation, U.Maryland, 2004.

2.54 Catastrophic rupture of a pressure vessel containing CNG will result in a rapid increase in the volume of the gas. This rapid mixing with air in the presence of an ignition source will form a fireball as soon as a flammable mixture is achieved. Also, a jet flame can result from the pressurised release of CNG from a crack in a line in the presence of an ignition source as was the case in this incident.

2.55 CNG cylinders can explode if overheated or over pressurised. In Queensland there have been two recent incidents of CNG cylinders exploding on buses, one in 2008 and one in 2012. In both cases, other vehicles over 100 metres from the site of the explosion were damaged.[19] Over-pressurisation or cylinder failure has been attributed as the cause on both of these occasions.

2.56 In August 2011 in India, five people, including two children, were killed when the CNG cylinder of a bus they were travelling on exploded. The bus caught fire immediately after the blast. In this incident defective manufacturing of the CNG cylinder was indicated as the cause.

2.57 In December 2011, a CNG powered bus suffered a catastrophic failure of a cylinder while stopped at traffic lights in Seoul, South Korea. The bus was torn apart, nearby windows were shattered and 17 people were injured including passengers, riders and pedestrians. Seoul's bus fleet consists of approximately 95% CNG powered buses.

Remedial Actions

2.58 In response to this incident the STA implemented a number of remedial actions:

- All Mercedes-Benz OC500 LE CNG and 0500 diesel powered buses were immediately inspected and a weekly checking program initiated.

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19 CNG storage cylinders involved in the incidents in Queensland, India and South Korea were Type 4 cylinders comprising of a non-metallic liner over which an overwrap of carbon fibre or fibreglass is applied in a full wrapped pattern over the entire liner. The STA CNG buses are fitted with Type 2 cylinders comprising of a metallic liner over which an overwrap of carbon fibre or fibreglass is applied in a hoop wrapped pattern over the liner’s cylinder sidewall. They are rated at a higher burst pressure than full composite cylinders (even with damage to the outer wrapping) but are heavier and so increase the tare weight of a vehicle.

- A training programme was implemented for all drivers incorporating the need to identify the fuel type of their bus when reporting a fire or thermal incident and, on CNG buses, the need to immediately isolate the CNG.
- Network Control operators were instructed to remind all drivers when they reported incidents to isolate the CNG if applicable.
- Network Control operators were instructed to determine the fuel supply of the bus for the information of emergency services when an incident is reported.
- A review has been conducted of the instructions to drivers as to correct procedures for evacuation of passengers and for use of fire extinguishers.
- All OC500 LE CNG buses have had the return coolant line and connecting hose fitting replaced.
- Tenders have been called for the retrofitting of fire suppression systems on all OC500 LE CNG buses.

2.59 The STA has stated its intention to have fire suppression fitted to all high risk vehicles in the future, both diesel and CNG fuelled. Further, STA is of the view that the supply and fitting of fire suppression should be included as part of the standard specifications for buses.

PART 3 FINDINGS

3.1 The investigation found that the most likely cause of the fire on STA bus MO4878 was coolant being sprayed onto the engine from a split hose connection on the turbocharger coolant return line to the compressor. The water content of the coolant evaporated on the hot surface of the engine allowing the residual ethylene glycol to crystallise and ignite. With the loss of coolant from the engine system, the external engine temperature to which the coolant was exposed would have risen progressively.

3.2 As the fire intensified, it burnt through the rear floor hatch and ignited the seating and other combustible interior materials. Although the timber plywood floor hatches were the most vulnerable area, they were not protected with stainless steel shielding like other areas of the engine bay.

3.3 Some 19 minutes after the initial fire was detected, the connection of the CNG line at the solenoid valve succumbed to the intense temperature and resultant increase in pressure and vented in a jet of flame.

3.4 At no stage did the driver shut off the CNG supply which could have been done either internally or externally. Depriving the fire of this major source of fuel may have impeded its rate of development, thus giving fire fighters greater opportunity to contain and extinguish it.

3.5 The dry powder portable extinguisher with which the bus was equipped was not effective as it could not be directed at the fire.

3.6 There were deficiencies in the training of drivers in handling a vehicle fire, in the provision of conversion training on the introduction of a new make or model of bus, and in providing refresher training.

3.7 It was identified that Network Control personnel could assist in emergencies involving gas powered buses by reminding drivers to shut off fuel supplies, and by forewarning emergency services personnel of any known additional hazards they may confront at the fire site.

3.8 The nature and extent of remedial action undertaken as a result of this incident precludes the need for recommendations for further action by the State Transit Authority.

PART 4 SUBMISSIONS AND ACKNOWLEDGEMENTS

Submissions

The Chief Investigator forwarded a copy of the Draft Report to the Directly Involved Parties (DIPs) to provide them with the opportunity to contribute to the compilation of the Final Report by verifying the factual information, scrutinising the analysis, findings and recommendations, and to submit recommendations for amendments to the Draft Report that they believed would enhance the accuracy, logic, integrity and resilience of the Investigation Report. The following DIPs were invited to make submissions on the Draft Report:

- Custom Coaches Pty Ltd
- Fire & Rescue NSW
- Independent Transport Safety Regulator
- Mercedes-Benz Australia/Pacific
- NSW State Transit Authority
- Rail Tram and Bus Union NSW Branch
- Transperth
- Transport for NSW

Submissions were received from all but the Independent Transport Safety Regulator and Transperth.

The Chief Investigator considered all representations made by DIPs and responded to the author of each of the submissions advising which of their recommended amendments would be incorporated in the Final Report, and those that would not. Where any recommended amendment was excluded, the reasons for doing so were explained

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- Custom Coaches NSW
- Fire and Rescue NSW- Fire Investigation and Research Unit

- Mercedes-Benz Australia/Pacific Pty Ltd
- State Transit Authority – Sydney Buses NSW
- Transperth- Public Transport Authority- Perth WA
- Transport Safety Victoria
- University Of New South Wales – Mark Wainwright Analytical Centre