ECTOS (Ecological City Transport System) Deliverable # 6

Contract No: EVK4-CT-2000-00033



Report on Maintenance Structure and Equipment

ECTOS - PROJECT DELIVERABLE MAY 2003

This document provides a description of the provisions for maintaining the Mercedes-Benz fuel cell buses to be operated in Reykjavik.

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1 Scope of Fuel Cell Bus Maintenance Concept

This document addresses aspects of service and maintenance of the Mercedes-Benz Citaro fuel cell powered bus. Specifically, it details:

- facility requirements as they pertain to accessibility and service of fuel cell engine components;
- special tool requirements specific to fuel cell related equipment;
- routine maintenance schedule expectations for the fuel cell engine;
- major fuel cell engine component removal and replacement concepts;
- documentation plan; and,
- training plan

2 Maintenance Facility

2.1 Sizes and Weights of the Fuel Cell Bus

For moving the buses into buildings, e.g. maintenance and parking buildings, the following sizes and weights need to be taken into consideration.

Figure: Sizes and weights of the fuel cell bus.



Figure: Actual turning circles of Citaro fuel cell bus.

2.2 Physical

The majority of the components of the fuel cell engine is located on the bus roof. Accordingly, access to the roof for maintenance purposes will be frequent. This necessitates a maintenance facility with the following equipment:

- Maintenance superstructure with walkways to provide safe access at roof level (approx. a height of 3,70 m). The walking height of the walkway should be the roof height of a standard Citaro bus, i.e. 2,90 m, or slightly higher, i.e. up to 3,10 m to allow for an easy access to the roof components. Please consider the maximum allowable step over barrier, typically 50 cm, which may vary from site to site.
- Overhead 1,1 ton gantry hoist to lift heavy roof modules and place them on the walkways or floor. (For sizes and weights of major components cf. section 5.) The hoist can be affixed to the ceiling or floor of the maintenance facility or the maintenance superstructure. In case a 500 kg gantry hoist exists this equipment will be sufficient for almost all work tasks. If however a new acquirement will be made a 1,1 ton gantry hoist ought to be considered.

Due to the height of the bus (almost 3,70 m) the lifting height of the hoist needs to be sufficient to remove all components safely.

- Standard bus wheel lifts to adjust bus height relative to maintenance superstructure walkways (6,500 kg capacity each)
- Adequate space to accommodate the bus, maintenance superstructure, work tables and tools with clearance on at least three sides to move module trolleys with ease. Accordingly, this space ought to be at least 6 m (better 8 m) wide and 18 m long. The width needs to accommodate the bus and walkways on both sides. Moreover, the roof modules need to be located on the floor in either position next to the bus.
- Flat floor with drain
- Repairs of the fuel cell stack modules comprise the removal of components (humidifiers, filters, etc.) and cell rows, i.e. part assemblies of elementary fuel cells. To allow for these repairs a dedicated clean room (medium cleanliness requirements, workshop office standard) is required.



NOTE: Most component enclosures on the bus roof can be walked on. Exceptions are clearly labelled and have indications where to step onto instead.

The maintenance superstructure concept is illustrated below.

Figure: Walkways for safe roof access during inspection and repairs. The walkways can in principle widely resemble construction scaffolding. (Source of figure: Ballard Inc., adapted)

Figure: Bus and component vertical measures of the Citaro fuel cell bus.

Figure: Bus and component longitudinal measures of the Citaro fuel cell bus.

Regarding the required height for the bus in terms of garage bay height (door and working headroom height) and hoisting crane working level the following vertical measures need to be considered:

- The maximum height of the vehicle is 3,70 m. However, if a door is enlarged a safety margin of approx. 10 to 20 centimetres should be considered to avoid that the bus scratches on the top bar of the open door if it is moved quickly in and out of the bus bay.
- The maximum height of the bus is determined by the radiator module (77 cm high, cf. section 5).
- All other modules are lower in height: hydrogen storage module (50 cm), cooling module (52 cm), fuel cell stack modules (50 cm) and the air condition system with clearly less than 50 cm height.

All modules might have to be removed from the roof for repair during the course of the project therefore the hoisting crane should allow to remove the modules and place them on the garage floor or walkways.

Figure: Figure showing need for vertical clearance for hoisting roof components and spreader bar dimensions.

The following figures show a gantry hoist mounted on the ceiling above the walkway and a wheel lift.

Figure: Gantry hoist with load lifting capacity of 1,1 tons. (Source of figure: Ballard Inc., adapted)

Figure: Wheel lift with 6.500 kg lift capacity. (Source of figure: Ballard Inc., adapted)

2.3 Gases

The maintenance facility must include the following gas provisions:

- Regulated 8 barg compressed shop air
- Regulated 2 barg pure nitrogen or clean (no grease or oil) air supply for leak tests with associated hoses and fittings
- Regulated 8 barg pure nitrogen for tank purging with associated hoses and fittings (one bottle with approximately 9 kg at 200 Bar)
- Hydrogen venting capability with associated hoses and fittings (typically part of fuelling station, cf. section 3.2.4 "de-fuelling connector")

2.4 Fluids

The maintenance facility must provide access to the following fluids:

Fluid specification		Estimated annual use in litres ¹		
•	De-ionised water filtration system or bottled supply - less than 2,0 $\mu\text{s/cm}$ (supplier Brenntag)		600	
	•	alternatives: within the on-site electrolys is verified that source could	de-ionised water of the required quality is most likely produced er and steam-reformer water filtration units. If conductivity level be used instead of purchased fluid.	
•	Сι	ustom 50% pure (no additive	s) ethylene glycol / 50% de-ionised water solution	240
	•	factory fitted type:	BASF Glysantin J 21725, BASF Ludwigshafen/Germany	
•	St eq	andard Mercedes-Benz Cita juivalent	ro synthetic automatic transmission fluid or approved ZF	200
•	M	otor Oil with the following spe	ecification:	200
	•	viscosity class (SAE grade)	: 0 W 30	
	•	motor oil type:	fully sythetic	
	•	specifications:	API, SJ, SK, SL	
	•	factory fitted type:	Titan Supersyn SL SAE 0 W 30, Fuchs Oil, Mannheim/Ger.	
	•	alternatives (motor oil):	BP Visco 7000 Special SAE 0 W 30,	

¹ Most of these estimated values are fairly conservative, i.e. taken on the high side, esp. transmission fluid. More precise estimates will follow closer to the date of actual start of demonstration. ECTOS - PROJECT DELIVERABLE MAY 2003

		C	astrol Formula SLX SAE 0 W 30,	
		N	obil 1 Fuel Economy SAE 0 W 30	
•	H	ydraulic Oil (for hydraulic drive	s of ventilator and water pump) with the following specification:	500
	•	viscosity class:	VG 32	
	•	viscosity index:	> 140	
	•	hydraulic oil type:	HVLP	
	•	properties:	emulsifying, detergent	
	•	pour point:	< - 30 °C	
	•	factory fitted type:	Renolin B 32 HVI , Fuchs Oil, Mannheim/Germany	
	•	alternatives:	BP Bartran HV32, Aral Vitam HF 32, Mobil DTE 10-ISO-VG-Klasse 32	
•	С	itranox cleanser		
•	Та	ap water and drain		

2.5 Electrical

The maintenance facility must include the following electrical provisions:

- Multiple 230 VAC, 50 Hz electrical outlets for power tools
- Suitable high voltage supply to power wheel lifts
- Facility ground point

2.6 Miscellaneous

The maintenance facility must include the following miscellaneous equipment:

- Work tables
- Pallet jack
- Clean (no grease or oil) wash station or basin
- Short ladders and steps for component access
- Dedicated funnels and non-metal storage bins for fluids
- Standard hand tools
- Standard battery charger for diesel buses. Capacity 2*200 Ah.

2.7 Office

Minimum recommendation for facility office

- 230 VAC, 50 Hz electrical outlets
- Storage locker for diagnostic equipment (1 * 2 * 1 m)
- Desk
- PC hook-up, including internet connection for downloads of updated bus system software
- Fax line
- Phone line
- Filing cabinet (1.5 * 0.5 * 0.5 m)
- Shelving (1.5 * 0.5 * 2 m)

2.7.8 IT Requirements

As the on-site technicians will provide Laptops or PCs the IT-requirements are:

- one access point to the internet at standard data rate, e.g. ISDN (64 or 128 kBit/sec), with a fix IP-address
- one access point to the internet at increased data rate (high speed access), again with a fix IP-address

The need for the fix IP-addresses is that the central server at Ballard in Vancouver will only allow access from outside via pre-defined IP-addresses. Thus, the chosen two IP-addresses of all sites (#1 to #10) will be stored in the central server. If a computer dials via

the internet into the central server, the server will compare the IP-address of the calling party to the stored list of IP-addresses and will thus grant or block access.

A symmetric high speed internet access is required to allow for an upload of the daily operational data, which is automatically recorded by a data acquisition circuit in the bus. And moreover a software download to the site is required from time to time. In both directions data of several megabytes needs to be transmitted.

Figure: Overall IT-requirement for European Bus Project including Ballard Vancouver installations. Fast Internet Access required at Transit Authority Office.

2.8 Training Room

The training room for onsite training should accommodate up to twenty people.

Recommendation for training room environment

- 230 VAC electrical outlets
- Overhead projector with screen
- Trainers desk
- Chairs and tables
- White Board, or Chalk Board or Flip Chart easel

2.9 Onsite Storage

Storage is required for fuel cell bus related parts and supplies.

Minimum recommendation for onsite storage

- Minimum area (5 * 2 m)
- Metal shelving (5 * 2 * 1.5 m)
- Space in existing transit facility bulk oil storage area (2 sq. m for 2*250 L drums)
- Access to fork lift and pallet jack to move and install fuel cell equipment

NOTE: The access door to the storage room needs to have an opening of 1,00 m minimum.

2.10 Stack Repair Area

Repairs of the fuel cell stack modules comprise the removal of components (humidifiers, filters, etc.) and cell rows, i.e. part assemblies of elementary fuel cells. To allow for these repairs a dedicated clean room (medium cleanliness requirements, workshop office standard) is required.

• Minimum area (12 m²)

NOTE: The access door to the stack repair area needs to have an opening of 1,00 m minimum.

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2.11 Workshop

Adequate space to accommodate the bus, maintenance superstructure, work tables and tools with clearance on at least three sides to move module trolleys with ease. Accordingly, this space ought to be at least 6 m (better 8 m) wide and 18 m long. The width needs to accommodate the bus and walkways on both sides. Moreover, the roof modules need to be located on the floor in either position next to the bus.

• Minimum area (6 m * 18 m, 108 m²)

2.12 In-door Parking Area

In the instance that a prolonged repair effort on one bus prevents its immediate return into transit service, the regular inspection of the remaining vehicles is still required. To avoid blocking of the workshop area by this idle vehicle it is thus recommended to

- either consider a workshop area that is sufficiently large to park a second bus
- or to provide an in-door parking area either for the bus to be repaired or for the buses to be inspected

Hydrogen safety aspects need to be considered in both instances.

3 Special Tools

3.1 Fuel Cell Module Removal and Replacement

- Socket wrench extension for fuel cell module bolts
- Fuel cell module spreader bar
- Fuel cell stack module cart
- Fuel cell module glycol drain, flush and refill apparatus

All of this equipment will be supplied by Ballard/Ballard onsite personnel.

3.2 Fuel Cell Row Removal and Replacement

- Fuel cell stack spreader bar
- Fuel cell stack cart
- Cell row support jig
- Cell row spreader bar
- Cell row removal hoist
- Cell row table (clean)

All of this equipment will be supplied by Ballard/Ballard onsite personnel.

3.3 Leak Tests

- Leak test equipment
- Fuel cell module adapter plate
- Cell row adapter plates

All of this equipment will be supplied by Ballard/Ballard onsite personnel.

3.4 Miscellaneous

- Power train trolley
- General lifting devices, cradles and trolleys
- Non-sparking hand tools (these tools will be limited to very few manual wrenches, a list of required wrenches will be defined)
- Handheld fuel consumption meter or alternatively use of filling station dispenser measurements
- Bus lifting jacks (wheel lifts)
- Bus roof access platform (walkways)
- Standard bus repair tools
- Standard electrical multimeter-tester
- Portable hydrogen sensing equipment ("hydrogen sniffer")

This equipment needs to be supplied by the transit authority.

• Diagnostic equipment for transmission, coach (star diagnostics)

This diagnostic equipment will be supplied by Evobus onsite personnel.

- Diagnostic equipment for fuel cell engine
- Insulation test equipment
- Portable hydrogen sensing equipment ("hydrogen sniffer")

This diagnostic equipment will be supplied by Ballard onsite personnel.

4 Routine Inspections and Maintenance

The fuel cell engine requires routine maintenance at daily, 80-hour, 6,000 km, 12,000 km, 24,000 km, and 48,000 km intervals. Fuel cell engine service is cumulative at each interval and is in addition to standard coach service. The field service personnel will train transit authority technical staff for these work tasks and will assist in the work itself.

4.1 Daily Service

Approximate Daily Service Time: 1 hour

Daily Inspection and Service	
Check for fluid leaks or puddles	
Check water level	
Check lubrication oil level	
Check transmission fluid presence	
Inspect water traps	
Inspect oil detector	
Inspect air intake	
Inspect air exhaust	
Inspect burst disk vent cap	
Inspect canopies	
Inspect hydrogen diffuser	
Check stack module vent fans	
Check ground fault monitor resistance; replace water or de-ionising filters on failure	

4.2 80-Hour Service

Approximate 80-Hour Service Time: 6 hours

80-Hour Inspection and Service		
Inspect stack air inlet filters; replace as required		
Inspect air vents; clean as required		
Inspect filter minder; replace air intake filter if indicated		
Drain turbocharger oil trap		
Inspect lubrication oil sump magnetic plug		
Check hydraulic fluid level		
Check water/glycol level		
Inspect manifold hoses		
Clean stack module vent fan filter elements		
Perform array leak-down test		
Check cell voltage monitor		
Perform Fuel Delivery System / manifold leak test (sniffer)		
Check transmission fluid level		

4.3 6,000 km Service

Approximate 6,000 km Service Time: 12 hours

6000 km Inspection and Service		
Inspect high pressure circuit / motive pressure circuit / fuel delivery circuit components		
Inspect roof vent caps		
Replace hydrogen particulate filter		
Perform high pressure circuit leak test		
Perform Glycol System integrity test		
Perform stack module leak tests		
Inspect belts		
Check power cable connections		
Inspect radiator		
Inspect header tank outlet strainer		
Inspect HVAC compressor oil		
Inspect Hydrogen Leak Detection System sensors		
Perform motive pressure circuit leak test		
Compare high pressure gauge (filling box) and display (inside coach)		
Inspect transmission		
Replace transmission fluid and filters		

4.4 12,000 km Service

Approximate 12,000 km Service Time: 8 hours

12000 km Inspection and Service	
Obtain lubrication oil sample	
Obtain transmission fluid sample	
Obtain hydraulic fluid sample	
Check dump chopper resistance	
Check the motive pressure regulator assembly solenoid valve	

4.5 24,000 km Service

Approximate 24,000 km Service Time: 8 hours

24000 km Inspection and Service	
Replace bus chassis air intake filter	
Perform tank installation and external inspections	
Perform ground integrity tests	
Inspect filter assembly water strainers	
Replace transmission fluid and filters	
Replace Hydraulic System filter and fluid	
Replace Lubrication System filters and oil	

4.6 48,000 km Service

Approximate 48,000 km Service Time: 8 hours

48000 km Inspection and Service	
Perform hydrogen tank internal inspection	
Replace fuel module	
Inspect power train vibration mounts	
Replace water/glycol	

5 Major Component Removal and Replacement

Generally, repairs will be performed by field service staff onsite. However, to achieve the aim of the European Commission funded project, ECTOS, a transfer of knowledge to transit authority technical staff is mandatory. Therefore, support during repair tasks and willingness to learn fuel cell maintenance and repair work tasks by transit authority technical staff is highly valued.

As can be seen most work tasks involve mechanical work quite comparable to jobs to be performed on conventional vehicles. Thus knowledge in mechanics is highly valued. Staff having knowledge in electronics and electrics is also highly welcomed.

All figures shown in this section have been sourced from Ballard, Inc.

Major fuel cell engine components are located on the bus roof and in the engine compartment as illustrated below:



5.1 Fuel Cell Stack Modules

Each fuel cell stack module contains a fuel cell stack and portions of the fuel, air, humidification, and clean-glycol systems.

In-Situ Inspection and Repair

The fuel cell stack modules allow for in-situ inspection and maintenance of some components depending on their location within the module. The right side and left side modules have different access potential.

To access:

- 1. Open the cooling module lids. The lids are hinged and equipped with gas struts so that they will stay open by themselves.
- 2. Remove the sealing strips between the cooling module and stack modules.
- 3. Remove top, inboard and end stack module covers as required. Each cover is a separate panel.



Removal

The fuel cell stack modules must be removed for fuel cell stack and other component service.

To remove:

- 1. Open the cooling module lids. The lids are hinged and equipped with gas struts so that they will stay open by themselves.
- 2. Remove the sealing strips between the cooling module and stack modules.
- 3. Remove the cooling module rear panel.
- 4. Uncouple the fuel, air, clean-glycol, drain, power and control signal connections. Quick-disconnect fittings seal both sides of the clean-glycol circuit to minimise spillage. The stack module remains full of clean-glycol and humidification water (which is a closed circuit) during removal.
- 5. Remove mounting bolts at each corner (socket wrench extension required).
- 6. Remove top cover tapped hole plugs and affix fuel cell module spreader bar.
- 7. Use the hoist to remove stack module and place onto fuel cell stack module cart.

Disassembly

The fuel cell stack modules must be disassembled to access the fuel cell stack and other components.

To disassemble:

- 1. Use the fuel cell module glycol drain, flush and refill apparatus to drain the clean-glycol solution from the module and flush with tap water. The glycol solution may be reused if kept clean.
- 2. Drain the humidification water.
- 3. Remove all stack module covers.
- 4. Disconnect the lid from base.
- 5. Uncouple the fluid, gas and electrical connections from the fuel cell stack.
- 6. Attach lifting handle to lid.
- 7. Pivot lid away from base with fuel, air, water and glycol system components attached.
- 8. Remove fuel cell stack mounting bolts.
- 9. Attach fuel cell stack spreader bar to stack.
- 10. Use the hoist to remove fuel cell stack and place onto fuel cell stack cart.
- NOTE: The fuel, air, water and glycol system components are now fully accessible on the lid.

Β. Α. Fuel Cell Module Glycol Drain, Flush Covers and Refill Apparatus Handle Fuel Cell Stack Fluid, Gas Electrical and Mechanical Connections D. Fuel Cell Stack Fuel Cell Stack Mounting Bolts Spreader Bar Lid Service Fuel, Air, Water and Glycol System Components Here Base Hinge

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NOTE: Cell row removal and replacement must be performed in a separate, dedicated clean room/area.

- 11. Rotate the fuel cell stack cart so that the six cell rows are vertical.
- 12. Remove the cell row electrical linkage cables, tie rods and mounting hardware.
- 13. Affix the cell row support jigs.
- 14. Attach the cell row spreader bar to the desired cell row.
- 15. Use the cell row removal hoist to pull the cell row from the fuel cell stack.
- 16. Place the cell row on the clean cell row table.



5.2 Cooling Module

The cooling module interfaces with each fuel cell stack module and contains the majority of the clean-glycol, dirty-glycol, and hydraulic system components.

In-Situ Inspection and Repair

Many cooling module components can be serviced in-situ.

To access:

- 1. Open the cooling module lids. The lids are hinged and equipped with gas struts so that they will stay open by themselves.
- 2. Remove the sealing strips between the cooling module and stack modules.
- 3. Remove the cooling module rear panel.



Removal

The cooling module must be removed to service some components.

To remove:

- 1. Remove both stack modules (see Section 5.1).
- 2. Remove both cosmetic panels at either side of the bus in the vicinity of the cooling module.
- 3. Drain the dirty-glycol and hydraulic fluid. The cooling module remains full of clean-glycol during removal.
- 4. Disconnect all fluid, gas and electrical connections from both sides of the cooling module.
- 5. Uncouple electrical connections from connector box within cooling module.
- 6. Disconnect braces between cooling module sides and pipe support structures.
- 7. Remove mounting bolts (socket wrench extension required).
- 8. Close cooling module lids, remove tapped hole plugs and affix cooling module spreader bar.
- 9. Use the hoist to remove cooling module and place onto a suitable work surface, such as the fuel cell stack module cart.

Disassembly

The cooling module must be disassembled to access some components.

To disassemble:

1. Open the cooling module lids.

- 2. Remove the gas struts, lids, and front cover.
- 3. Use the fuel cell module glycol drain, flush and refill apparatus to drain the clean-glycol solution from the module and flush both the dirty- and clean-glycol circuits with tap water. The glycol solution may be reused if kept clean.

5.3 Hydrogen Storage Module

NOTE: Hydrogen storage module work to be performed by authorised personnel only.

The hydrogen storage module contains nine hydrogen storage tank assemblies (each with associated valves and pressure relief devices), a pressure regulator assembly, and some instrumentation.

In-Situ Inspection and Repair

Most hydrogen storage module components can be serviced in-situ.

Removal

The hydrogen storage module as a whole never needs to be removed from the bus, although individual tank assemblies may.

To remove an individual tank assembly:

- 1. Isolate and vent the tank assembly.
- 2. Disconnect all gas and electrical connections to the tank assembly.
- 3. Remove the tank assembly mounting brackets at either end.
- 4. Affix an appropriate spreader bar, such as the cooling module spreader bar.

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5. Use the hoist to remove the tank assembly.
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5.4 Radiator Module

The radiator module contains the two radiator cores, the hydraulic motors, and hydraulic fluid flow control equipment.

In-Situ Inspection and Repair

All radiator module components can be serviced in-situ.

5.5 Hydrogen Diffuser Module

The hydrogen diffuser module contains the diffuser fan, a heating tube, and an air/hydrogen mixing conduit.

In-Situ Inspection and Repair

The hydrogen diffuser module can be serviced in-situ.

5.6 Inverter Module

The inverter module receives DC electrical power from the fuel cell stacks and converts it into variable frequency, AC power to operate the drive motor.

Removal

- 1. Remove the access panel from the rear of the bus.
- 2. Uncouple all electrical connections.
- 3. Attach the hoist to the eye on the top of the inverter.
- 4. Disconnect the bottom mounting bolts (that attach the inverter module to the bottom mounting bracket) and then disconnect the top mounting bolts (that attach the top mounting bracket to the bus).
- 5. Allow the inverter module to swing out of the side of the bus.

5.7 Power Train

The power train contains the drive motor, transmission, gearcase and bus auxiliary equipment such as the alternators, the air brake compressor, the power steering pump, the radiator fan pump, the screw compressor and the air conditioning compressor.

In-Situ Inspection and Repair

Most power train components can be serviced in-situ via the engine compartment and surrounding access panels.

Removal

- 1. Drain the dirty-glycol, lubrication oil, and hydraulic fluid.
- 2. Disconnect all gas, fluid and electrical connections.
- 3. Disconnect the driveshaft.
- 4. Support the power train with the power train trolley.
- 5. Disconnect all mounting bolts.
- 6. Raise the bus until the power train is clear. Remove with all ancillary components still attached.

5.8 Control and Data Acquisition Systems

The control and data acquisition systems contain the fuel cell engine controller, the data acquisition computer, electrical power distribution equipment, and sensor signal conditioning equipment.

In-Situ Inspection and Repair

All control and data acquisition system components can be serviced in-situ.

6 Documentation

The bus will be supported by extensive operating and maintenance documentation.

6.1 Operator's Manual

• Evobus will supply a coach operating manual similar in form to their CNG bus manual, with a fuel cell specific appendix based on information supplied by BALLARD. This manual will be available in English, German, Spanish and Portuguese.

6.2 Maintenance Manuals

- BALLARD will supply a combined maintenance/service manual that pertains to fuel cell related components only. The manual will contain the following sections:
 - 1. Safety
 - 2. Introduction
 - 3. General Service Information
 - 4. Service Schedule
 - 5. Diagnostics
 - 6. Alarm and Fault Codes
 - 7. Power Train
 - 8. Stack Modules
 - 9. Air System
 - 10. Fuel Storage System

- 11. Fuel Delivery System
- 12. Humidification Water System
- 13. Primary Glycol System
- 14. Secondary Glycol System
- 15. Lubrication System
- 16. Hydraulic System
- 17. Electrical/Control System
- 18. Leak Detection System

Sections 7 to 18 will include routine maintenance procedures, as well as component removal, service and replacement information. This manual will be available in English, German, Spanish and Portuguese. This manual will be published as a single-volume book and will be available in hardcopy only.

• Evobus will supply separate maintenance and service manuals for all standard bus components. These manuals will be available in English, German, Spanish and Portuguese.

6.3 Parts Manuals

- BALLARD will supply a parts manual that pertains to fuel cell related components only. This manual will provide exploded-view graphics of all fuel cell related bus parts to the line-replaceable-unit (LRU) level. Part descriptions will be annotated in English, German, Spanish and Portuguese. This manual will be published as a single-volume book and will be available in hardcopy only.
- Evobus will supply a parts manual for all standard bus components. This manual will be available in English, German, Spanish and Portuguese.

6.4 Other Documentation

- BALLARD will compile a library of vendor-supplied information for third party components used within the fuel cell systems. This information will be reproduced as received from the vendor and will not be translated. This information is for the reference of BALLARD/Evobus personnel only and will be available at selected locations only, likely one copy per region.
- BALLARD will provide documentation to support training activities (see Section 7).
- BALLARD will provide other miscellaneous documentation, as required.

7 Training

The bus operation and maintenance will be supported by extensive operator, maintenance technician, and field service personnel training.

The different staff categories involved in onsite work at the operator's site are listed below:

Figure: Categories of onsite staff.

7.1 Operator's Training

This training is intended for transit agency bus driver *trainers*. This course will likely also be attended by other transit agency personnel, such as supervisors, schedulers, dispatchers, and people directly involved with the European program.

• This training will be a joint effort between BALLARD and Evobus. Evobus will be responsible for aspects of training that relate to standard coach operation. BALLARD will be responsible for aspects of training that pertain to the hydrogen/fuel cell nature of the bus; specifically:

orientation safety start-up operation (weight distribution) warnings and alarms shutdown

- Training will occur at each transit agency site, or at combined locations common to several agencies concurrent with bus delivery.
- Training will include classroom and hands-on aspects. Classroom training will be taught by an Evobus or BALLARD classroom instructor with concurrent translation into the native language. Hands-on training will occur on the bus through interaction with BALLARD/EvoBus field support personnel.
- The EvoBus operating manual is the primary reference for the course material. Additional training materials will consist of training booklets that provide copies of all classroom slides. All training materials will be available in English, German, Spanish and Portuguese.
- Course duration is 1 day. Some transit agencies may require more than 1 session depending on the number of participants and scheduling restraints.
- After training is complete, the transit agency trainers will train their individual drivers. The total number of drivers trained may be very large.

7.2 Coach Maintenance Training

This training is intended for transit agency technicians who will perform routine bus service. This course will likely also be attended by other transit agency personnel, such as supervisors, schedulers, and people directly involved with the European program.

- Evobus will supply training for all coach related maintenance and service activities according to their standard syllabus.
- Training will occur at each transit agency site, or at combined locations common to several agencies concurrent with bus delivery.
- Training may include classroom and hands-on aspects. All material will be taught by an Evobus instructor with concurrent translation into the native language.
- Training materials will be provided by EvoBus in English, German, Spanish and Portuguese.

7.3 Fuel Cell Engine Maintenance Training

BALLARD will provide fuel cell engine maintenance training. This training falls into three categories:

- 1. Fuel cell technology introductory training
- 2. Field service personnel training
- 3. Transit agency training

7.3.1 Fuel Cell Technology Introductory Training

This training is intended for all BALLARD and EvoBus field service personnel, *not* for the mechanics employed by the individual transit agencies.

• Training will provide the fundamentals of fuel cell technology, and will explore the following topics. Material will be non-hardware specific:

Introduction to Hydrogen Gas Manufacture

Storage

Transportation

Hydrogen Properties

Atomic Structure

Physical Properties

Chemical Properties

Hydrogen Gas Mixtures

Gas Laws

Safety

Hydrogen

High Temperatures

High Pressures

Electrical Shock

Chemical

Rotating Equipment

Physical

Facility Safety Systems

Standards

Fuel Cell Technology

Principle of Operation

Types of Fuel Cells

Fuel Cell Technology Use

PEM Fuel Cell Stacks

Fuel Cell Systems

Air System

Fuel System (Storage and Delivery)

Humidification System

Cooling System (Water, Clean Glycol and Dirty Glycol)

Lubrication System

Hydraulic System

Electrical/Control Systems

Power Train

Fuel Cell System Maintenance ECTOS - PROJECT DELIVERABLE MAY 2003

General

- Routine Maintenance
- Diagnostics

Hydrogen Use in Internal Combustion Engines

Fuel Cell Hybrid Electrics

Current Regulations

- Material will be taught by a classroom instructor, at one North American location, in English.
- Course duration is approximately 1 week.
- Training material will include a course manual in English.

7.3.2 Field Service Personnel Training

This training is intended for all BALLARD and EvoBus field service personnel, *not* for the mechanics employed by the individual transit agencies. This course is also applicable to other BALLARD or EvoBus employees who require in-depth knowledge of the bus and its service.

• The goal of this training is to enable personnel to troubleshoot and repair the bus. Topics covered may include:

Review of safety issues

Review of general service requirements

Detailed orientation to each system, its schematic, theory of operation, and the location and function of components (air, fuel, cooling, electrical, etc.).

Definition of all standard operating parameters (temperatures, pressures, etc.)

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Interpretation of warnings and alarms, and data/fault handling

Troubleshooting of all systems (what to look for, specific types of faults)

Tools and methods used to access the controller and DAC

Use of special tools (Hi-pot tester, portable gas detector, diagnostic equipment, cradles, etc.)

Routine maintenance requirements and procedures (daily, 80-hour, 6000 km, etc.)

Removal and replacement of major components (stack rows, inverter, etc.)

Maintenance and service reporting requirements and methods

- Material will be taught by 2 senior field service technicians, at BALLARD Vancouver, in English. The course will be hands-on with classroom support as appropriate. The course structure will be informal.
- Course duration is approximately 1 month.
- The maintenance manual will be the primary reference for the course material. Other material may be compiled and provided (in English), as appropriate.

7.3.3 Transit Agency Training

This training is intended for transit agency technicians who will perform routine bus service. This course will likely also be attended by other transit agency personnel, such as supervisors, schedulers, and people directly involved with the European program.

- Training will occur at each transit agency site, or at combined locations common to several agencies concurrent with bus delivery.
- BALLARD will supply training for all fuel cell related routine maintenance only and will include:

orientation safety system introduction general service information routine service schedule diagnostics alarm and fault codes daily service procedures 80-hour service procedures 6000 km service procedures

Training will include classroom and hands-on aspects. Classroom training will be taught by an BALLARD classroom instructor (in English) with concurrent translation into the native language. Hands-on training will occur on the bus through interaction with BALLARD/EvoBus field support personnel. The 2 senior field service technicians that performed the field service personnel training will remain at each transit agency for 3 weeks after delivery of the buses to provide hands-on training support.

- The maintenance manual is the primary reference for the course material. Additional training materials will consist of orientation and training booklets. The orientation booklet will introduce each system and show the location of each component within that system. The training booklets will provide copies of all classroom slides. All training materials will be available in English, German, Spanish and Portuguese.
- Course duration is 4-5 days.