STASHH

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PUBLIC

Final design of Ballard FCM

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Towards a standardised fuel cell module

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Revision History

Date	Description	Author
2024/Nov/08	Initial Draft	Christina Mikkelsen (BPSE)
2025/Jan/31	Update to include revision table	Christina Mikkelsen (BPSE)

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1 Introduction

The Ballard FC Move HD+ module is a next generation medium heavy duty fuel cell module for use in zero-emission motive applications. It offers a durable, compact and easy installation solution for system integrators and vehicle manufacturers. The AA size aligns closest to the original footprint of the module design, lending itself to a more stabilized path for a proposed design alteration in the coming development cycles

Lower Life Cycle Cost –With better fuel economy and fewer maintenance requirements, total cost of ownership is 40% lower than previous product generations.

System Integration Flexibility – Available either in a low-profile or small footprint form factor to enable greater flexibility in commercial truck and bus vehicle designs.

Robust Components – Designed with a new generation of more robust balance of plant components to improve reliability.

Freeze-Start Capability – freeze start from -25°C, with no need to plug in the vehicle or use special start procedures.

Humidification - Integrated humidification system provides maximum system performance and durability through a wide range of environmental conditions.

High Performance - Robust PEM fuel cells deliver the power, range, and efficiency demanded by fleet operators.

High Temperature Operation - Permits a smaller cooling package for integration flexibility and generates HVAC heating, significantly improving overall vehicle fuel economy.

Climate Protection - IP6K9K-rated enclosure system guards against premature deterioration of key module components in extreme climates.

High Pressure System - Offers better performance, fuel efficiency and durability by preventing degradation of the fuel cell power module.

Fuel Efficiency - Two to three times more efficient than CNG/diesel engines, fuel cell buses reduce overall fuel consumption.

Remote Diagnostics - Direct or wireless (WiFi or cellular) connection allows customers to monitor performance data remotely, and anticipate preventative maintenance.

Safety Features - Integrated safety system with ventilation fans and hydrogen sensor built into the module to ensure highest safety and ease of installation.

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.

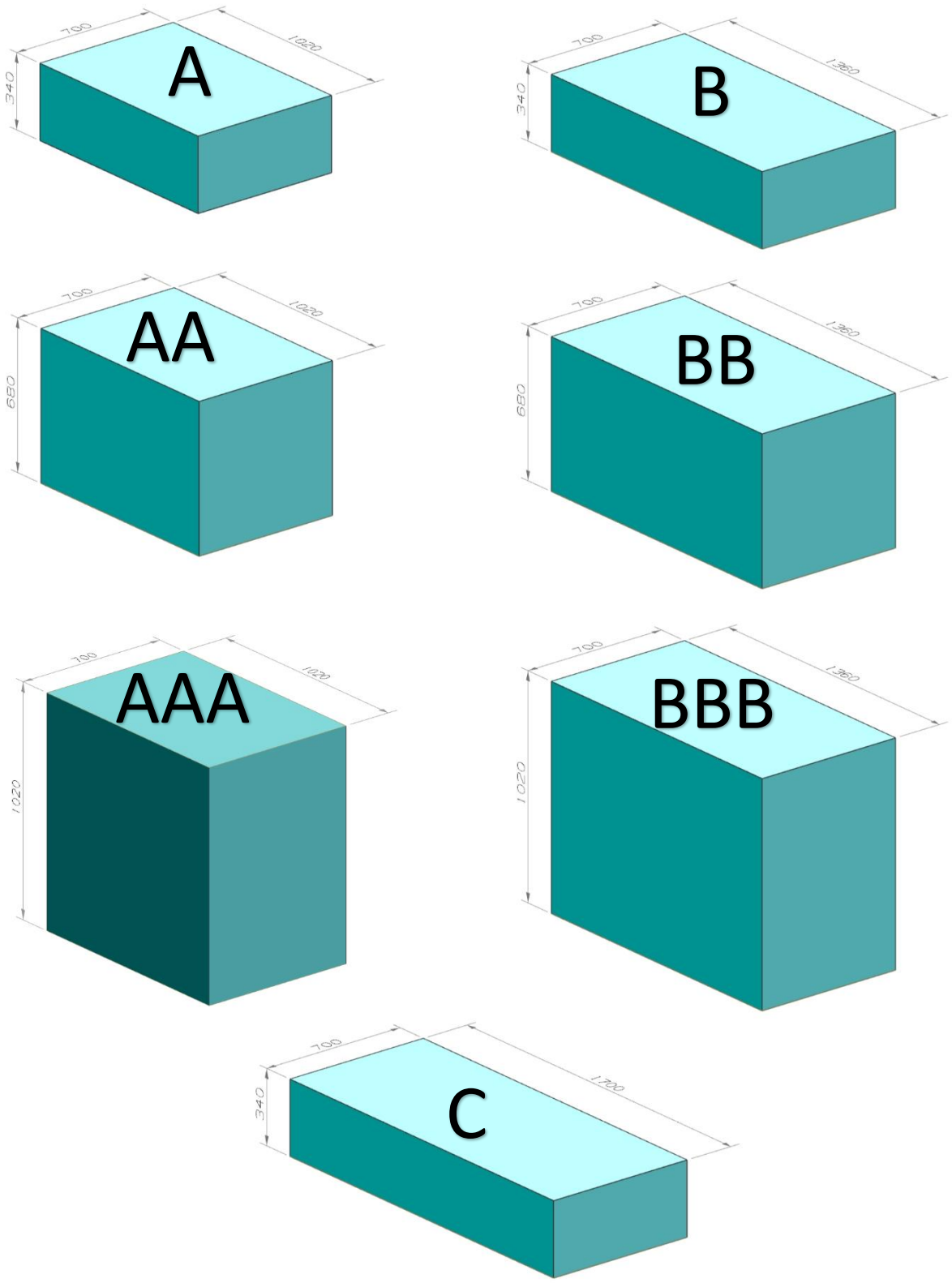


Figure 1: FC modules A, B and C

The orientation of all FC boxes is fixed according to the Length x Width x Height 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

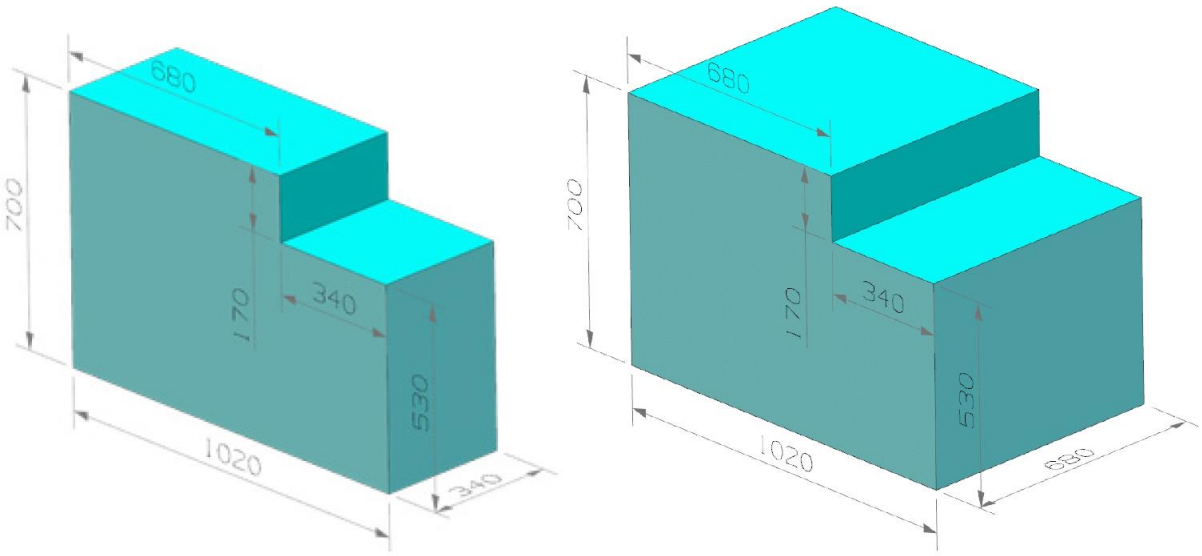


Figure 2: A and AA on their side

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 L x H 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 W x H side FC module. See Figure 3. The dimensions of the interface area will be max. 700mm x $Depth_{main}$ x Module Height

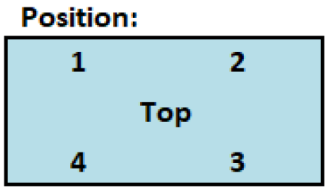


Figure 3: Top view of FCM for interface area definition

"$Depth_{main}$" 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.

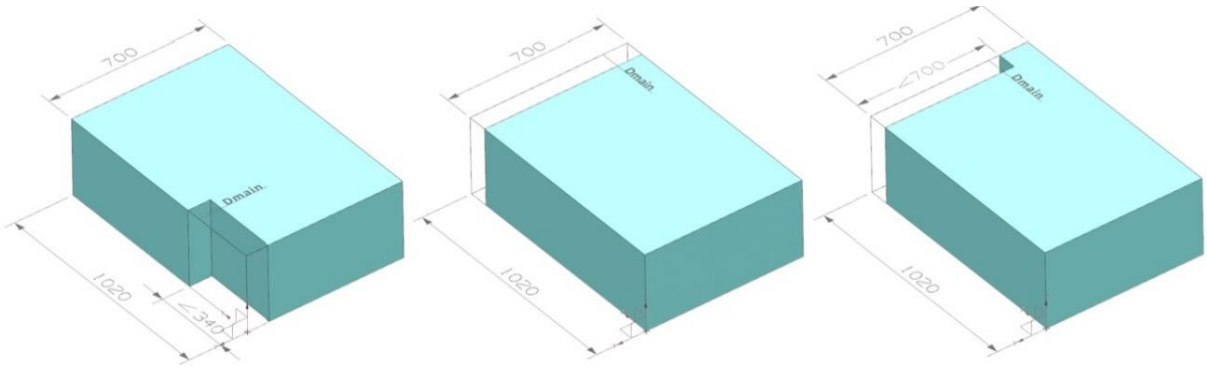


Figure 4: FCM interface areas possibility (1st side)

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	$\geq D_{main}{}^{x}$	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	$\geq D_{main}{}^{x}$	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	≥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

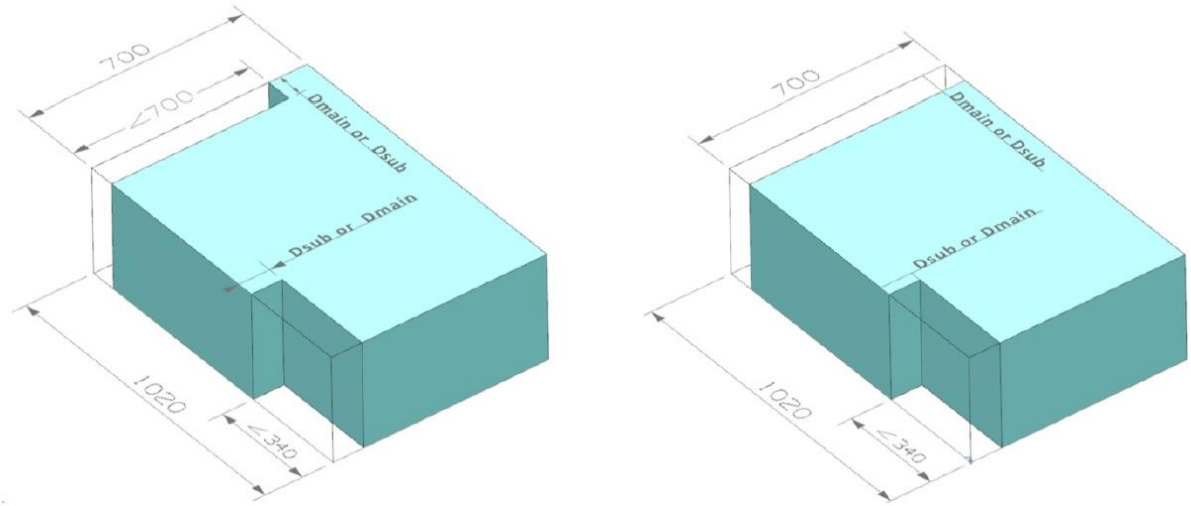


Figure 5: Example of FC module interface area with 1st side and optional 2nd side

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.

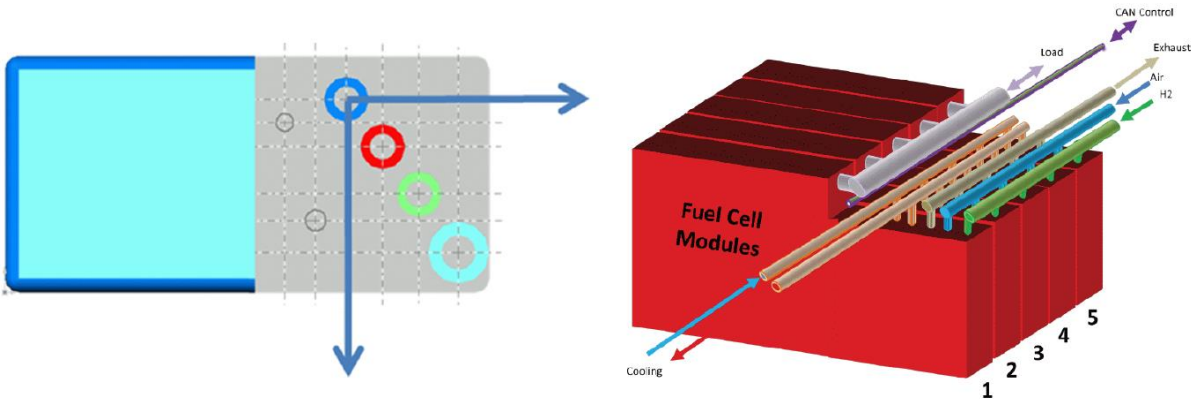


Figure 6: Non-interfering hydraulic and pneumatic connections

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.

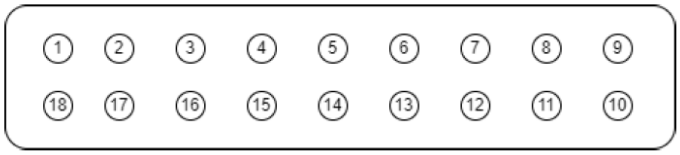


Figure 7: Pinout

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

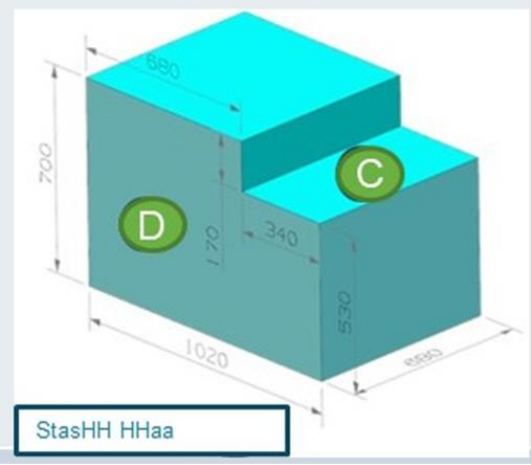
In the following the messages that are used in the communication between the application ECU and FCCU are listed:

- 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 Ballard Power Systems Europe (BPSE)

Ballard Power Systems Europe (BPSE) chose to use the existing module, the FC Move HD+ 100 kW (engine bay model), as the exemplar for this project. This module was 80% compliant with the AA classification with deviations in the interface locations and length.



In order to become StasHH compliant, BPSE has made the following proposed design changes to bring the module into compliance in a future iteration.

The main changes were in the movement of the interfaces onto the X side of the AA model as well as shortening the length by ca. 41cm. This module has not been built but is in the pipeline for proof of concept and refining. The following specifications are modelled on the current iteration of the FC Move HD+ module that would most likely translate over to any new design iterations.

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	15000 hrs
Geographical heights / m	< 3.000m with derating	<2.000m with derating
IP class	> IP54	
Low voltage / V	24DC	280V
High voltage output / V	160 – 850 DC	560V
Operational ambient temperature / °C	-25 to 45	-25c to 50c
Conductivity glycol / µS/cm	< 6 (ASTM D 1125	≤ 5 µS /cm at 20°C
H_2 input pressure / bar	6 - 22	6-10 bar
Hydrogen quality	ISO 14687 or SAE J2719	SAE J2719

Additional technical specifications of FCM are listed below in Table 6

Table 6: Additional key technical specifications of FCM

Requirement	FCM
Net continuous system power output P_{net} BOL / kW	105 +/- 2 kW
Weight / kg	255 kg
DC/DC included in FCM / -	No
Peak system efficiency / %	57%
System efficiency at P_{net} BOL	53%

3.2 Exterior design

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

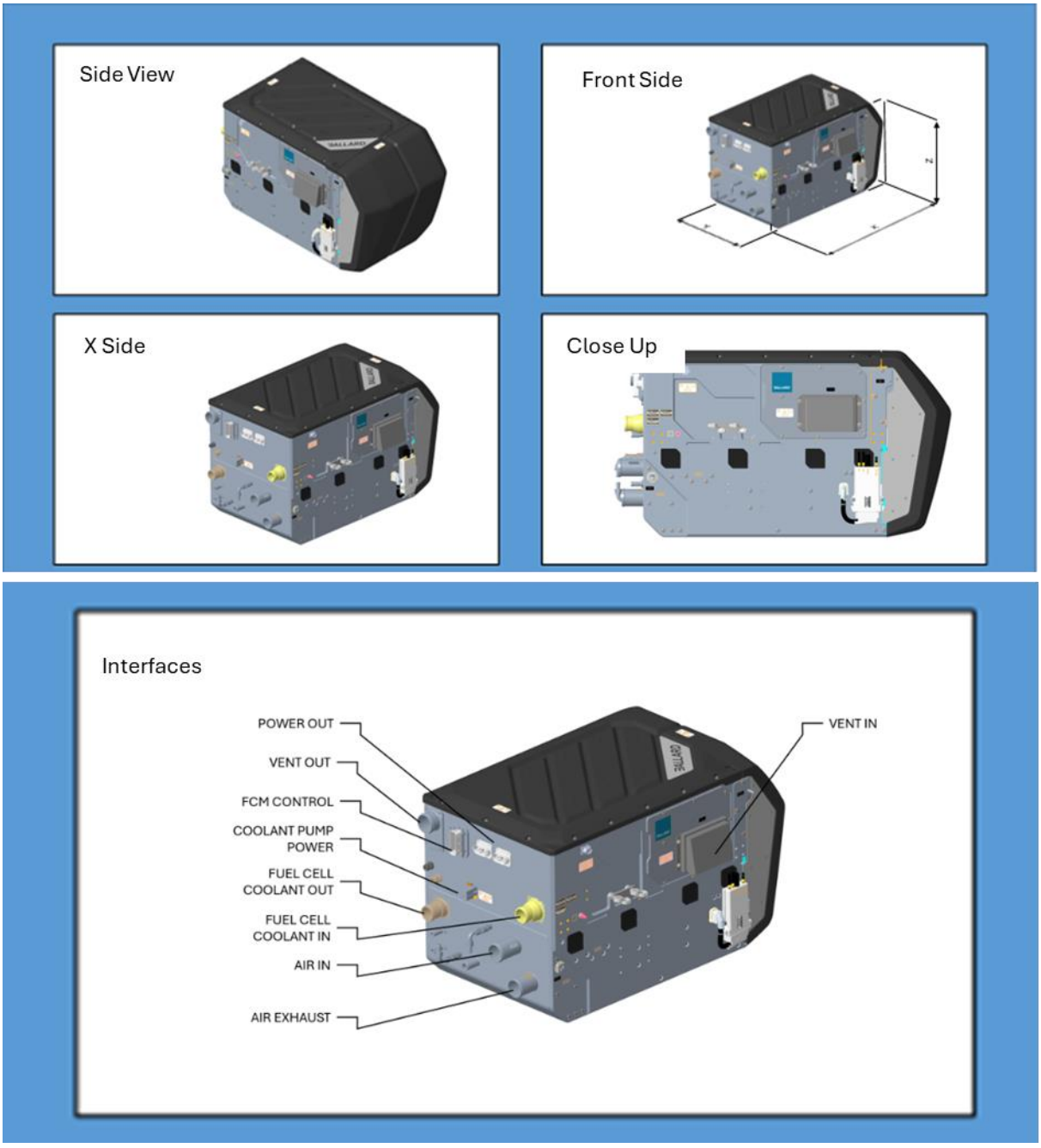


Figure 8: Exterior design with main dimensions of FCM [please add CAD images of all sides to verify compliancy to StasHH]

3.3 Module Pictures

Pictures of the module built for testing shown in

Figure 9.

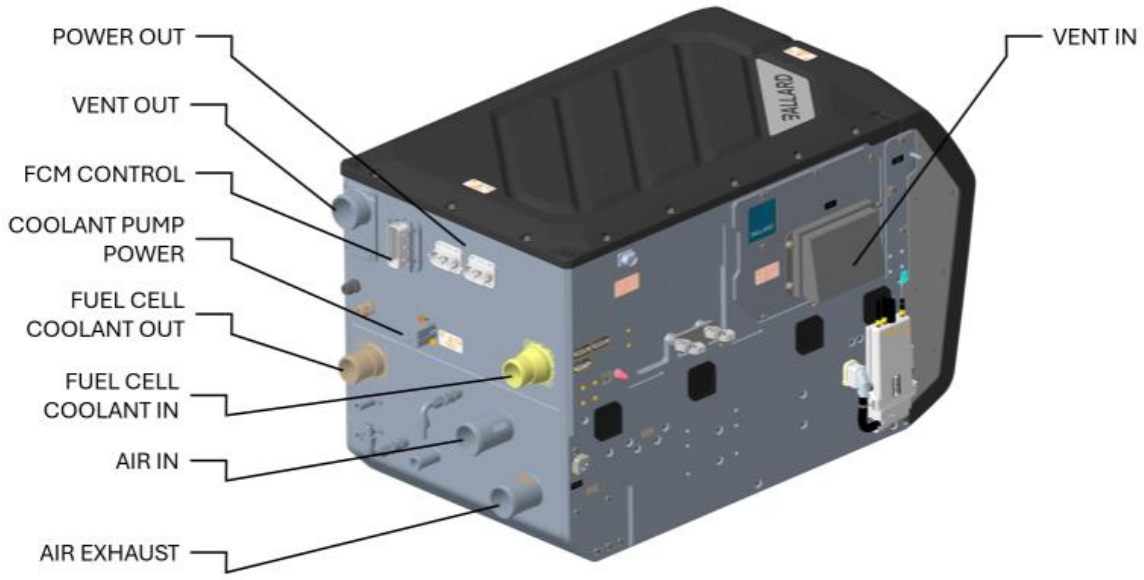


Figure 9: Pictures of the FCM Module built for testing

3.4 Interface specification and area

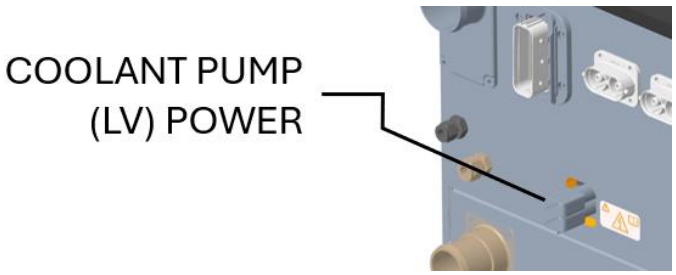
3.4.1 Interface area including hydraulic and pneumatic interfaces

The design and dimensions of the interface area is depicted in Electrical interfaces

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

3.4.1.1 LV

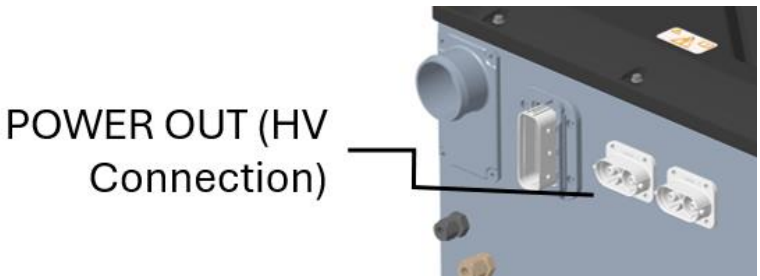
The LV power connections service only the coolant motor as the module will have a built in DC/DC converter.



Operation Mode/State	Fuel Cell Module (Current Draw for 24V Power)	Coolant Delivery System (Current Draw for 24V Power)
Standby State	<5 A	0 Amps
Freeze Start	Max. 10 A	65 A
Running State	Max. 10 A	65 A

3.4.1.2 HV

The HV power requirements for the auxiliaries will vary between 80 -800 VDC and 4 – 50 A.



Description	Specifications
Positive HV Connections	10mm 2-way receptacle
Negative HV Connections	10mm 2-way receptacle
Electrical Isolation (HV to Chassis)	>100 kΩ

3.4.1.3 Communication

The FCM Control portal for this new design is still under development, more details to be available soon.