INN·BALANCE
AUTOMOTIVE FUEL CELL

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Public results of the architecture and system level optimization

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RE	Restricted to a group specified by the consortium (including the FCH2 JU Services)	**-**
CO	Confidential, only for members of the consortium (including the FCH2 JU Services)	**-**

Change Control

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Introduction

This document is a summary of the deliverable D1.2 Overall architecture and systems. The main goal of this document is to give to the public audience a brief insight into the specification work performed during the first year of the INN-BALANCE project without revealing confidential information.

Deviations

No deviations to the original definition.

Specifications

In this section, a summary of the main specifications for the fuel cell system is presented. Due to confidentiality issues, the complexity is strongly reduced.

1. General specifications

The specifications presented in this section apply to all modules.

Environmental	
Minimum temperature for starting up	-30°C
Operating temperature range	-40°C to 52°C

Safety and standards
Compliance with ISO 23273:2013 – Fuel cell road vehicles -- Safety specifications -- Protection against hydrogen hazards for vehicles fueled with compressed hydrogen: ISO 23273:2013 specifies the essential requirements for fuel cell vehicles (FCV) with respect to the protection of persons and the environment inside and outside the vehicle against hydrogen-related hazards. It applies only to such FCEV where compressed hydrogen is used as fuel for the fuel cell system. ISO 23273:2013 does not apply to manufacturing, maintenance, and repair.
Compliance with EC79/2009 Type-approval of hydrogen-powered motor vehicles, and amending Directive 2007/46/EC. This Regulation establishes requirements for the type- approval of motor vehicles with regards to hydrogen propulsion and for the type-approval of hydrogen components and hydrogen systems. This Regulation also establishes requirements for the installation of such components and systems. This Regulation shall apply to: 1. hydrogen-powered vehicles of categories M and N, as defined in Section A of Annex II to Directive 2007/46/EC, including impact protection and the electric safety of such vehicles; 2. hydrogen components designed for motor vehicles of categories M and N, as listed in Annex I; 3. hydrogen systems designed for motor vehicles of categories M and N, including new forms of hydrogen storage or usage.
Chemical compatibility, ISO 16750-5, part 5: Chemical loads

1.1. Fuel Cell System

The fuel cell system will be able to continuously operate in nominal conditions while in peak conditions the operation is limited to 10 seconds.

Power output

System power for different ambient conditions, car running on flat surface	Net electric output [kW]	System electric consumption [kW]
Nominal at 25°C and 1000 mBar	89	11
Nominal at 42°C and 1000 mBar	76	10
Peak at 25°C and 0m altitude (1000 mBar)	100	14

1.2. Fuel Cell Stack

Power output

Operating point	Current [A]	Cathode inlet pressure [mbarg]	Electric power [kW]	Heat [kW]
Nominal	450	1.2	100	89
Peak	570	1.2	114	125

These data correspond to steady-state operation of the stack.

1.3. Anode Module

Appearance	
Total weight of all module components	2kg

Hydrogen Supply	
Temperatures	73°C nominal 90°C maximum
Pressure range	150-2350 mbarg, 1350 mbarg nominal
Quality	ISO 14687-2 or SAE J2719. Traces from oils or ionic liquids from filling station gas compression not acceptable.

Safety	
Opening pressure for safety relief valve on stack inlet	2.4barg

Module power consumption	
At minimum load	24-72W (during hold)
At nominal load	24-72W (during hold)
At maximum load	24-72W (during hold)
Peak/Transient	168-240W (1-2 ms)

1.4. Cathode Module

Appearance	
Total weight of all module components	45 kg
Module volume and/or drawing	55 L

Cathode Air Supply Performance	
Stack inlet temperature	73°C nominal 90°C maximum
Pressure range at stack outlet	200-2200 mbarg, 1200 mbarg nominal
Accumulation of liquid water after freeze shutdown	Needs to be kept at a minimum, no water droplet formations
Active humidity control	Continuous control of humidification from no humidification to maximum performance of humidifier
Evacuation of cathode department after shut-down	After shut-down no air exchange from cathode department to ambient shall be possible
Fast pressure control	The pressure at the stack outlet shall be controllable. The control speed shall be faster than the mass flow ramps up
Dilution of purge gas during shut down	The cathode module shall enable dilution of anode purge gases even during shut down when air flow through the fuel cell stack cathode is prohibited

Module power consumption					
Inlet pressure mbar(a)	Inlet temp. °C	Mass flow g/s	Outlet pressure mbar(a)	Compressor max power kW	Operating point remark
1000 (Sea level)	20	95.7	2200 (Pr*=2.2)	10.4	Continuous
1000 (Sea level)	42	83	2200 (Pr*=2.2)	8.3	Continuous

*PR = Pressure ratio is the ratio between compressor outlet pressure divided with compressor inlet pressure

1.5. Cooling Module

Appearance	
Total weight of all module components	17.2kg

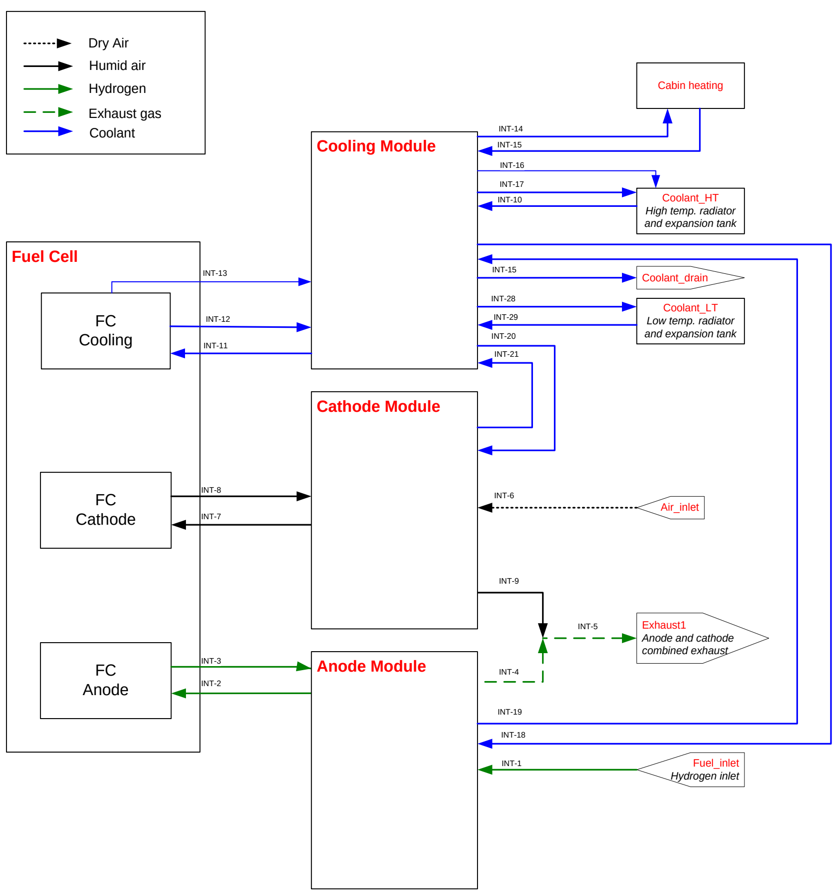
Cooling Supply Performance	
Inlet temperature	-30 to 85°C, 68°C nominal
Pressure range	300-2400 mbarg, 1650 mbarg nominal
Composition	BASF® Glysantin® FC G 20-00/50
Nominal cooling power (kW heat) per altitude (meters above sea level), at 20°C ambient	89kW
Nominal cooling power (kW heat) at sea level and 42°C ambient	77kW
Peak (10s) cooling power (kW heat) per altitude at 20°C ambient	125kW

2. Design and Architecture

This section describes the layout of the different sub-systems and the work being done within WP1. The description of the piping and instrumentation diagram (PID) and interfaces is the output of the work done together with the project partners during the first year of the project.

2.1. Overall System Design

The PID diagrams developed for the overall fuel cell system are used as a basis for the definition of interfaces and protocols. A simplified version of the PID is presented in the Figure 1 where only the mechanichal interfaces of the different sub-modules are shown.



Interface list

Displayed Text	Module	Description
INT-1	Anode	Hydrogen inlet
INT-2	Fuel Cell	FC anode inlet
INT-3	Fuel Cell	FC Anode outlet
INT-4	Anode	Exhaust/purge
INT-5		Combined exhaust pipe
INT-6	Cathode	Air inlet
INT-7	Fuel Cell	FC Cathode inlet
INT-8	Fuel Cell	FC Cathode outlet
INT-9	Cathode	Cathode exhaust
INT-10	Cooling	HT radiator outlet
INT-11	Fuel Cell	FC coolant inlet
INT-12	Fuel Cell	FC coolant outlet
INT-13	Fuel Cell	FC coolant/air outlet
INT-14	Cooling	Cabin heater inlet
INT-15	Cooling	Cabin heater outlet
INT-16	Cooling	FC coolant/air outlet
INT-17	Cooling	HT radiator inlet
INT-18	Anode	HT coolant inlet
INT-19	Anode	HT coolant outlet
INT-20	Cathode	LT coolant inlet
INT-21	Cathode	LT coolant outlet
INT-28	Cooling	LT Radiator outlet
INT-29	Cooling	LT Radiator inlet

Object		PowerCell Sweden AB			
Fluid Interfaces INN-Balance		*This is a printed copy and might therefore not be the latest version*			
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DRAWN	Patrik Karlsson	*Confidential*			3
ISSUED	2017-10-19		Not released	SHEET	1 of 5

Figure 1 INN-Balance sub-module mechanical interfaces

Figure 2 shows the different supply voltages of the different components.

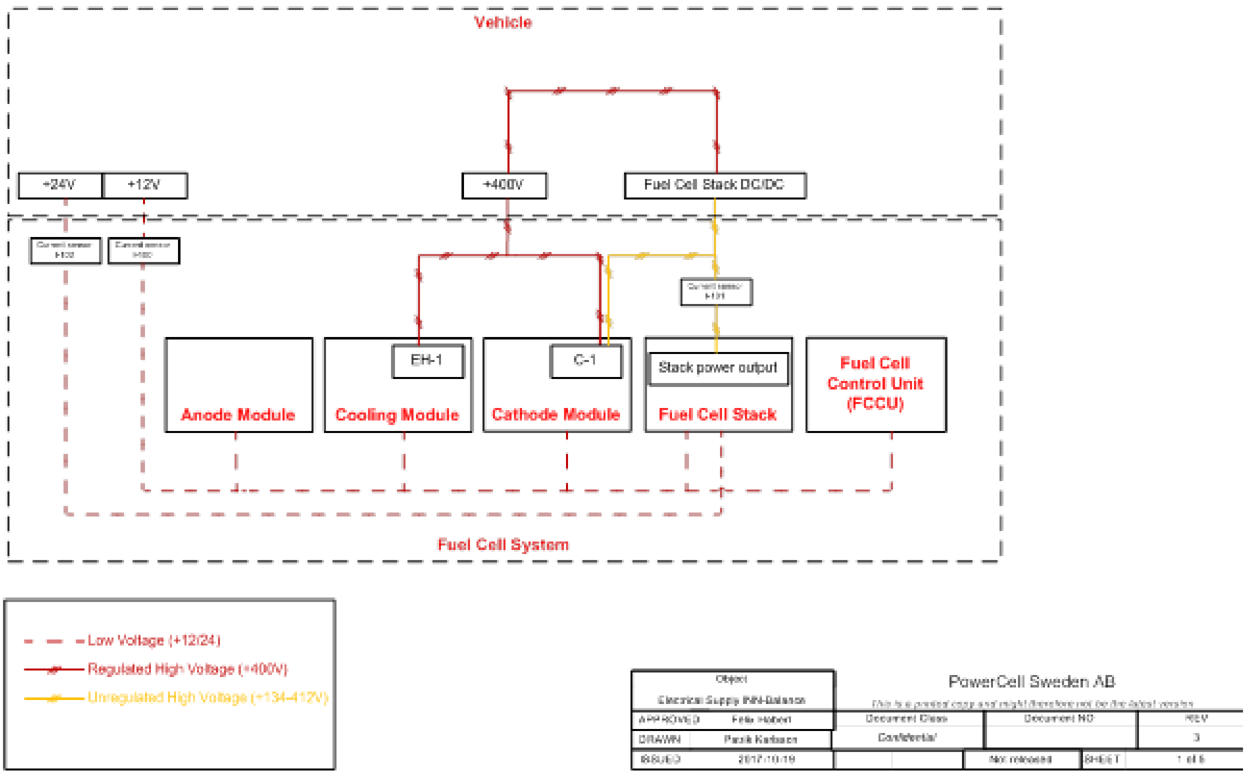

Figure 2 INN-Balance supply voltage diagram

2.2. Stack housing & POD

The mechanical design work at PowerCell focused on the fuel cell stack housing and the fuel cell pod design. The "pod" is an adapter plate between the fuel cell gasket surfaces on the fuel cell stack and the first parts on the sub-modules. Part of the design work is to define the functionalities of the sub-modules to be integrated into the pod. For the anode module, almost all parts are integrated or attached to the stack pod. The cooling and cathode module will have less integration in the pod due to their physical size.

The stack housing was designed according to the installation orientation and the ingress protection rating. The idea is to have all electrical connections (supply to end-cell heaters, CAN and 12VDC supply to CVM) collected at one side. Figure 5 presents the final concept obtained after several iterations.

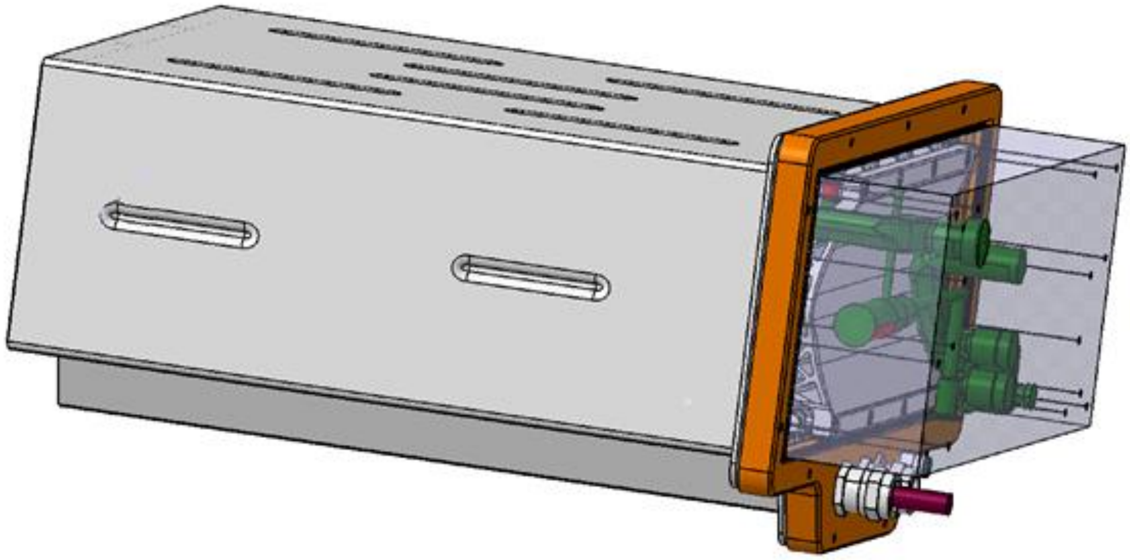

Figure 3 INN-Balance Fuel cell housing and pod for PowerCell S3-335

2.3. System functionality

This subsection includes the description of the operation and functionalities of the different submodules.

2.3.1. Fuel Cell stack

The fuel cell stack provides a means to convert hydrogen and air into water in a controlled manner to release electrical power and heat. The principle of operation is based on an electric power demand that is translated by the control unit into a stack current. The stack is then fed with hydrogen from the anode module, air from the cathode module and coolant from the thermal module corresponding to the calculated flows needed for the electric stack load. The current is then pulled from the stack and a certain voltage is acquired depending on the cell efficiency for the different loads. The cell efficiencies are lower at higher currents mainly due to electrical resistivity losses and mass transport losses. The cell efficiencies are also dependent on the state of the fluids that are fed to the stack with for example increasing efficiencies for higher mass flow, humidity and pressure. The cell voltage drops sharply if there is a lack of mass flow over the cell while drawing current, proper flow as well as an even flow distribution between the cells in the stack is therefore crucial. The pressure drop over the cell decreases with lower volumetric flow and hence worsens the flow distribution, this is compensated by running at higher stoichiometries at low loads as well as running the stack at low pressures at low loads.

Fuel Cell interfaces

At the bottom of the fuel cell (when placed vertically) there are inlets and outlets for hydrogen, air and coolant, making up for a total of six connections. The ports are different for each fluid, but for each fluid the inlet and outlet have the same shape and dimension. The coolant inlet is located next to the air inlet, while the hydrogen inlet is on the opposite side at the bottom of the stack. At the top of the stack, at the same side as the coolant outlet there is a connection to bleed the coolant circuit to get rid of eventually trapped air bubbles, which should be kept at a continuous minimum flow to ensure that no air gets trapped inside the stack. Electrically the stack has two power output connections (+ and -) and a power supply connection for the end-cell heaters. For communication, there is a power supply and CAN communication port for the stack cell voltage monitoring device.

2.3.2. Anode Module

The anode module is devoted to supply the hydrogen demanded at every given load to the fuel cell stack. As nitrogen and water are transported through the membrane from the cathode to the anode side a purge strategy is required, to maximize power output from the stack while minimizing hydrogen losses by purging.
The design strategy is to use an integrated ejector\injector solution that can operate without mechanical recirculation pump. This compact solution can be placed between the stack anode outlet and the stack anode inlet. A hydrogen heat exchanger for pre-heating is incorporated in the anode module in order to avoid condensation when cold dry hydrogen is mixed with warm humid nitrogen and hydrogen coming out from the stack outlet. This solution gives the anode module a mechanical interface towards the high temperature cooling loop.

Description of anode module operation strategy

The control of the anode flow passing through the stack is based on the feed pressure to the ejector\injector unit and the adjustment of the injector needle. This will be managed by a very precise and fast valve upstream of the ejector\injector unit and a stepper motor for the injector needle. The hydrogen content in the anode loop will be controlled by the purge valve (especially used during start-up to quickly get rid of air in the anode loop) and the bleed valve, which are on\off valves.

2.3.3. Cathode Module

The cathode module filtrates, compresses and humidifies a controlled amount of ambient air before entering the fuel cell stack. The excess air (with reduced oxygen content) will then be used to dilute purged hydrogen from the anode below LFL (Lower Flammbility Level).

The main balance of plant component of the cathode module is the high-speed turbo compressor developed by the Celeroton AG (CEL). At the inlet of the cathode module there will be a “weather station” recording the ambient conditions (T, p, RH). Prior to the weather station, there will be a special fuel cell air filter which is mounted in the vehicle and will be connected to the cathode module inlet.

The required stack inlet pressure at nominal load is above 1 [barg] which per definition results in high air exit temperatures from the compressor. Therefore, intercooling is required to protect the membrane humidifier from thermal damages.

The compressor controller will require access to the 12VDC supply voltage as well as to the 400VDC battery during start-up before it will be switched over to the variable fuel cell voltage.

Description of cathode module operation strategy

The pressure and flow will be controlled via CAN by the fuel cell module controller. The cathode module will include several functionalities as, for example, continuous humidifier by-pass, to be able to control the stack humidity. There will be a back-pressure valve that will control pressure and flow independently from each other within the pressure-flow map of the compressor. Cathode shut-off functionality will be implemented to be able to evacuate the cathode compartment from oxygen during shut down.

2.3.4. Cooling Module

The cooling module aims to keep the fuel cell stack at an optimal operation temperature as well as to condition the hydrogen and air feed. The cooling liquid requires to be non-conductive to not generate any leak current inside the fuel cell stack and to keep the isolation resistance high.

The cooling module has the most complex interfaces of all three modules, due to the high level of integration towards the vehicle and to all other sub-systems. The low temperature cooling loop will cool the compressor, the compressor controller and the intercooler. The high temperature cooling loop has an important interface towards the stack as the cold start by-pass line requires a minimized amount of cooling liquid to be able to fast heat up from the specified lower temperature limit of -40°C. The stack cooling will be connected to the vehicle cabin heater loop to be able to supply heat to the cabin as fast as possible. Thus, the main interface of the fuel cell cooling module will be to the vehicle radiators.

Description of cooling module operation strategy

The cooling module will require control of the coolant pump speeds (all three pumps: freeze-start pump, LT-cooling pump and main cooling pump). The radiator fan speeds will require control as well as the electrical heaters and the 3-way valves. For this reason, several temperature sensors will be required.