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Final design of Toyota Europe FCM

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Towards a standardised fuel cell module

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Abstract: This deliverable contains the supplier specific design of the FCM according to the WP3 Standard

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1 Introduction

The fuel cell module is developed for the design targeted size HH_{AA} on its side [L1.020xH700xW680]. It has a high voltage output of 400～750VDC and a Net continuous system power output of 80kW (Pnet/BOL). It consists of a FC stack assy, all BOP's and control ECU's. The FC stack assy is composed of the stack itself (330cells) and the FC boost converter. The main BOP's are air compressor, FC water pump, H2 pump and PCU. It can be used in all sort of applications such as truck, bus, stationary, maritime, railroad and off road/special vehicles.

2 WP3 standard overview

The following sub-sections provide an overview of the WP3 standard definition, which is necessary to verify the compliance of the FCM design according to the StasHH definitions. The exact and binding requirements are listed in the official documents. A minimum power output of 30 kW (Beginning of life, BOL) of the FCM is mandatory for the StasHH standard.

2.1 Standard size definition

Three series of FC boxes were defined within the standard: A, B, and C series. For the A-series a doubling in the height direction is possible, which will be denoted with the subscript AA. The B-series allows for doubling or tripling in height direction denoted with the subscript BB and BBB respectively. The dimensions of the boxes can be found in Table 1 and the following tolerances in all directions are tolerated: +0/-100 mm.

Table 1: dimensions FC module A,B and C

StasHH	Length / mm	Width / mm	Height / mm	Expected PEM kW
A	1.020	700	340	50
AA	1.020	700	680	110
AAA	1.020	700	1020	160
B	1.360	700	340	70
BB	1.360	700	680	145
BBB	1.360	700	1.020	220
C	1.700	700	340	90

The respective volumes of the different sizes are as follows:

- A external volume is max. 0.243 m^3
  AA external volume is max. 0.486 m^3
  AAA external volume is max. 0.729 m^3
- B external volume is max. 0.324 m^3
  BB external volume is max. 0.647 m^3
  BBB external volume is max. 0.971 m^3
- C external volume is max. 0.405 m^3

A visual representation of the A to C series boxes including the multiple sizes is shown in Figure 1.

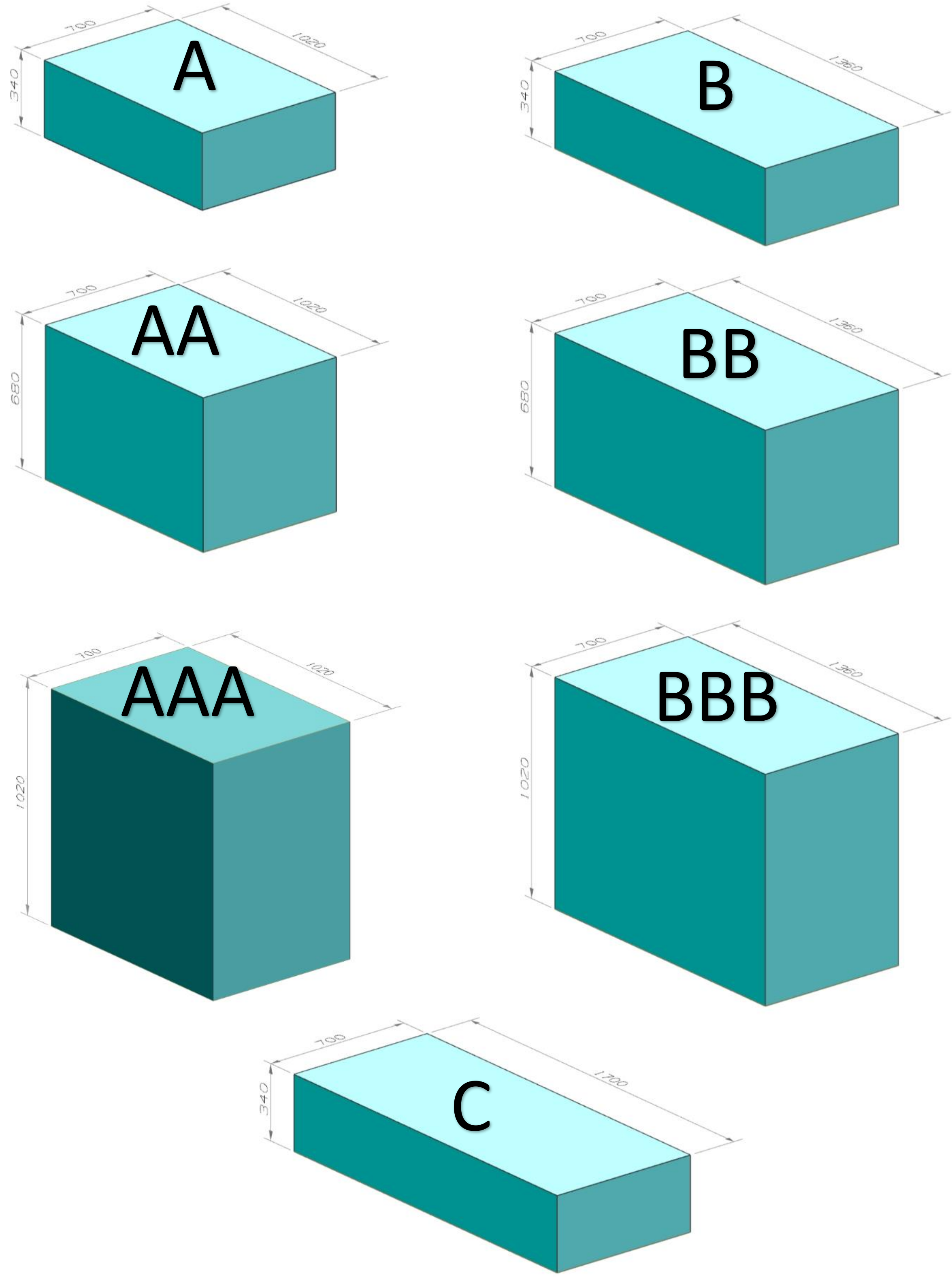

Figure 1: FC modules A, B and C

The orientation of all FC boxes is fixed according to the LengthxWidthxHeight definition except for the A(A) boxes which can be orientated optionally on its side. This is not a StasHH requirement. The optional orientation on the side is shown in Figure 2

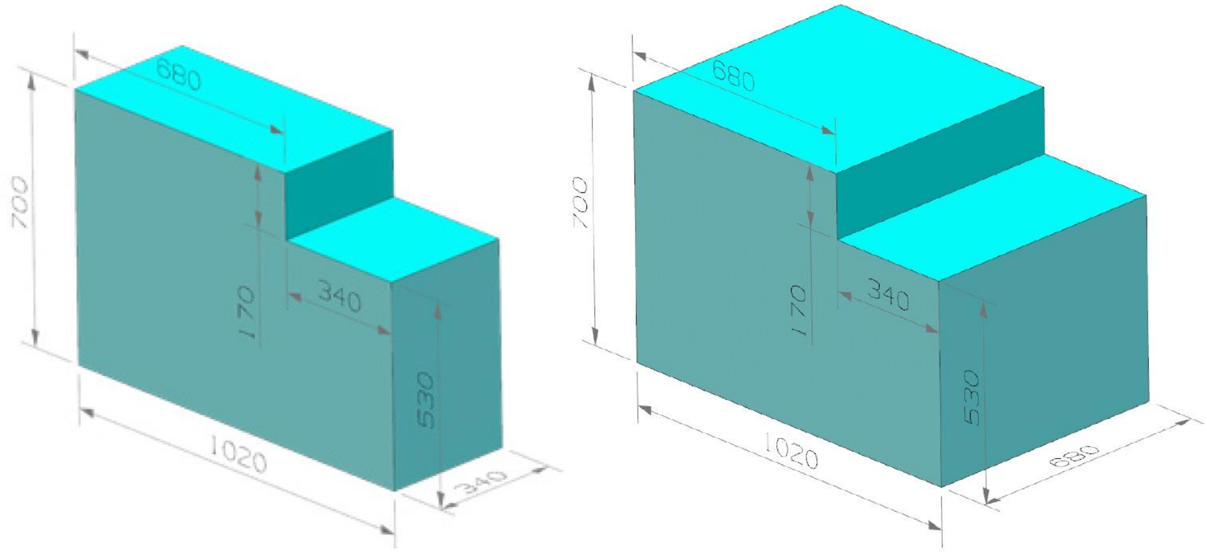

Figure 2: A and AA on their side

2.2 Standard interface definition

The interface areas and requirements for the pneumatic, hydraulic, and electronic connections are defined in the following.

2.2.1 Interface area

The interface area can be on two different sides. At least all pneumatic and hydraulic connections are within this interface area (except eventually the drain or (box) ventilation). Sides are defined with FC module in horizontal position:

1. In corner 3, on the LxH side FC module. See Figure 3. The dimensions of the interface area will be max. 340mm x $Depth_{main}$ x Module Height
2. In corner 4, on the WxH side FC module. See Figure 3. The dimensions of the interface area will be max. 700mm x $Depth_{main}$ x Module Height

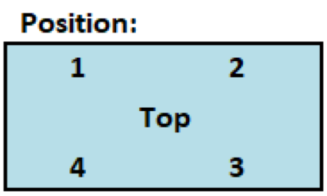

Figure 3: Top view of FCM for interface area definition

"$Depth_{main}$" or "D_{main}" is defined as the minimum depth needed to stay within the overall FC module volume (defined in D3.2), with connected male and female connectors.

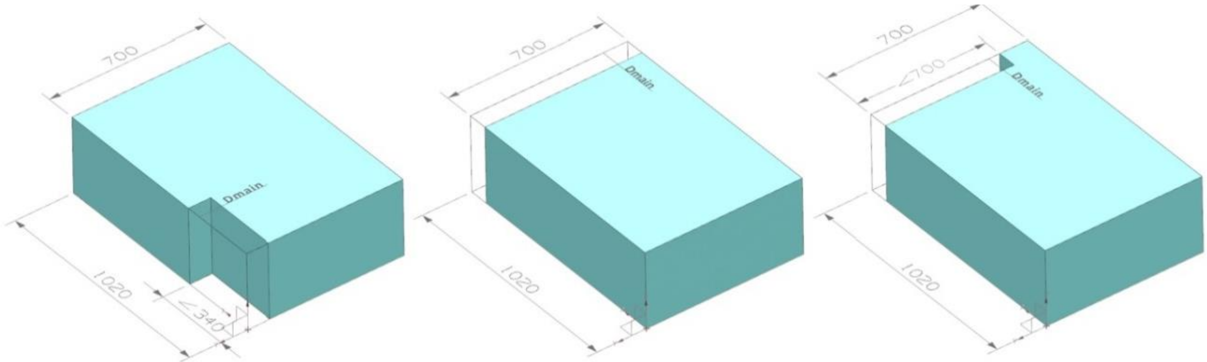

Figure 4: FCM interface areas possibility (1st side)

The size definitions of the interfacial areas can also be found in a tabulated manner in Table 2

Table 2: Dimensions FC module interface areas (1st side)

Interface 1st side	Length / mm	Depth / mm	Height / mm
A	Max. 340	≥D_{main}^x	340
AA			680
AAA			1.020
B			340
BB			680
BBB			1.020
C			340

Interface 1st side	Length / mm	Depth / mm	Height / mm
A	Max. 700	≥D_{main}^x	340
AA			680
AAA			1.020
B			340
BB			680
BBB			1.020
C			340

*Depth is min. Depth needed to stay within overall FC module volume with connected interfaces

Optionally, a second interface area can be utilized under the following conditions:

3. The main side complies with 1. with depth “Dmain”, and the second side complies with 2. with depth “Dsub”

OR

4. The main side complies with 2. with depth “Dmain”, and the second side complies with 1. with depth “Dsub”
5. Both connections areas are mechanically redundant, i.e., all pneumatic and hydraulic connections are on both sides (except eventually the drain or (box) ventilation)

“$Depth_{sub}$” or “D_{sub}” is defined as the minimum depth needed to stay within the overall FC module volume, with not connected male or female connectors.

Table 3: Dimensions of FC module interface areas (optional 2nd side)

Interface 2nd side	Length or width / mm	Depth / mm	Height / mm
A	Max. 340 or 700	$\geq D_{sub}^{x}$	340
AA			680
AAA			1.020
B			340
BB			680
BBB			1.020
C			340

An exemplary image of the optional second interface area is depicted in

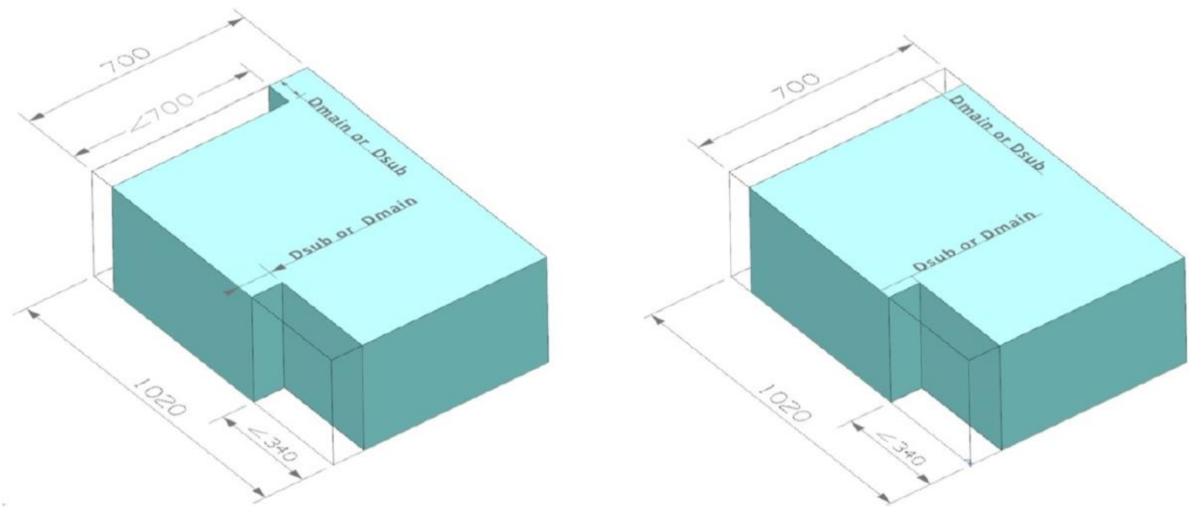

Figure 5: Example of FC module interface area with 1st side and optional 2nd side

2.2.2 Hydraulic, pneumatic, and electrical interfaces

All hydraulic and pneumatic interfaces must comply with the following conditions:

- All the pneumatic and hydraulic connections, excluding the optional drain or (box) ventilation, are positioned in the defined interfaces areas
- The connections' principle will be fixed for all FCMs, but can be different depending on usage. For example, for air this can be a hose, for hydrogen a pipe. See Table 4
- The connection size ranges (in mm) are defined, but will vary with the power range of the FC module Table 4.
- The electrical and I/O communication can be positioned anywhere within the chosen overall dimensions of A, B and C.

Table 4: Hydraulic and pneumatic interfaces of FC modules

	Interfaces	Inner diameter / mm Nominal power				Remark
		≤ 70 kW	71 - ≤ 100 kW	101 - ≤ 130 kW	131 - ≤ 160 kW	
Hydrogen	Pipe fitting	6-8	8-12	12-16	16-20	6-22 bar
Air	Nozzle + Hose	30-60	45-75	60-90	75-105	
Steam	Nozzle + Hose	30-60	45-75	60-90	75-105	
Drain	Nozzle + Hose	6-8	8-12	12-16	16-20	optional
Cooling FC	Nozzle + Hose	20-40	30-50	40-60	50-70	In/Out
Cooling -E	Nozzle + Hose	15-35	20-40	25-45	30-50	Optional
Breather	Banjo	M14x1.5	M14x1.5	M14x1.5	Tbd	Optional
Ventilation	Nozzle + Hose	20-40	20-40	20-40	20-40	Optional

An additional condition for the main hydraulic and pneumatic connections is that they may not interfere in the horizontal and vertical directions, see Figure 6.

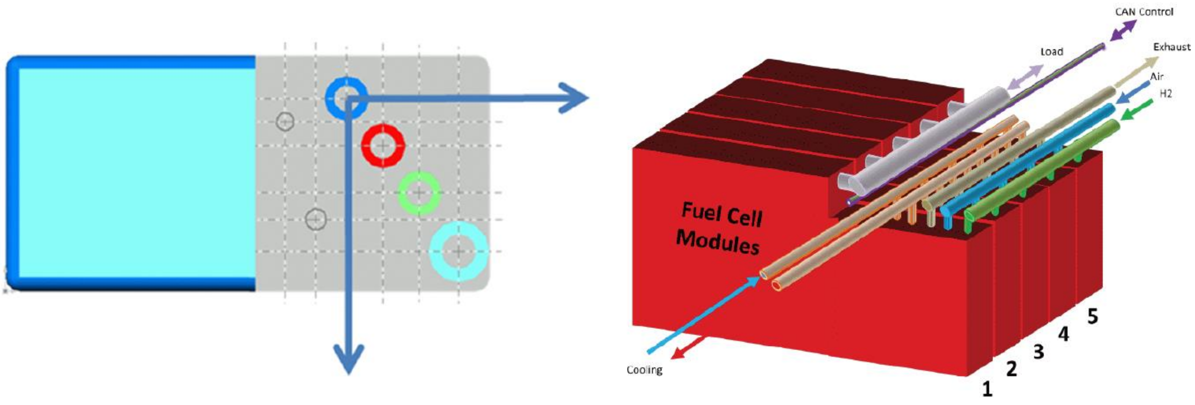

Figure 6: Non-interfering hydraulic and pneumatic connections

2.2.3 Low and high voltage connectors

Within StasHH the pins for the LV and HV connection are specified but not the specific connector.

High voltage connector:

The connector must have two pins, plus and minus. Additionally, it must withstand the maximum FCM voltage and current. Connectors, already utilized in heavy-duty applications are preferred.

Low voltage connector:

The LV connector must withstand up to 100 A and cable lugs are suggested.

2.3 Standard API definition

2.3.1 Physical connector

For the physical connector for the communication with the FCM only the pins are specified and not the connector itself. It is proposed to use an 18 pin connector to include additional functions of needed. The connector shall at least have an ingress protection level of IP54 with a proposed pinout, depicted in Figure 7.

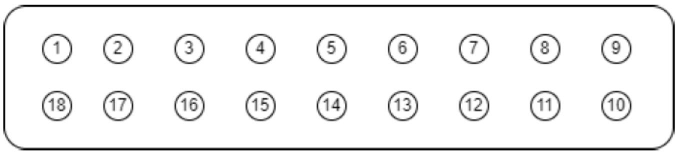

Figure 7: Pinout

The physical connector shall have enough pins to transfer all electrical signals needed and must fulfil the requirements resulting from the working environment or use case of the application.

The following pins must be included in the connector:

1. CAN ground
2. CAN high
3. CAN low
4. OPTIONAL shield
5. Wakeup signal
6. Emergency stop

The following optional pins are also specified:

7. OPTIONAL HVIL in
8. OPTIONAL HVIL out
9. OPTIONAL 24V
10. OPTIONAL ground for LV power
11. OPTIONAL CAN high for DC/DC or secondary FCM
12. OPTIONAL CAN low for DC/DC or secondary FCM
13. OPTIONAL CAN high manufacturer specific diagnostic bus
14. OPTIONAL CAN low manufacturer specific diagnostic bus

The remaining pins 15 to 18 are intended for future use and additionally deployments

2.3.2 State machine

The state machine shall at least contain the following states:

- Idle:
  In this state the FCM has LV power sufficient to activate the FCCU. This state corresponds to “Power on” in J1939. Periodic counter messages are transmitted
- Standby:
  No HV output power but necessary subsystems are powered and ready such that it can start producing output within a short time. Error and diagnostic messages can be sent
- Starting:
  FCM is transitioning from standby to running state. Power is ramping up and HV bus is enabled – Module can consume and provide energy
- Running:

FCM is active and delivering power. Power may be limited due to derating which will be indicated by FCM

- Stopping:
  FCM is ramping down and returning to standby state. HV bus must be enabled during shut-down procedures.
- Error:
  Error state must be enabled from any other state. FCM shall be brought in a safe state

Proprietary substates can be defined by the FCM manufacturers.

For further information see D3.4 document.

2.3.3 Messages

In the following the messages that are used in the communication between the application ECU and FCCU are listed:

- State machine control
- State machine feedback
- Emergency stop request
- Reference power value
- FCM actual current and voltage
- Power limits
- Voltage limits
- High voltage bus information
- FCM temperature
- Time and date
- Ambient conditions
- Vehicle speed
- FCM gas leakage
- Alarm messages

For a generic description of the messages including a mapping to a J1939 message, please refer to the official D3.4 document.

3 Design of Toyota FCM

The fuel cell module is developed for the design targeted size HH_{AA} on its side [L1.020xH700xW680]. It consists of a FC stack assy, all BOP's and FC/HV ECU's. The FC stack assy is composed of the stack itself (330cells) and the FC boost converter. The main BOP's are air compressor, FC water pump, H2 pump and PCU. To ensure safety related use of hydrogen and high voltage, countermeasures were implemented that were cultivated during the development of electrified vehicles such as FCEVs and HEVs. The module was designed to work in a broad range of operating environments, ensuring system operation at low or high temperature, at higher altitude where the oxygen level is lower, and under applications involving vibration. The module has a wide voltage range (400 to 750 V) and can be directly connected to an existing electrical instrument provided with a motor, inverter, and battery, etc. It can be used in all sort of applications such as truck, bus, stationary, maritime, railroad and off road/special vehicles.

3.1 Key technical specifications

The mandatory key technical specifications are listed in Table 5.

Table 5: Mandatory technical specifications of FCM according to StasHH

Requirement	**StasHH requirement**	**FCM**
Service life / h	> 15.000	15.000※1
Geographical heights / m	< 3.000m with derating	<3400m (less than 500m@80kW(BOL)※2)
IP class	> IP54	IP57 (Without ACP breathing pipe)
Low voltage / V	24DC	12DC (see 3.3.2.1 LV)
High voltage output / V	160 – 850 DC	400～750VDC
Operational ambient temperature / °C	-25 to 45	-30～+70℃ (the maximum intake temperature is 45℃@elevation ≦700m)
Conductivity glycol / µS/cm	< 6 (ASTM D 1125	<20µS/cm※2
H_2 input pressure / bar	6 - 22	(8.7)～16bar abs
Hydrogen quality	ISO 14687 or SAE J2719	ISO 14687, SAE 2719

※1 Depends on usage pattern

※2 Over 500m altitude operation may affect durability and performance

※3 It is linked to the resistance of our module. OEM must decide a specific value and they must control it for the high voltage safety.

Additional technical specifications of FCM are listed in

Table 6: Additional key technical specifications of FCM

Requirement	**FCM**
Net continuous system power output P_{net} BOL / kW	80kW
Net continuous system power output P_{net} EOL / kW	-
Weight / kg	<250kg
DC/DC included in FCM / -	Yes
Peak system efficiency / %	-
System efficiency at P_{net} BOL	-
System efficiency at P_{net} EOL	-
Gravimetric system power density @ BOL / kW/ton	-
Volumetric system power density @ BOL / kW/m³	-

3.2 Exterior design

The exterior design of the FCM with all main dimensions is shown in Figure 8.

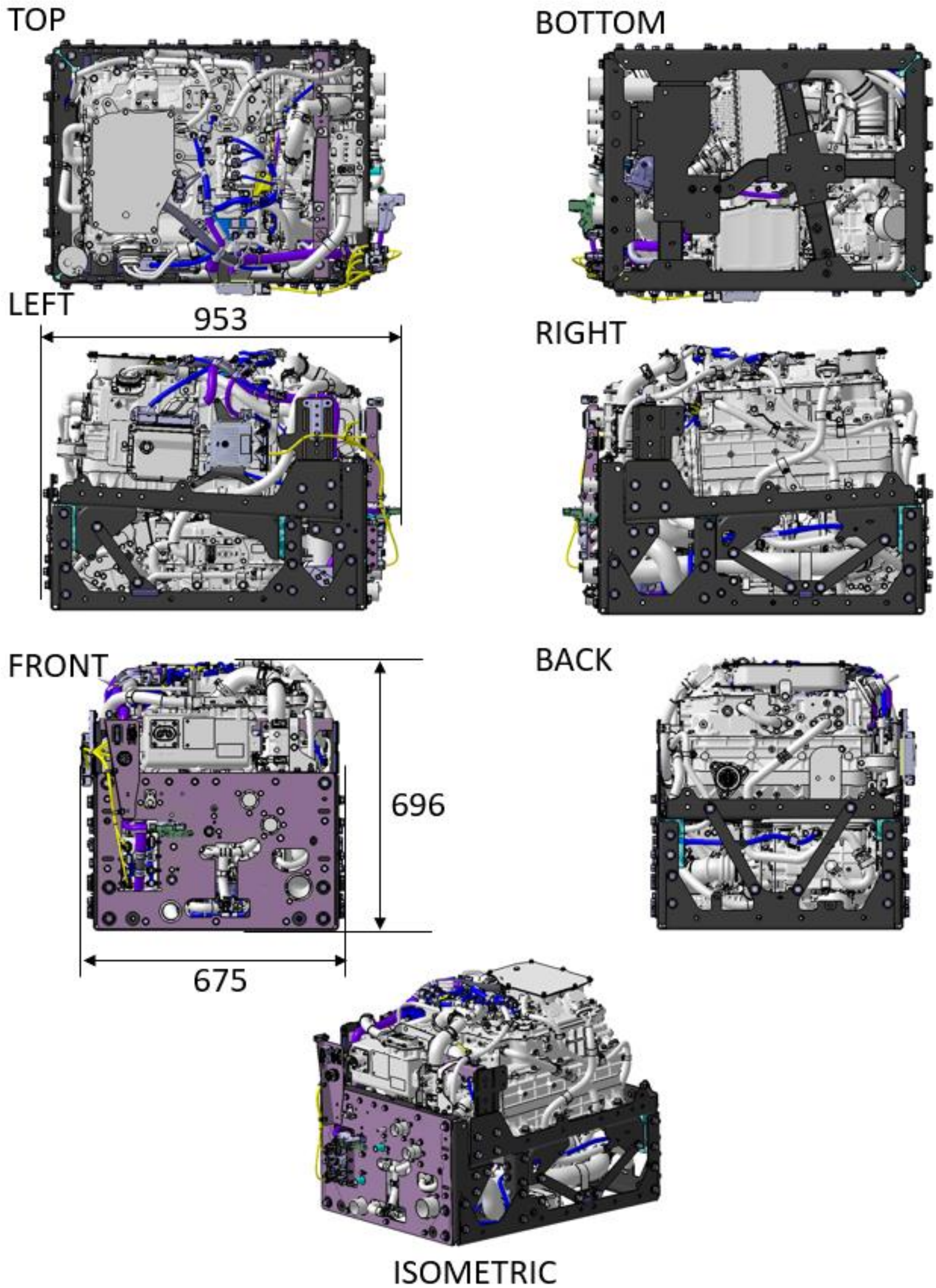

Figure 8: Exterior design with main dimensions of FCM

3.3 Module Pictures

Pictures of the module built for testing shown in Figure 9.

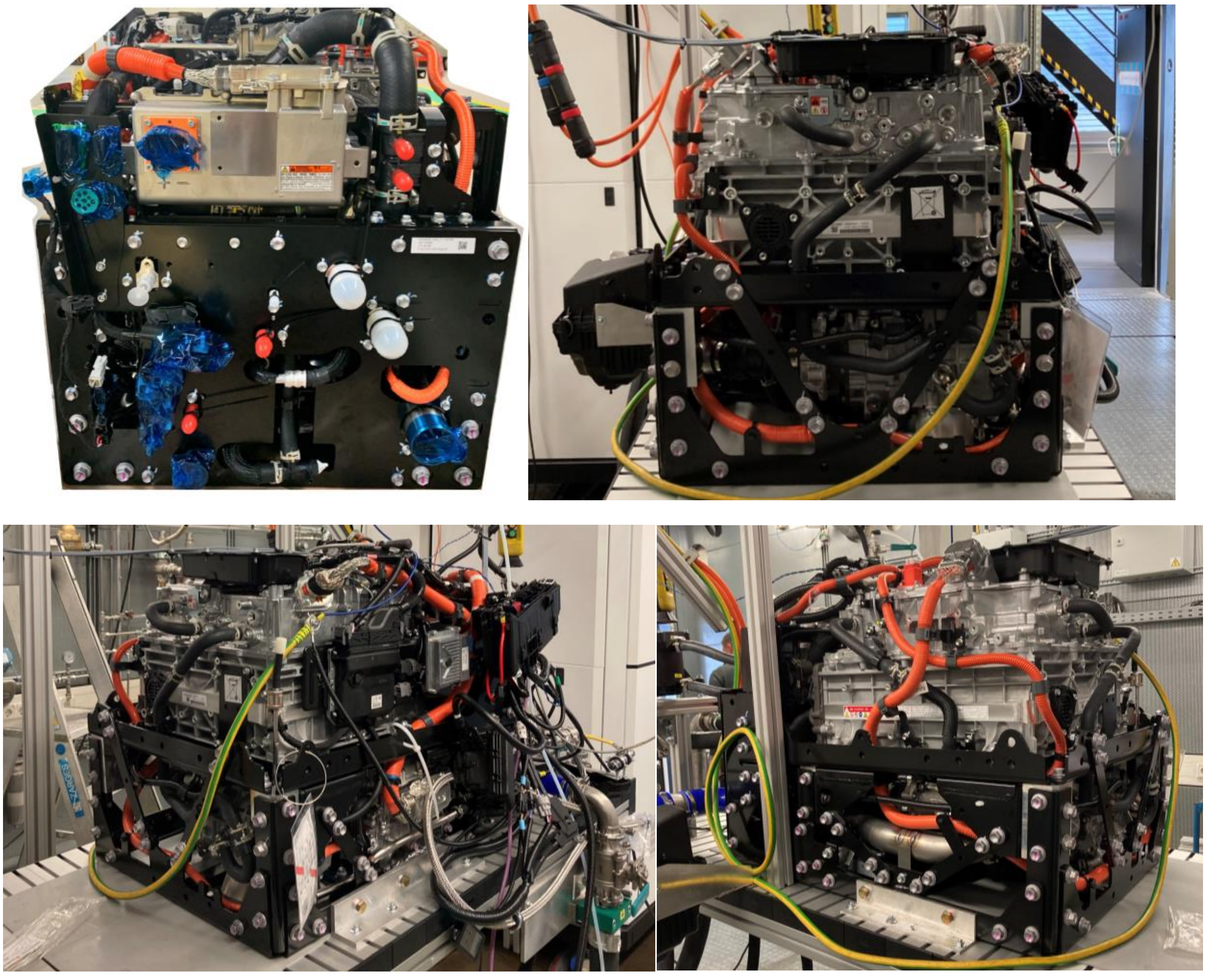

Figure 9: Pictures of the FCM Module built for testing

3.4 Interface specification and area

3.4.1 Interface area including hydraulic and pneumatic interfaces

The design and dimensions of the interface area is depicted in Figure 10

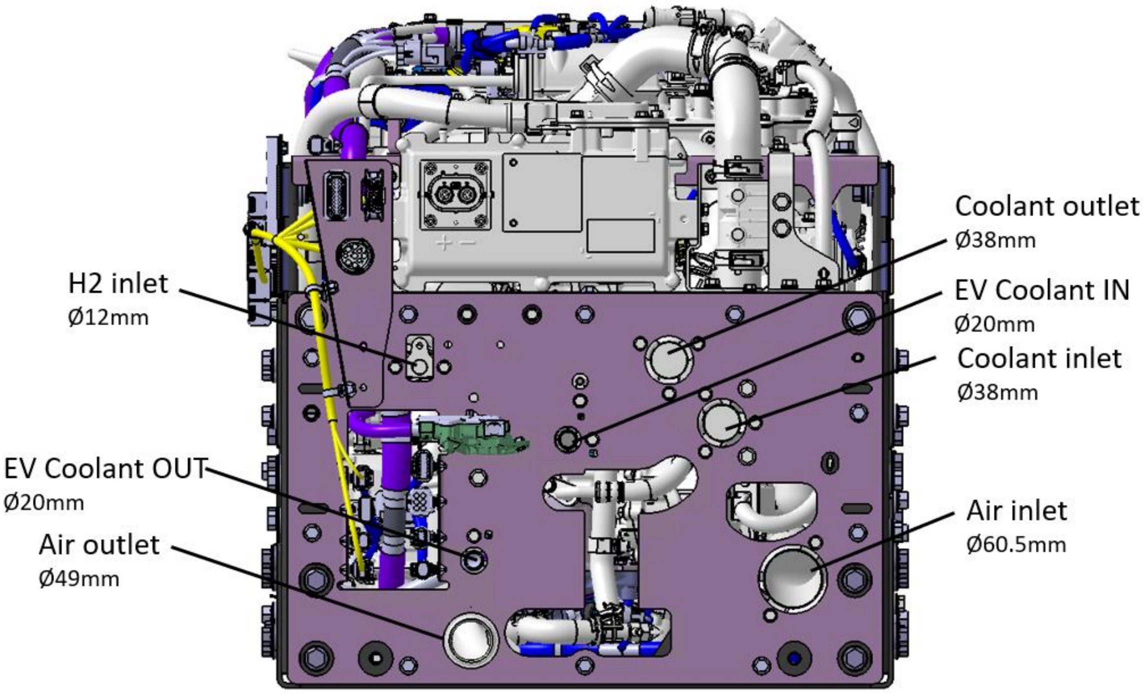

Figure 10: Main interface area of FCM

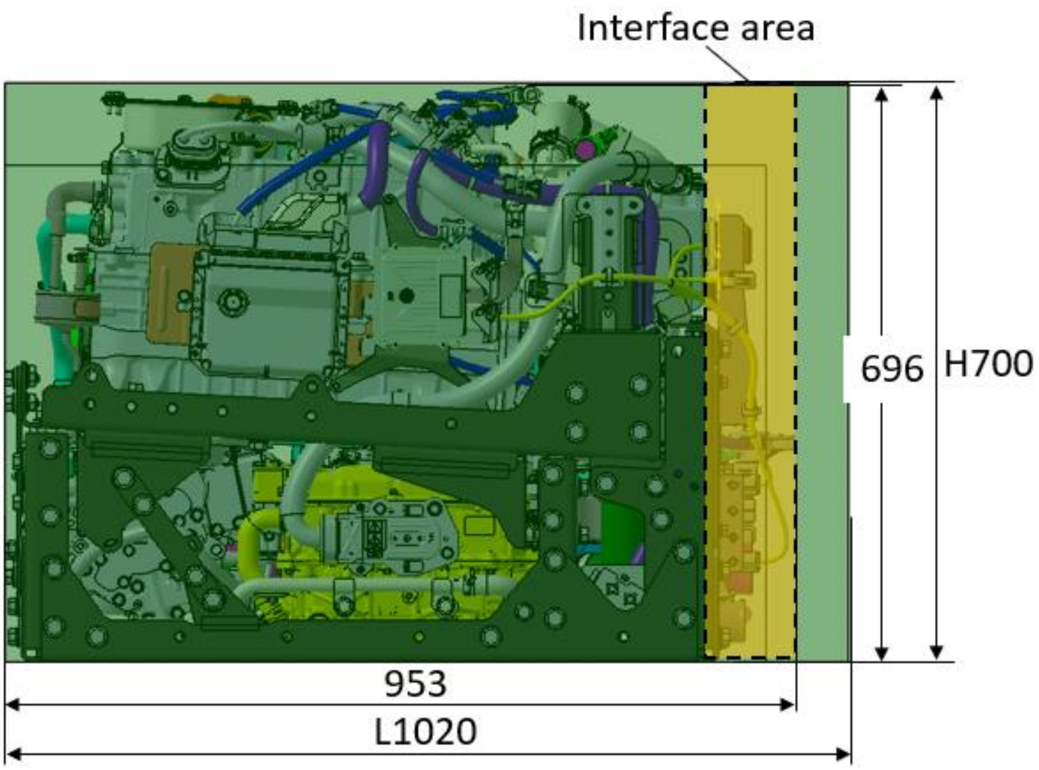

Figure 111: Side view of interface area of FCM inside HH_{AA} size

The positioning of the pneumatic and hydraulic connections of the FCM within the interface area are shown in Figure 12. The specifications of the interfaces are summarized in Table 7.

Table 7: Specifications of hydraulic and pneumatic interfaces

	Interface type	Inner diameter / mm
Hydrogen	Pipe	Ø12
Air	Nozzle+hose	Ø 60.5
Steam	Nozzle+hose	Ø 49
Drain	NA	-
Cooling FC	Nozzle+hose	Ø38
Cooling -E	Nozzle+hose	Ø20
Breather	NA	-
Ventilation	NA	-

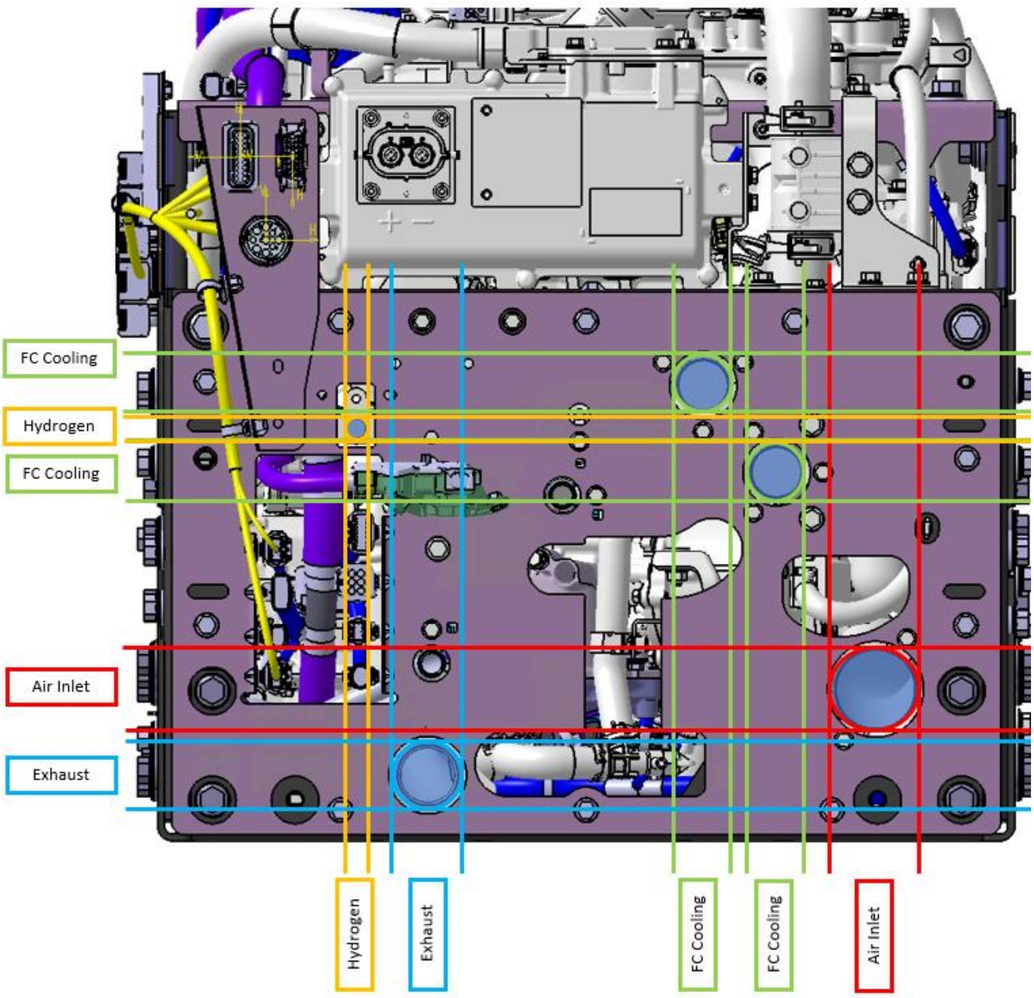

Figure 12: Position of hydraulic and pneumatic connections of FCM

3.4.2 Electrical interfaces

Within this chapter the electrical interfaces and specification of the connectors are summarized.

3.4.2.1 LV

The low voltage (12V) power terminal uses a M8 cable lug connection and is in the red circle shown in below picture. Maximum electrical current allowed through the terminal is 150A. It's directly connected to the PCU with a wire section of $30mm^2$. In most applications (including demonstrator), it is connected to a 12V battery through the relay box.

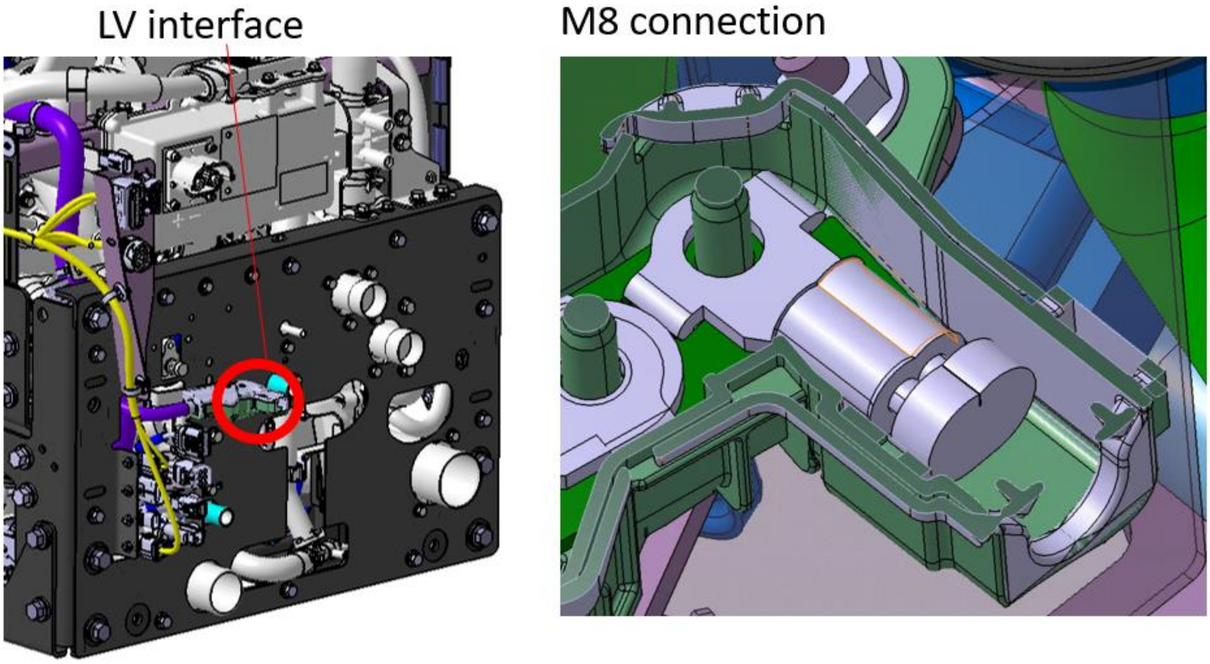

Figure 13: LV interface

The module can only operate with 12V on that power terminal, and so do all ECUs connected inside the unit. Allowing 24V connection there would imply too high workload/cost to modify the hardware, ECU and PCU, so this is an intentional deviation to the standard. However, as shown on the interface diagram in chapter 3.4.1, compatibility with 24V is offered on control signals. See related chapter for more information.

3.4.2.2 HV

The High voltage connection is a Tyco 35sq HVP800 Series connector and is in the red circle shown in below picture. It's available in 2 orientations, 90 or 180degrees.

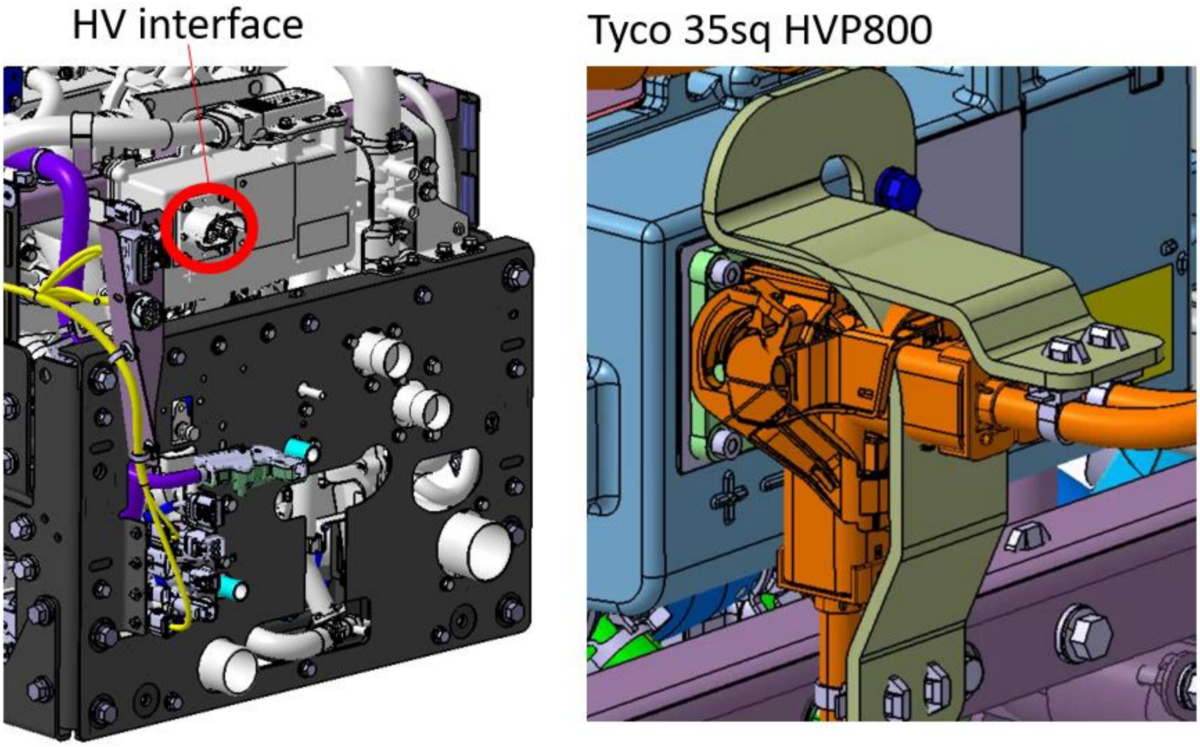

Figure 14: HV interface

The specification of Tyco HVP800 connector can be found in below table

Number of pins	2
Wire outlet direction	90 / 180 degrees
Operating temperature	-40~140°C
Operating voltage	1000 VDC
Type of pin	8mm round pin
Wire size	35mm²
Allowable current	130A@120°C with 35mm² cable
Waterproof	IP6X9X/IP67

Table 8: Specifications of High Voltage interface

3.5 API definition

3.5.1 Communication

To comply with the StasHH standard Toyota has developed an interface ECU (VCU) to translate the CAN protocol from Toyota CAN communication to StasHH required format. Since the CAN protocol (J1939) defined in WP3 during the first year of StasHH didn't match Toyota FCM CAN protocol (CAN 2.0 A). To comply with the standard Toyota needed to develop an interface ECU (VCU) which sits between FCCU (FC ECU) and the STASHH interface. Toyota developed the Interface ECU with an EU partner to be able to translate the CAN protocol from Toyota CAN communication to StasHH required format.

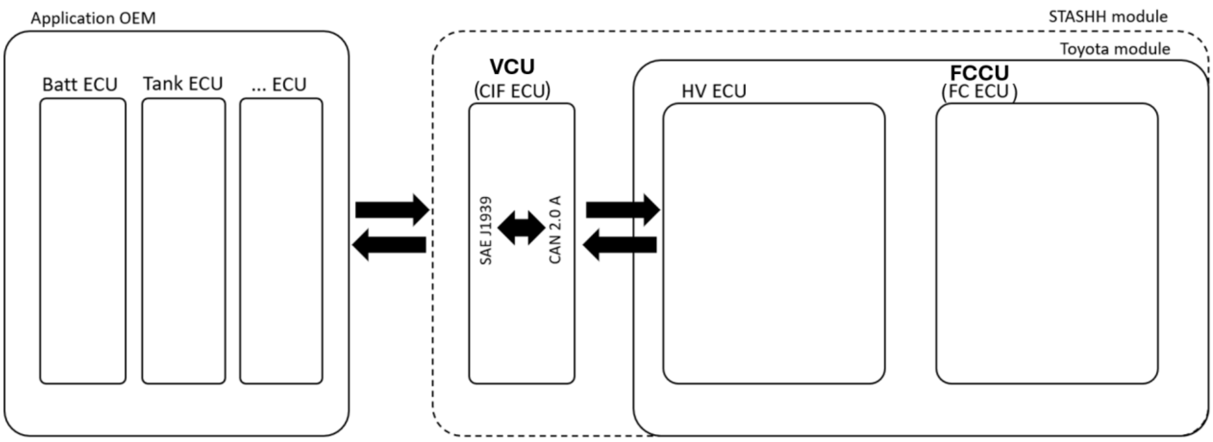

Figure 15: Communication schematic

3.5.2 Physical connector

In terms of interface signals connection, the recommended standard API connector by TE Connectivity is selected.

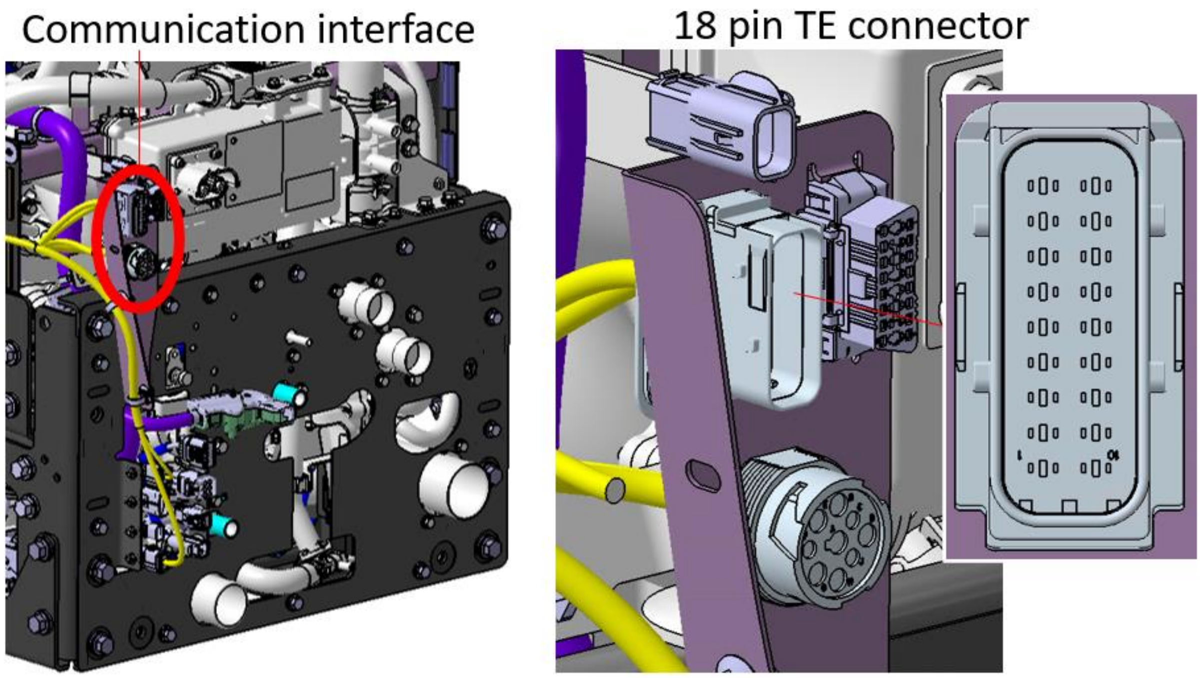

Figure 16: Communication interface

See connector's part numbers and gender information in below drawing. Complete pin layout is shown in point 2.3.1 and is as per the standard. Option terminal 4 is to be used in case of CAN shielding. Terminals 13/14 are for internal use and debug purpose. Finally, supplying 24V to terminal 9 and switching CIF ECU power supply connectors accordingly will allow connection to 24V applications. Note the system can't switch from 12V to 24V within a same application.

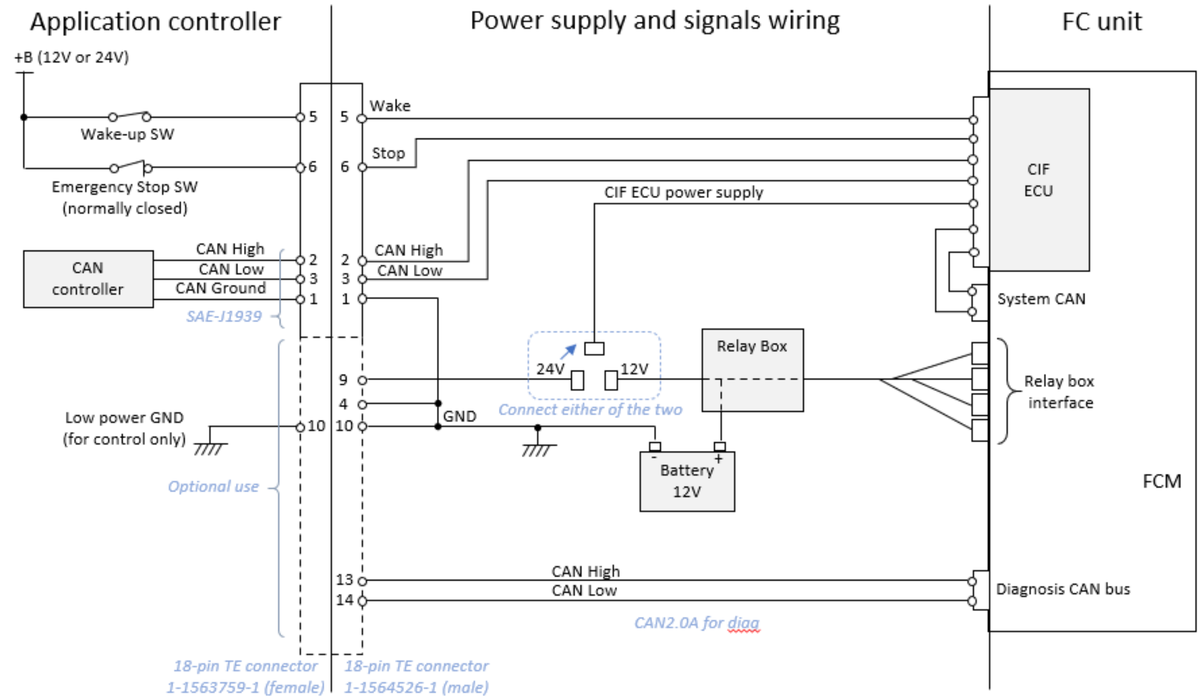

Figure 17: Low voltage schematic

3.5.3 State Machine

Within the STASHH project a general state machine has been defined to describe the main states of the fuel cell modules. According to STASHH it should be possible for a fuel cell module manufacturer to enhance / update the pre-defined state machine according to actual states of the considered fuel cell module. The state machine for the Toyota fuel cell system has been updated accordingly (see figure below).

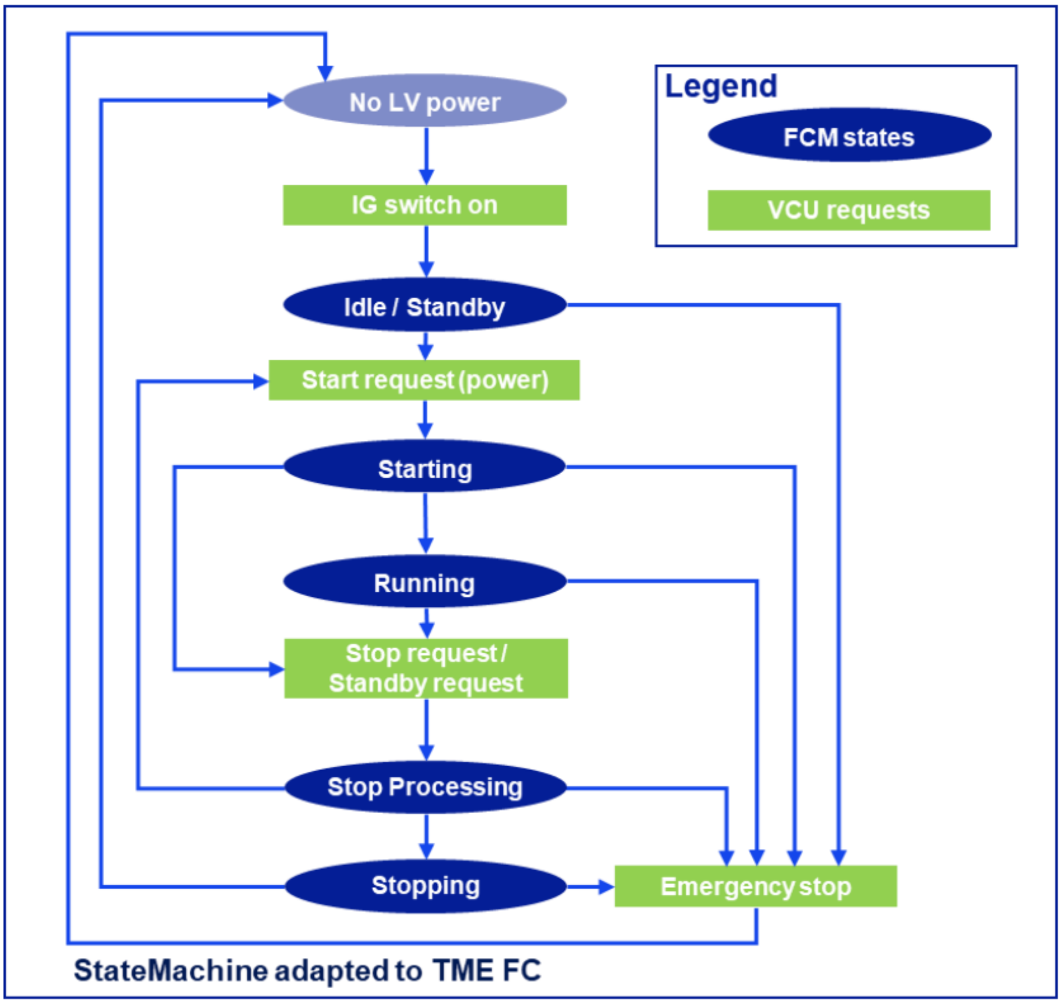

Figure 18: State Machine

3.5.4 Supported / Unsupported Signals

Several signals defined by STASHH are optional. Some of these optional signals are supported by the Toyota fuel cell, some of them are not supported. The latter case is because not all signals provided by the VCU have a corresponding signal on FCCU side. A complete list of STASHH defined signals and information on their support is provided in the table below.

PGN	PGN label	SPN	SPN label	Origin	Supported	Comment
9728	MG1IC	10162	Setpoint mode	VCU	✓	Setpoint mode will be considered
9728	MG1IC	10163	Setpoint request	VCU	✓	Setpoint request will be considered
61825	MG1IMF1	10167	FCM State	FCCU	✓	FCM State will be communicated
61825	MG1IMF1	9103	HVIL status	FCCU	✓	HVIL status will be communicated
6912	HVESSC1	8124	Power-Down Command	VCU	✓	Emergency stop is considered
64371	MG1IR2	10202	Reference Current	FCCU	✓	Information is communicated
64371	MG1IR2	10203	Reference Voltage	FCCU	✓	Information is communicated
64373	MG1IR1	10172	Reference Power	FCCU	✓	Information is communicated
64372	MG1IS1	10175	Current	FCCU	✓	Information is communicated
64372	MG1IS1	9101	Voltage	FCCU	✓	Information is communicated
61826	MG1ILAP	10186	Active DC Side Power Maximum	FCCU	✓	Information is communicated
61826	MG1ILAP	10187	Active DC Side Power Minimum	FCCU	✓	Information is communicated
64605	HVESSCFG	8115	Nominal Voltage	VCU	✓	FC will not request this information
64605	HVESSCFG	8116	Minimum Operating Voltage	VCU	✓	FC will not request this information
64605	HVESSCFG	8117	Maximum Operating Voltage	VCU	✓	FC will not request this information
64363	HVBI	20802	High Voltage Bus Driveline Availability	VCU	✓	Information is considered
64369	MG1IMT	9059	Motor/Generator 1 Temperature 1	FCCU	✓	FC coolant output temperature

64369	MG1IMT	10220	Motor/Generator 1 Temperature 2	FCCU	✓	FC coolant input temperature
64369	MG1IMT	10221	Motor/Generator 1 Temperature 3	FCCU	✓	Radiator outlet temperature
64369	MG1IMT	10222	Motor/Generator 1 Temperature 4	FCCU	✓	PCU inlet temperature
64976	IC2	2809	Engine Air Filter 2 Differential Pressure	FCCU	✗	Signal not available on FCCU. Message is never sent.
64930	GFI3	3467	Engine Fuel System 2 Gas Mass Flow Rate	FCCU	✓	Information is communicated
65253	HOURS	247	Engine Total Hours of Operation	FCCU	✗	Signal not available on FCCU. If requested by VCU FCCU will communicate "FFFFFFFF" (not available).
65254	TD	959	Seconds	VCU	✗	No corresponding signal on FCCU – message will never be requested.
65254	TD	960	Minutes	VCU	✗	No corresponding signal on FCCU – message will never be requested.
65254	TD	961	Hours	VCU	✗	No corresponding signal on FCCU – message will never be requested.
65254	TD	963	Month	VCU	✗	No corresponding signal on FCCU – message will never be requested.
65254	TD	962	Day	VCU	✗	No corresponding signal on FCCU – message will never be requested.
65254	TD	964	Year	VCU	✗	No corresponding signal on FCCU – message will never be requested.
65254	TD	1601	Local minute offset	VCU	✗	No corresponding signal on FCCU – message will never be requested.
65254	TD	1602	Local hour offset	VCU	✗	No corresponding signal on FCCU – message will never be requested.
65269	AMB	108	Barometric Pressure	VCU	✗	No corresponding signal on FCCU – message will never be requested.
65269	AMB	171	Ambient Air Temperature	VCU	✓	Signal is considered – if not available calibrated replacement value is set

65132	TCO1	1624	Tachograph vehicle speed	VCU	✓	Signal is considered – if not available calibrated replacement value is set
64595	EGLI	6834	Gaseous Fuel Leakage 1 Concentration	FCCU	✓	Information is communicated
64595	EGLI	6835	Gaseous Fuel Leakage 2 Concentration	FCCU	✓	Information is communicated
64595	EGLI	6836	Gaseous Fuel Leakage 3 Concentration	FCCU	✓	Information is communicated
64595	EGLI	6837	Gas Leakage Detection 1 Pressure	FCCU	✗	No corresponding signal on FCCU. Signal is always set to “FF”.
64595	EGLI	6838	Gas Leakage Detection 2 Pressure	FCCU	✗	No corresponding signal on FCCU. Signal is always set to “FF”.
64595	EGLI	6839	Gas Leakage Detection 3 Pressure	FCCU	✗	No corresponding signal on FCCU. Signal is always set to “FF”.
65226	DM1	987	Protect Lamp	FCCU	✓	See chapter *Diagnostics*
65226	DM1	624	Amber Warning Lamp	FCCU	✓	See chapter *Diagnostics*
65226	DM1	623	Red Stop Lamp	FCCU	✓	See chapter *Diagnostics*
65226	DM1	3041	Flash Protect Lamp	FCCU	✓	See chapter *Diagnostics*
65226	DM1	3040	Flash Amber Warning Lamp (AWL)	FCCU	✓	See chapter *Diagnostics*
65226	DM1	3039	Flash Red Stop Lamp (RSL)	FCCU	✓	See chapter *Diagnostics*
65226	DM1	3038	Flash Malfunction Indicator Lamp	FCCU	✓	See chapter *Diagnostics*
65226	DM1	1214	Suspect Parameter Number	FCCU	✓	See chapter *Diagnostics*
65226	DM1	1215	Failure Mode Identifier	FCCU	✓	See chapter *Diagnostics*
65226	DM1	1216	Occurrence Count	FCCU	✓	See chapter *Diagnostics*
65226	DM1	1706	SPN Conversion Method	FCCU	✓	See chapter *Diagnostics*

Table 9: List of supported/unsupported signals

3.5.5 Proprietary Messages

Additional to the signals defined by STASHH, there are several optional signals which may be send by the VCU for an optimal operation of the Fuel Cell. Proprietary messages are defined based on the J1939 standard. Proprietary messages are optional. If a proprietary message is not sent by the VCU, the corresponding values provided to FCCU are set to default values.

send/receive	PGN	Msg. Lable	SPN	Signal label	Signal name	Scaling	Range	Length	Time
send	65300	DiagRecData14	516100	VL	VL voltage	2 V per bit	0 to 500 V	1 byte	1000 ms
send	65300	DiagRecData14	516101	BATT12V	Battely voltage(12V)	0.2 V per bit	0 to 50 V	1 byte	1000 ms
send	65300	DiagRecData14	516102	PAFIC	Air pressure	2 kPa per bit	0 to 500 kPa	1 byte	1000 ms
send	65300	DiagRecData14	516103	QAF	air flow	0.5 l/min per bit	0 to 32127.5 l/min	2 byte	1000 ms
send	65300	DiagRecData14	516104	ACPREV	Air compresser rev	1 rpm per bit	-32127 to 32128 rpm	2 byte	1000 ms
send	65300	DiagRecData14	516105	PHL	H2 low pressure	2 kPa per bit	0 to 500 kPa	1 byte	1000 ms
send	65301	DiagRecData15	516106	HPREV	H2 pump rev	32 rpm per bit	0 to 8 000 rpm	1 byte	1000 ms
send	65301	DiagRecData15	516107	THIC	IC outlet tmeparture	1 °C per bit	-40 to 210 °C	1 byte	1000 ms
send	65301	DiagRecData15	516108	PAMB	Atmospheric pressure	0.5 kPa per bit	0 to 125 kPa	1 byte	1000 ms
receive	65302	VCUopt_16	516109	VH_DCREQ	VH Discharge request	2 states	0 to 1	1 bit	10 ms
receive	65304	VCUopt_18	516110	ION_RQ	Ion request	2 states	0 to 1	1 bit	100 ms
receive	65303	VCUopt_17	516111	PFCREFPM	FC Power Reuest (Limit)	0.05 kW per bit	0 to 3212.75 kW	2 bytes	10 ms

Figure 19: List of Proprietary Messages

3.5.6 Diagnostic Message 1 (DM1)

General information:

• Alarm messages are used to inform the VCU that some signals are out of range and consequently faults may be active. The actual fault response will be part of the FCCU. The alarm messages are implemented using the Diagnostic Message 1 (DM1).

• The monitored signals considered for DM1 (and their corresponding minimum and maximum acceptable values) have been defined by TME

Signals considered for DM1 are listed in the table below

Data Label	Data Name	Unit	Min accept. Value	FMI if below minimum	Max accept. Value	FMI if above maximum
VL	VL voltage	V	230	4	450	3
BATT12V	Battery voltage (12V)	V	11	4	14.5	3
PAFIC	Air pressure	kPa	66	17	266	15
QAF	Air flow	l/min	0	-	5469	15
ACPREV	Air compressor rev	rpm	0	17	17000	15
PHL	H2 low pressure	kPa	110	1	270	0
HPREV	H2 pump rev	rpm	0	-	7220	16
THIC	IC outlet temp	°C	-	-	100	16
PAMB	Ambient pressure	kPa	66	17	113	17

Figure 20: DM1 considered signals

• All potential issues (signals being out of the permissible range) are prioritized

• If several issues are active simultaneously, only the issue with the highest priority is communicated via DM1 message

Priority #	Signal	SPN	Issue Description	FMI
1	PHL	516105	H2 low pressure above max acceptable value	0
2	PHL	516105	H2 low pressure below min acceptable value	1
3	VL	516100	VL voltage above max acceptable value	3
4	BATT12V	516101	Battery voltage (12V) above max acceptable value	3
5	VL	516100	VL voltage below min acceptable value	4
6	BATT12V	516101	Battery voltage (12V) below min acceptable value	4
7	PAFIC	516102	Air pressure above max acceptable value	15
8	QAF	516103	Air flow above max acceptable value	15
9	ACPREV	516104	Air compressor speed above max acceptable value	15
10	HPREV	516106	H2 pump speed above max acceptable value	16
11	THIC	516107	IC out temp above max acceptable value	16
12	PAFIC	516102	Air pressure below min acceptable value	17
13	ACPREV	516104	Air compressor speed below min acceptable value	17
14	PAMB	516108	Ambient air pressure above max acceptable value	17
15	PAMB	516108	Ambient air pressure below min acceptable value	17

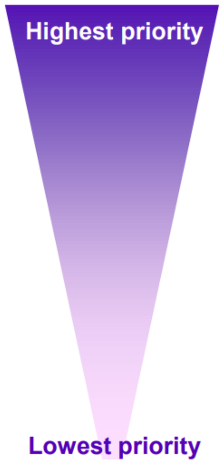

Figure 21: Priority of DM1 considered Issues

• There is no diagnostic implemented on CIF ECU, CIF ECU solely serves as a gateway communicating information provided by the fuel cell → there is no fault "reaction" despite from sending the DM

DM1 signal	Signal value in case of at least one active issue	Signal value in case of no issues
Protect Lamp	0 (Lamp Off)	0 (Lamp Off)
Amber Warning Lamp	0 (Lamp Off)	0 (Lamp Off)
Red Stop Lamp	0 (Lamp Off)	0 (Lamp Off)
Flash Protect Lamp	3 (Unavailable / Do Not Flash)	3 (Unavailable / Do Not Flash)
Flash Amber Warning Lamp	3 (Unavailable / Do Not Flash)	3 (Unavailable / Do Not Flash)
Flash Red Stop Lamp	3 (Unavailable / Do Not Flash)	3 (Unavailable / Do Not Flash)
Flash Malfunction Indicator Lamp	3 (Unavailable / Do Not Flash)	3 (Unavailable / Do Not Flash)
SPN Conversion Method	0	0
DM1 Occurrence Count	0	127 (Not Available)
DM1 SPN	SPN of signal causing issue with **highest priority**	0
DM1 FMI	FMI of issue with **highest priority**	0

Figure 22: Structure of DM1 message