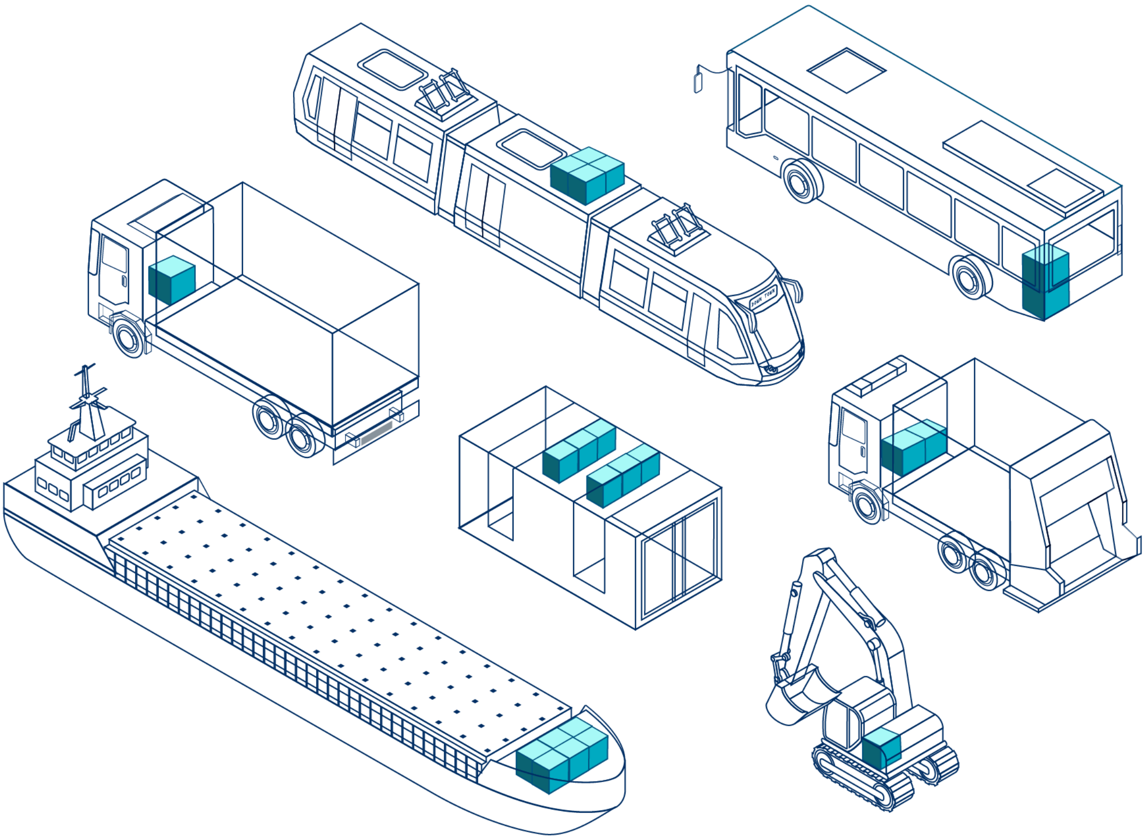
Standard Size definition

DELIVERABLE D3.2

PUBLIC



Ruud Bouwman (VDL)

Quality Assurance: Federico Zenith (SINTEF)

Project acronym: StasHH
Project title: Standard-Sized Heavy-duty Hydrogen
Project number: 101005934
Document date: January 24, 2022
Due date: December 31, 2021
Keywords: Standard Sized, HH, Fuel Cell, Fuel Cell Module, FC stack, FC Balance of Plant
Abstract: This document describes the Fuel Cell Module Standard for the outside size. This standard is written for PEMFC, but the proposed sizes can also be used for other FC technologies.

Revision History

Date	Description	Author
12-08-2021	Draft version 0.1	Ruud Bouwman (VDL)
12-08-2021	QA	Federico Zenith (SINTEF)
22-11-2021	Update after Consortium meeting (V03) And several remarks from partners	Ruud Bouwman (VDL)
07-01-2022	Updated sizes for HH B and C version after project meeting on 2 and 3 December	Ruud Bouwman (VDL)
19-01-2022	Divided in 2 documents D3.2 and D3.3	Ruud Bouwman (VDL)
23-01-2022	Quality assurance	Federico Zenith (SINTEF)

Table of Contents

1 Introduction

1.1 Document overview

Work package 3 as defined in the StasHH proposal:

***VDL** will define the maximum size of the FC modules and their interface areas for the different power ranges with input from all **OEMs** for maximum available space claim and other relevant specifications for all applications. **VDL** will define other relevant physical specifications (mechanical, after-sales serviceability etc.) for the identified standard sizes, which will be validated by **FCM suppliers**.*

1.2 StasHH objectives

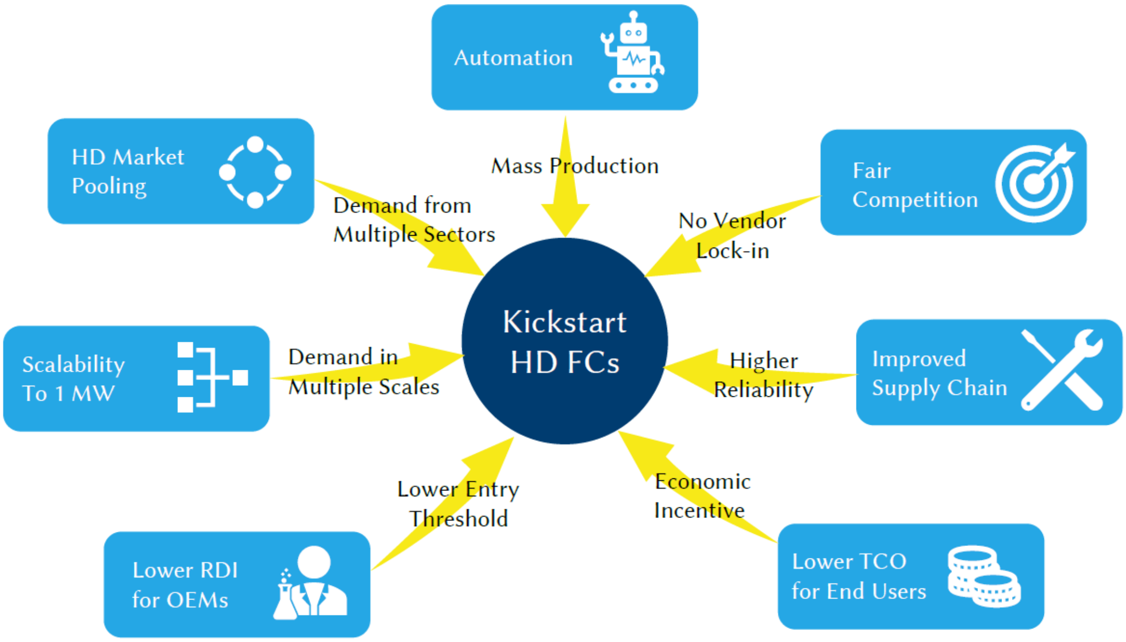


Figure 1: StasHH' specific objectives and their contribution to the overall objective

1.3 Scope of deliverables D3.2 and D3.3

Report D3.2 and D3.3 are the outcome of the standard development workshops of WP3, including the comments from the latest workshop in December 2021 on this subject and some clarifications, which are not all approved by the partners yet. The objective of this document is summarising the current status of the "Standard Definition".

1.4 Responsibilities

VDL is responsible for this document, with the support of the FCM suppliers and OEMs in this project.

2 Key-Terminology and StasHH goal

The StasHH project's paramount objective is to standardize the sizes of the fuel-cell (FC) **module**. The FC module is defined as the FC Stack and the Balance-of-Plant (BoP) components. The BoP consists of (at least) the air-supply system, the cooling system, the hydrogen recirculation system and the control system. Excluded are the hydrogen storage, the cooling radiator(s), the expansion tank, the filters, the exhaust (all of which are meant to be part of the vehicle) and the DC/DC converter. The DC/DC converter can optionally be integrated into the module. The FC module will act as subordinate and follow the requested power or current asked by the vehicle control system. The module must be intrinsically safe.

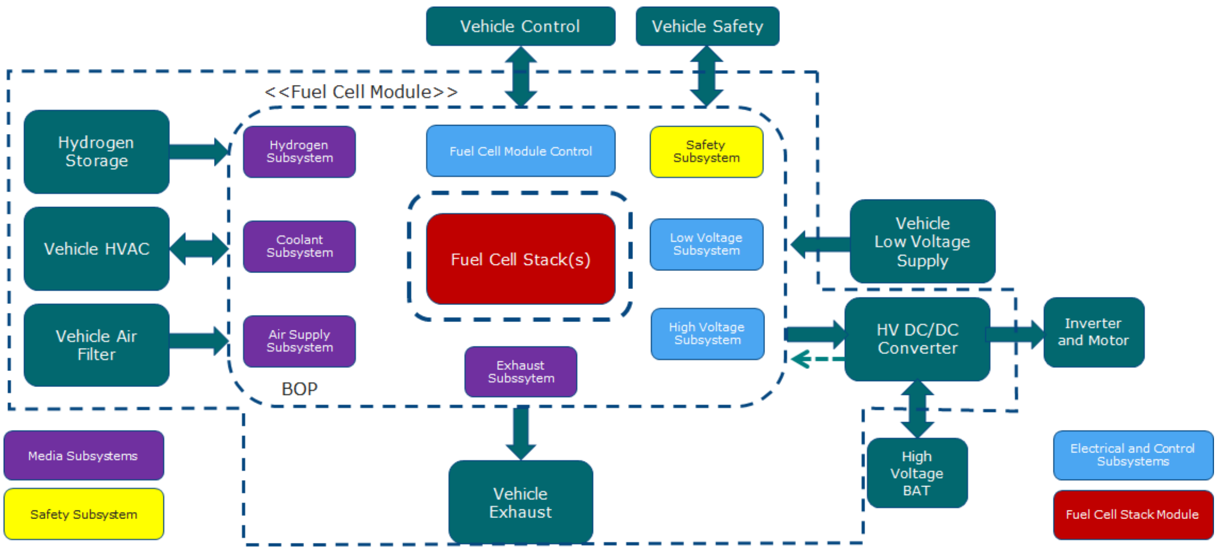


Figure 2: Key Terminology

The goal of WP3 in the StasHH project is to define the:

- Standard Size (outside) (D3.2 chapter 3.2)
- Interface area(s) (incl. position) (D3.3)
- Hydraulic and pneumatic interfaces (D3.3)
- Electrical interfaces (D3.3 and D3.4)
- I/O communication (D3.4)

In D3.2 chapter 3.3 “Serviceability” and 3.4 “BoL and EoL” are not required for StasHH, but will be described in 2022 as proposal for further standardisation.

The StasHH definition should be a kind of overall specification that can be used by any OEM in any application. A high rate of interchangeability between the FC module manufacturers is the ultimate goal.

NOTE:

The IP background of the system architecture and components inside the defined Standard-Sized volume remains the property of the FC module manufacturer and is *not* part of this project. There will be therefore differences in used stacks, air-supply systems, etc.

3 StasHH definitions

3.1 Introduction

All the definitions are on dimensions and interfacing, and there are **NO** requirements concerning power or power density as long as it is above 30 kW (BoL).

3.2 Standard Size

There are three series of FC boxes defined, the A, the B and the C series. This is done together with the OEMs and the FCM. The A, B and C series are defined in 3.2.1, 3.2.2 and 3.2.3 (See table 1):

3.2.1.	HH_A	or 1.020x700x340 mm	(LxWxH)
	HH_{AA}	or 1.020x700x680 mm	(LxWxH)
3.2.2.	HH_B	or 1.360x700x340 mm	(LxWxH)
	HH_{BB}	or 1.360x700x680	(LxWxH)
	HH_{BBB}	or 1.360x700x1.020 mm	(LxWxH)
3.2.3.	HH_C	or 1.700x700x340 mm	(LxWxH)

All dimensions are tolerated with 0/-100 mm.

Table 1: Dimensions FC module HH_{ABC}.

StasHH	Length* mm	Width* mm	Height* mm	Expected PEM kW
HH_A	**1.020**	**700**	**340**	**50**
HH_{AA}	**1.020**	**700**	**680**	**110**
HH_B	**1.360**	**700**	**340**	**70**
HH_{BB}	**1.360**	**700**	**680**	**145**
HH_{BBB}	**1.360**	**700**	**1.020**	**220**
HH_C	**1.700**	**700**	**340**	**90**

*Width, Height and Length are **+0/-100mm**

The maximum volumes of the different sizes given in m^3 ranges from 0,243 to 0,971 m^3 (or 243 to 971 litres):

- HH_A external volume is max. 0.243 m^3
  HH_{AA} external volume is max. 0.486 m^3
- HH_B external volume is max. 0.324 m^3
  HH_{BB} external volume is max. 0.647 m^3
  HH_{BBB} external volume is max. 0.971 m^3
- HH_C external volume is max. 0.405 m^3

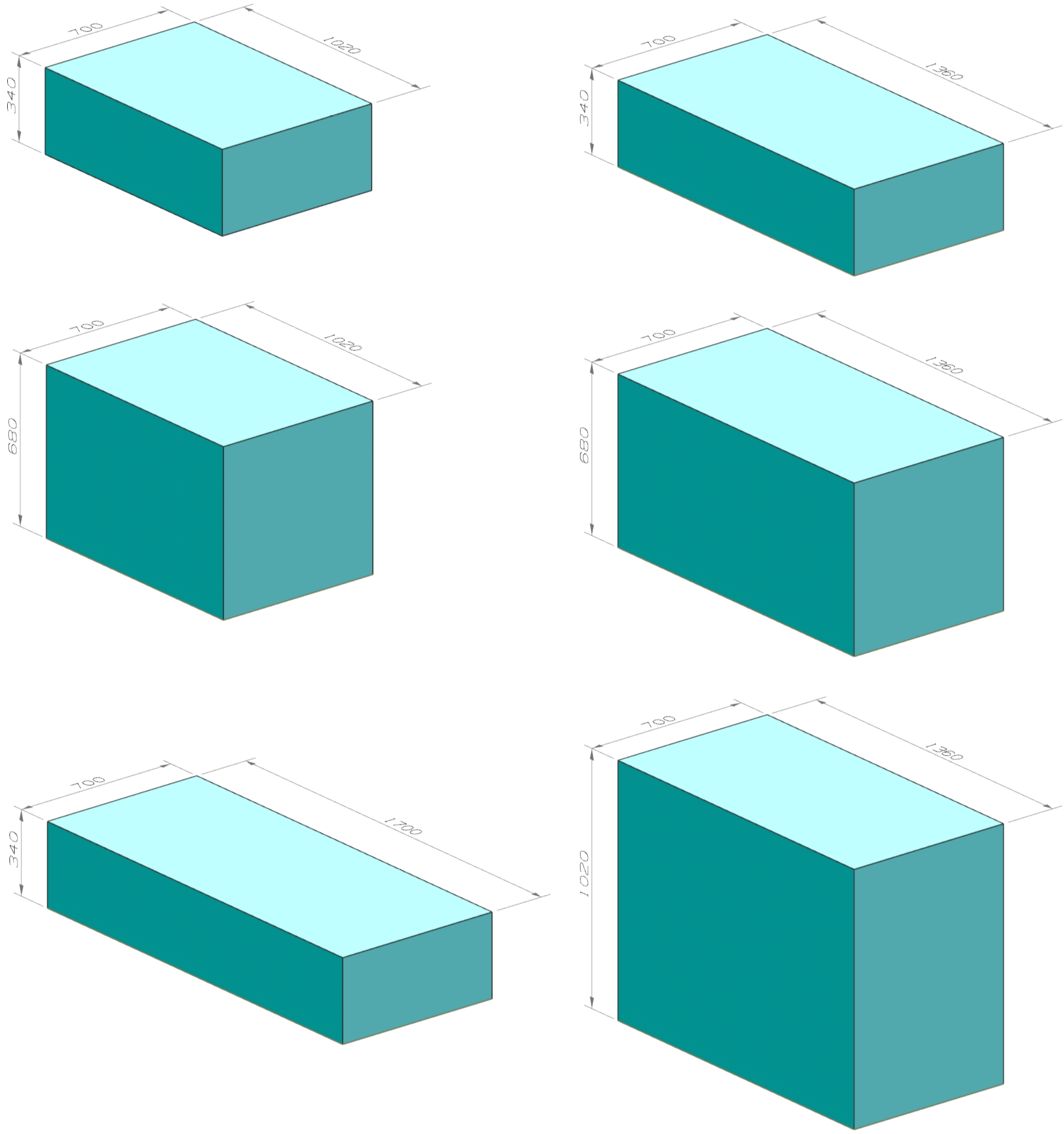


Figure 3: FC modules HH_{ABC}

The $HH_{A(A)}$ can be orientated on its side (optional) for special applications (*not* a StasHH requirement).

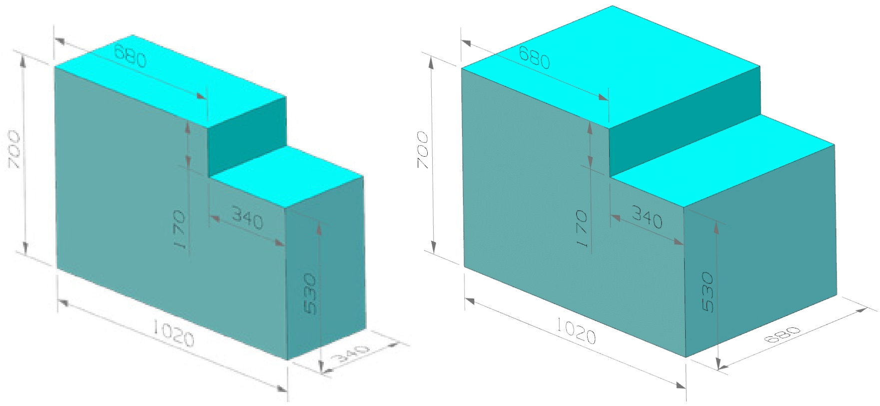


Figure 4: HH_A and HH_{AA} on its side

For the $HH_{A(A)}$ there were initially 7(14) proposals, for the HH_B 5 and for the HH_C 7. The FCM manufacturers, as stated in the General Assembly meeting of December 2021 will build in 2022 first the $HH_{A(A)}$ (70%) and the $HH_{B(B)(B)}$ (30%) versions.

The HH_{ABC} versions can be used in engine bays (trucks, buses and construction equipment), at the location were now the diesel tanks are situated, in GenSets, but also on the roof or underfloor for trailers and train wagons (for example for auxiliary power). A list with possible applications of the different sizes is shown in the next table, and shared with the OEMs in December 2021.

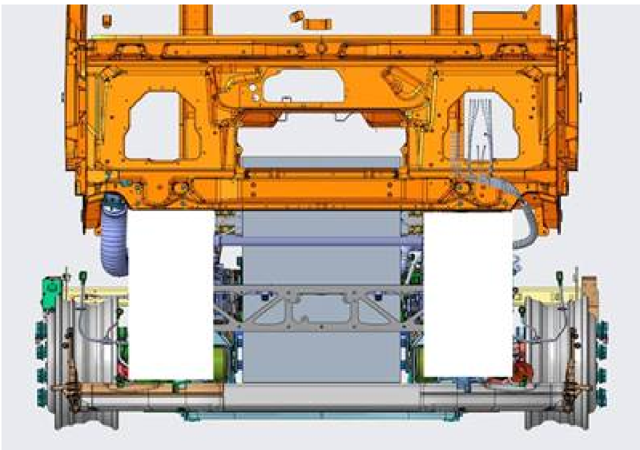


Figure 5: HH_{BBB} in engine bay (Example)

Table 2: HH_{ABC} applications

Application		StasHH Standard
(Semi-) Stationary	**Container**	HH_A or HH_{AA} (horizontal or vertical) (multiple) or $HH_{B(B)(B)}$, H_C (horizontal)
	GenSet	HH_A or HH_{AA} (horizontal or vertical) (multiple) or $HH_{B(B)(B)}$, H_C (horizontal)
	APU	HH_A, H_B or H_C
Rail	**Train**	
	Engine compartment	HH_{BBB} (multiple)
	Roof or Underfloor	HH_A, HH_B or HH_C (multiple)
Water	**Small Ships**	
	Engine compartment	HH_{BB} or HH_{BBB}
	Inland Ships	
	Engine compartment	HH_A or HH_{AA} (horizontal or vertical) (multiple) or $HH_{B(B)(B)}$, H_C (horizontal)
	Deck	Container
	Short Sea Shipping	
	Engine compartment	HH_A or HH_{AA} (horizontal or vertical) (multiple) or $HH_{B(B)(B)}$, H_C (horizontal)
	Deck	Container
	Special Ships	
	Engine compartment	HH_A or HH_{AA} (horizontal or vertical) (multiple) or $HH_{B(B)(B)}$, H_C (horizontal)
	Deck	Container
Off-Road	**Construction equipment**	Depending on vehicle
	Wheelloader	
	Engine Bay	HH_{BBB}, HH_C (multiple, up to 3)
	Excavator	
	Engine Bay	All possible
Road	**Truck <44T (DAF-VOLVO-Iveco)**	
	Engine compartment	HH_{BBB}
	Dieseltank area	2 HH_{AA} or HH_{BB} (Left and Right)
	Truck >18T and <26T	
	Engine compartment	HH_{BB} or HH_{BBB}
	Dieseltank area	1 (or 2) HH_{AA} or HH_{BB} (Left or (and) Right)
	Trailer (APU)	
	Under Floor	HH_A, HH_B or HH_C
	City-Bus (12 or 18m)	
	Engine compartment	HH_{AA} or HH_{BB}
	Roof or Underfloor	1 (or 2) HH_A, 1 (or 2) HH_B or 1 HH_C
	Regional-Bus (12 or 18m)	
	Engine compartment	HH_{AA}, HH_{BB} or HH_{BBB}
	Roof or Underfloor	2 HH_A , 2 HH_B or 1 (or 2) HH_C
	Coach (>=12m)	
	Engine compartment	HH_{AA}, HH_{BB} or HH_{BBB}
	LDV and Car	Integrated solutions

3.3 Serviceability

Foreseen for 2022:

- Test connector
- Repair tree
- List with diagnostic codes

3.4 BoL and EoL

The Begin of Life (BoL) and the End of Life (EoL) definition can be very different depending on the intended application. The definitions must be consistent and based on practical use of the FC module. A compromise on this could be the next definitions:

- BoL will be used for first testing and for comparison
- For EoL, the (maximum) electric CONTINUOUS power in kW_e at which the FCM can be used safely/reliably. At EoL, the maximum needed heat rejection power in kW_T (@T_{FC}) at this (maximal) CONTINUOUS electric power should be within the product definition of the FC module manufacturer. With these values, a FC module application can be designed by the OEM.
- **"Service life" is the number of hours after which the FC reaches the EoL.**
- It is possible to supply a graph between kW_e and kW_T @BoL and EoL hours (See example below in Figure 6)

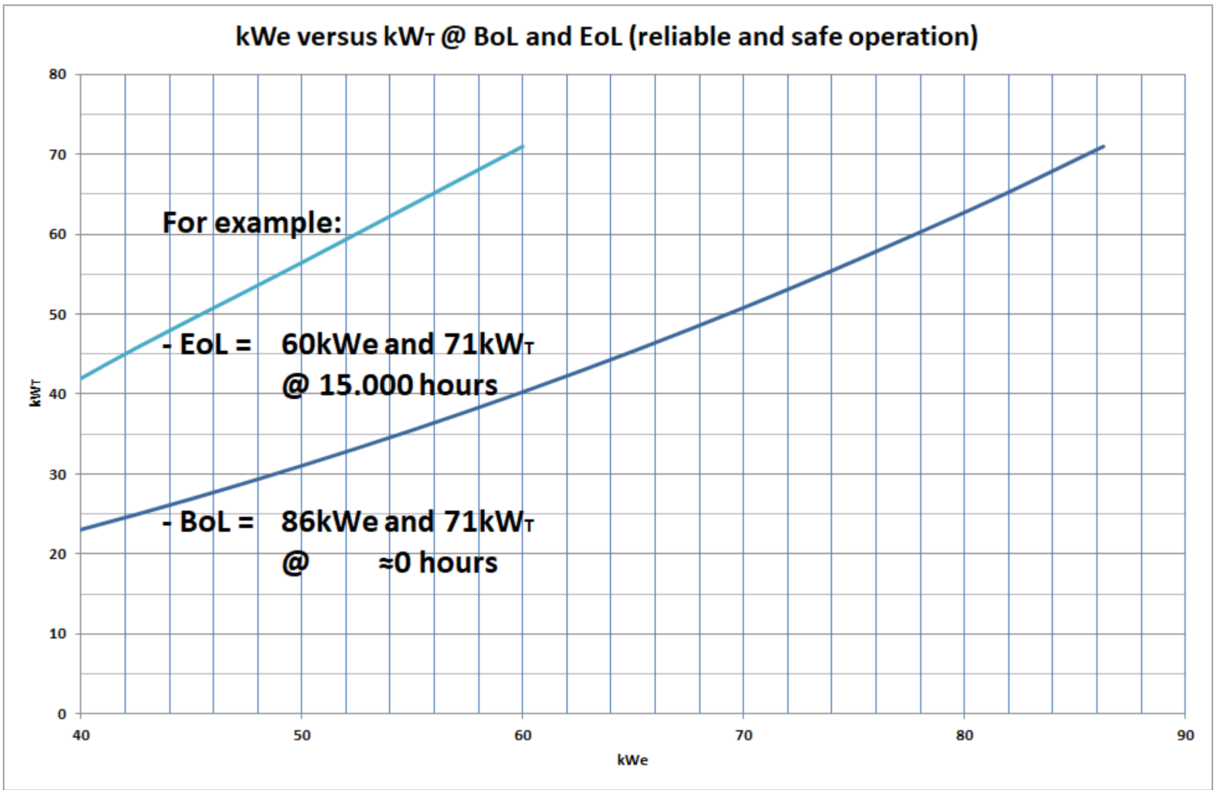


Figure 6: Example BoL and EoL curve

4 Requirements and KPIs for different applications

The “Requirements and KPIs” are divided in three categories:

1- The mandatory requirements according StasHH (Table 3)
2- The Norms and Standards for the different applications (See WP6)
3- The KPIs from the “Multi-Annual Work Plan 2021-2027” from Clean Hydrogen Joint Undertaking for the different applications (Table 4). The black figures in the table are official, the red ones are expected values

Table 3: Mandatory Requirements

Requirements	PEM	**General**
Service Life	**hours**	>15.000
Geographic Heights	**m**	<3.000m with derating
IP	**Class**	>54
Low Voltage	**V**	24DC
Output	**V**	160-850DC
Ambient T	**C**	-25 to 45
Conductivity Glycol	**uS/cm**	<6 (ASTM D 1125)
Hydrogen Input	**bar**	6-22
Hydrogen Quality	**-**	ISO 14687 (D), SAE J2719

Table 4 (3 Sections): KPI's for different applications (still as draft)

PEMFC-Mobility 1		Year	Heavy Duty	Maritime	Train	Aviation
Capex FC System	€/kW	2020	1.500	2.000	-	
(Excluding Storage)		2024	<480	1.500	-	
		2030	<100	1.000	<50	
Availability	%	2020	85	94	94	85
		2024	95	97	97	95
		2030	98	>99	>99	98
Durability	hours	2020	15.000	20.000	15.000	15.000
	@nominal power	2024	20.000	40.000	20.000	20.000
		2030	30.000	80.000	30.000	30.000
Nr. Starts	-	2020	5.000		5.000	
		2024	12.000		12.000	
		2030	30.000		30.000	
Power Rating	kW	2020	200	500		-
	@max power	2024	300	3.000		23MW
		2030	-	10.000		46-82MW
Power Density	kW/ton	2020	250		-	750
	@max power	2024	350		135	1.000
		2030	>400		>160	2.000

PEMFC-Mobility 2		Year	Heavy Duty	Maritime	Train	Aviation
Volumetric Density	kW/m^3	2020	150	15	-	
	@max power	2024	250	25	53	
		2030	>300	30	60	
Hydrogen Consumption	$kgH_2/100km/ton$	2020	0,30		0,12	-
	@nominal power	2024	0,27		0,11	0,70
		2030	0,24		0,08	1,40
Fuel Flow	$kgH_2/hour$	2020	12	30		-
	@max power	2024	18	180		1.400
		2030	-	600		2.800-5.000
System Efficiency	%	2020	50,0	re-use heat	50,0	43,5
	@nominal power	2024	53,0		53,0	45,0
		2030	56,0		56,0	50,0
Areal Power/Density	W/cm^2 @ V	2020	1.0 at 0.650	-	-	-
		2024	1.0 at 0.675	1.0 at 0.675	1.0 at 0.675	1.0 at 0.675
		2030	1.2 at 0.675	1.2 at 0.675	1.2 at 0.675	1.2 at 0.675
PGM loading	g/kW	2020	0,40	0,40	0,40	0,40
		2024	0,35	0,35	0,35	0,35
		2030	0,30	0,30	0,30	0,30

PEMFC-Stationary		Year	Stationary		
			<5kWe	5-50kWe	51-500kWe
CAPEX	€/kWe	2020	6.000	2.500	1.900
		2024	5.000	1.800	1.200
		2030	4.000	1.200	900
O&M cost	€ct/kWh	2020	10	10	5
		2024	8	7	3
		2030	4	3	2
Electrical Efficiency	% LHV	2020	50	45	50
	@nominal power	2024	50	50	52
		2030	56	56	58
Availibility	%	2020	97	97	98
		2024	97	98	98
		2030	98	98	98
Warm start time	sec	2020	60		
		2024	15		
		2030	10		
Degradation @ CI	%/1.000h	2020	0,40		
	@nominal power	2024	0,20		
		2030	0,20		
Stack Production cost	€/kWe	2020	400		
		2024	240		
		2030	150		
Non recoverable CRM	mg/W_{el}	2020	0,10		
		2024	0,07		
		2030	0,01		

5 Conclusion

Mechanical Standards are described and defined in this document. It will still be a challenge to get a maximum of uniformity in the FC module regulations for the different applications, like mobility, maritime and rail (see WP6).

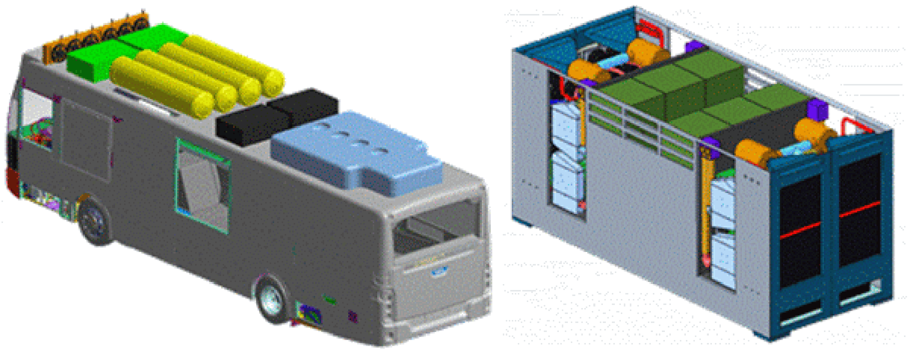


Figure 7: Example Bus and GenSet

6 Figure and Table overview