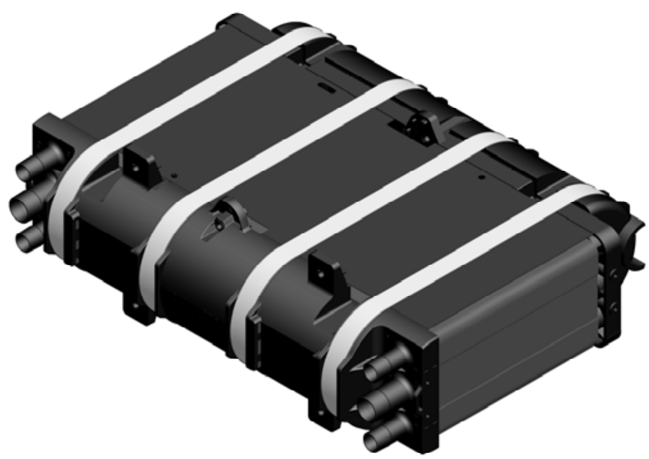
FCgen®-1310 Fuel Cell Stack

Design Characteristics



Model Name: FCgen®-1310
Part Number: 5119705, 5120575, 5120120, 5120100

Document Number: SPC5103106 rev 0C
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This document is intended for initial evaluations of fuel cell system options and should be used as guidance only.

It may contain estimated values for stack and system attributes, and it may contain errors or omissions.

"TBD" is used where information does not exist or has not been validated

Values are subject to change without notice.

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1.0 GENERAL

1.1. Scope

This document describes the target design characteristics for the FCgen®-1310 Fuel Cell Stack developed by Ballard Power Systems. Unless noted otherwise, all specification values stated are applicable at the beginning of operational lifetime. Some characteristics will change over time as the fuel cell stack is operated.

1.2. Product Configurations

The FCgen®-1310 stack is available in sizes ranging from 27 cells up to 120 cells.

<table>
<tr><th>Number of Cells</th><th>Part Number</th><th>Typical Power Application</th></tr>
<tr><td>27</td><td>5119705</td><td>1 - 2 kW</td></tr>
<tr><td>50</td><td>5121050</td><td>3 kW</td></tr>
<tr><td>75</td><td>5120575</td><td rowspan="2">5-8 kW</td></tr>
<tr><td>100</td><td>5120100</td></tr>
<tr><td>120</td><td>5120120</td><td>8 - 10 kW</td></tr>
</table>

1.3. Glossary

Term	Description
Air bleed	Term used to describe the addition of air to the fuel loop for the purpose of oxidizing Carbon Monoxide (CO)
ATR	Auto Thermal Reformate
BOL	Beginning of Life
CVM	Cell Voltage Monitoring System
MEA	Membrane-Electrode Assembly
sccm	standard cubic centimeter per minute (evaluated at 1 atmosphere and 0°C)
slpm	standard liter per minute (evaluated at 1 atmosphere and 0°C)
stoic	Stoichiometry, used to describe reactant flow rate: Fuel Flow (slpm) = stoic X Load X Number of Cells X 0.00696 [slpm/A/cell] / %H2 Oxidant Flow (slpm) = stoic X Load X Number of Cells X 0.00349 [slpm/A/cell] / %O2
TBD	To be determined

In general, standard SI units and their abbreviations are used in this document, with exceptions noted above. Chemical components are described using standard chemical nomenclature (e.g. H2 for hydrogen gas).

1.4. Reference Documents

- MAN5100304 FCgen®-1310 Product Manual and Integration Guide
- DRW5113912 Interface Control Drawing for 1310 Stacks

2.0 SPECIFICATION

2.1. General Characteristics

The 1310 stack design is built to operate without active cell voltage monitoring provided operating conditions are within the specified regions. The 1310 stack is suitable for operation in an always on steady state power mode or in an on/off cycling power mode.

The 1310 stack may take up to 50 hours of operation in order to be fully conditioned, thus stack performances upon receipt may be lower than stated in this document until this burn in time has been achieved.

2.2. Stack Performance

Stack performances reported in this document are all representative of a steady state stack that has been fully conditioned. Polarisation values are always taken from a higher current to a lower current state. The stack performance shown in Table 1 is based on a typical set of operating conditions utilizing a pure hydrogen system listed in table 3.

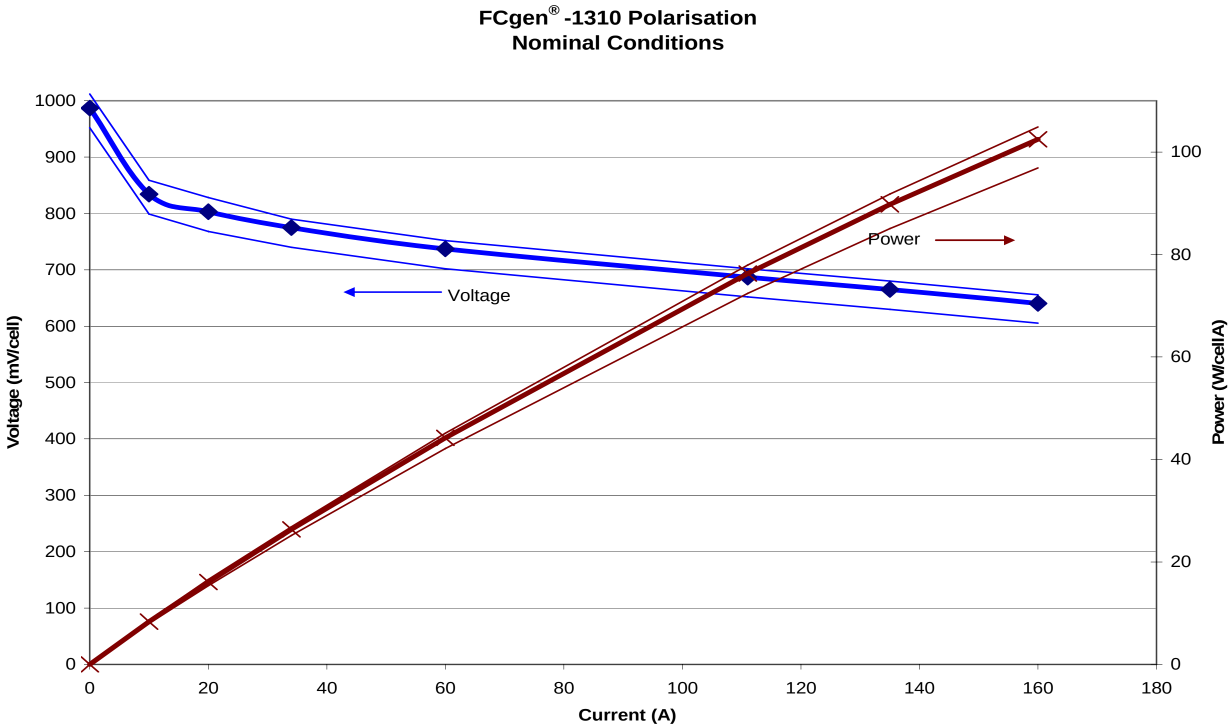
Table 1: Stack Performance at Beginning of Life

Performance Parameter		Stack Current (A)					
		0	34	60	111	135	160[1]
Average Power	W/cell	0	26	44	76	90	102
Average Voltage	mV/cell	987	775	737	687	665	640
Fleet Performance Variability[2]	mV	+25 / -35	+15 / -35	+15 / -35	+15 / -35	+15 / -35	+15 / -35

[1] A nominal operating current of 135A, minimum operating current of 34A, and a maximum operating current of 160A is recommended. See Section 2.3 for details

[2] Performance variability defines the expected variability in performance from stack to stack at Beginning of Life due to manufacturing variability.

Figure 1 = Polarisation (V-I) Curve for range of operation with error bands



2.3. Operating Conditions

Table 2: Specified Operating Condition Ranges

Electrical	
Load	160 A max, 34 A min[3]
Voltage	1.18 V/cell max, 0.50 V/cell min
Current Ramp Rate	1000 A/sec provided conditions for a given load are within specifications.
Fuel	
Composition	H2/N2 Blend or Reformate[4], target ≥80%-vol H2 (dry)
Stoic	≥1.45
Inlet Pressure	< 300 mbar(g)
Pressure Drop	> 50 mbar
Anode-Cathode inlet overpressure	> 0mbar, < 200 mbar, 25 mbar target
Inlet Temperature	Coolant inlet temperature +/- 2 °C
Inlet Humidity	80%-100% RH
Liquid Water Ingestion	Acceptable limits have not been defined for this design
Oxidant	
Composition	Ambient Air
Stoic	>= 1.8
Inlet Pressure	< 300 mbar
Pressure Drop	> 50 mbar
Inlet Temperature	Coolant inlet temperature +/- 2 °C
Inlet Humidity	95% - 100% (non-condensing)
Liquid Water Ingestion	Acceptable limits have not been defined for this design
Coolant	
Composition	De-ionized Water and/or Ethylene Glycol, or Propylene Glycol. < 50% glycol
Conductivity	< 5 µS/cm @ 20 °C
Flow	> 0.1 L/min/cell
Inlet Pressure	> 25 mbar, < 500 mbar
Inlet Temperature	Target: 55 – 60 °C,
Temperature Rise	Target: 0.8 °C per 20 A +2 °C

[3] Recommended minimum and maximum. See Ballard for operation outside these limits.

[4] While this stack can be used with a reformate based fuel system, it requires a fuel purification system between the fuel processor and stack to ensure CO levels are substantially eliminated. Periodic anode recoveries may be required.

Table 3: Nominal Operating Conditions

1.8855psi 3.626psi

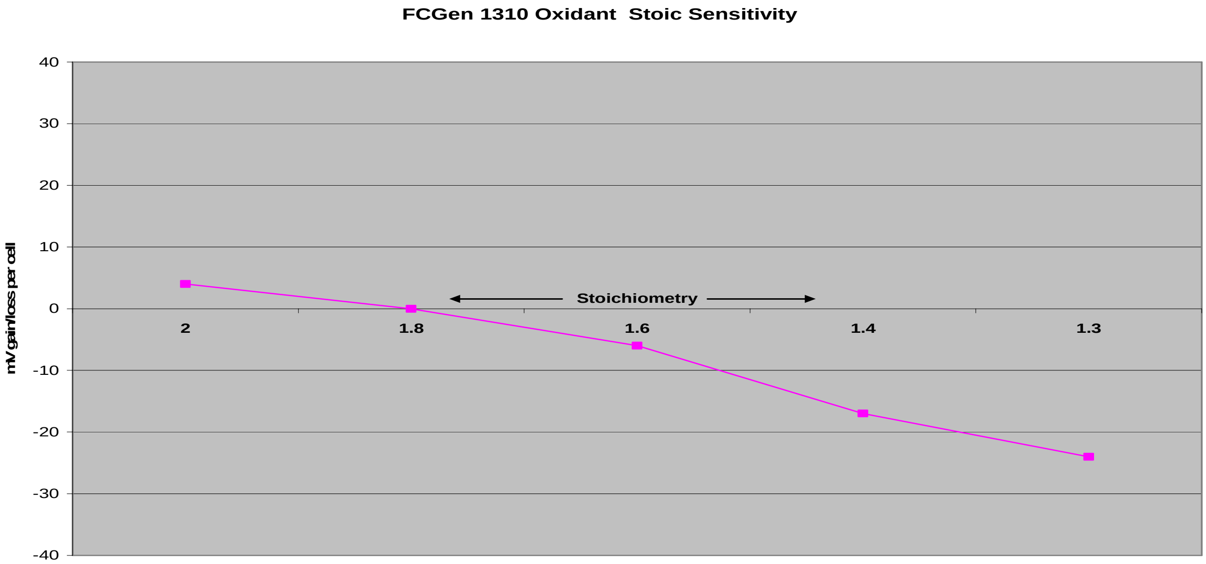
Operating Condition		**Stack Current (A)**				
		34	60	111	135	160
Fuel						
Composition (H2/N2 Blend)	%H2	90	90	90	90	90
Stoic	-	4.5	2.5	1.45	1.45	1.45
Inlet Pressure	bar(g)	0.130	0.140	0.190	0.220	0.250
Pressure Drop[5]	mbar	50	50	50	56	60
Inlet Temperature	°C	60	60	60	60	60
Inlet Humidity	% RH	57.8	57.8	57.8	57.8	57.8
Oxidant						
Stoic	-	1.8	1.8	1.8	1.8	1.8
Inlet Pressure	bar(g)	0.11	0.12	0.17	0.20	0.23
Pressure Drop[6]	mbar	50	75	130	158	190
Inlet Temperature	°C	58.9	58.9	58.9	58.9	58.9
Inlet Humidity	% RH	95	95	95	95	95
Coolant						
Composition	-	100% De-ionized Water				
Flow	L/min/cell	0.16	0.17	0.18	0.18	
Inlet Temperature	°C	60	60	60	60	60
Temperature Rise	°C	1.9	3.3	5.6	7.5	8.5

[5] Based on 100 cell stack, value will vary due to stack variability.

2.4. Parametric Responses

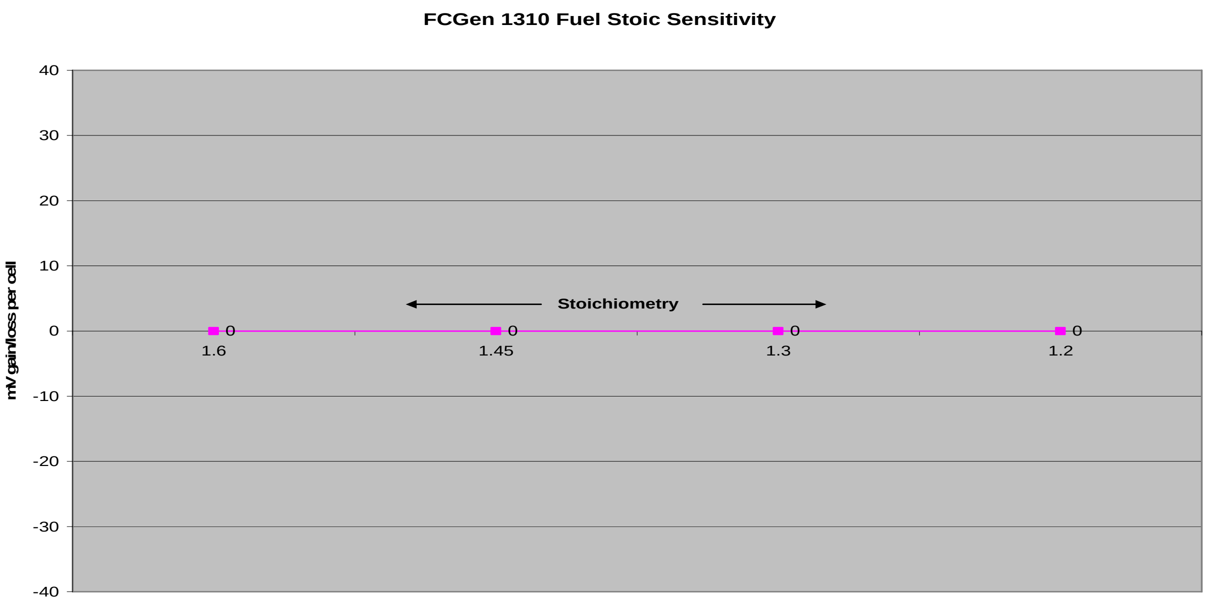
Figures 2 and 3 below show stack response to variables in operating conditions. See 135A point in table 3 for the balance of conditions used.

Figure 2 – Oxidant Stoichiometry Sensitivity at 135A.



Oxidant stoic response is immediately seen on fuel cell stack performance.

Figure 3 – Fuel Stoichiometry Sensitivity at 135A



Fuel stoic does not impact performance as seen in figure 3 above where the performance values are within measurement error of test equipment. However, insufficient fuel stoichiometry can have a serious effect on cell to cell variation within the stack and it is important to stay within the parameters of table 2.

2.5. Ambient Environment Specifications

Table 4: Ambient Environmental Conditions

Ambient Conditions	
Operating Pressure/Altitude	-400m to 4600m
Ambient Temperature, Operation	-20°C to 70°C
Total Allowable Freeze-Thaw Cycles	TBD
Ambient Relative Humidity	TBD
Shock/Vibration	TBD

The ambient conditions refer to environment around the fuel cell stack and not necessarily what the exterior system environment is. For example, the stack will have a nominal ambient temperature of 50 °C when installed in a system enclosure.

2.6. Reactant Specifications

The 1310 stack is designed specifically for use with a purified H2 fuel stream, with zero CO or CO2 present (H2/N2 blend). The stack is compatible with steam or ATR reformate; however, lower performance and durability should be expected if any CO is present and an air bleed is used, or if a significant amount of CO2 is present.
Tables 5 and 6 contain maximum levels for common contaminants. A comprehensive list is available in the FCgen®-1310 stack integration guide.

Table 5: Fuel Specification

Description	**Specification**
Inert Diluents	
CH4	< 4%
N2	< 25%
Chemical Contaminants	
Carbon Monoxide (CO)	< 0.1 ppm (with air bleed)
Carbon Dioxide (CO2)	<25%
Air Bleed	< 1%
S	< 1 ppb
NH3	< 1 ppb

Table 6: Oxidant Specification (Ambient Air)

Description	**Specification**
Chemical Contaminants	
NOx	< 0.1 ppb

SOx	< 0.1 ppb
Particulate	
Airborne Particles(solid or liquid)	< 20 µg/m^3, < 5 µm diameter
Salt	< 20 µg/m^3, < 5 µm diameter

2.7. Emissions (BOL)

Table 7: Maximum Beginning of Life (BOL) Emissions

Stack Leakage	
External Fuel Leak	1 sccm/cell air @ 0.5 barg
External Coolant Leak	0.1 sccm/cell air @ 0.5 barg
External Oxidant Leak	10 sccm/cell air @ 0.5 barg
Internal Transfer (Fuel To Oxidant)	1 sccm/cell air @ 0.5 barg
Internal Transfer (Fuel to Coolant)	0.1 sccm/cell air @ 0.5 barg
Internal Transfer (Oxidant to Coolant)	0.1 sccm/cell air @ 0.5 barg

2.8. Shipping / Storage Conditions

Table 8: Shipping and Storage Environmental Conditions

Environmental Condition Limits	
Temperature Range	5 °C to +70 °C
Total Allowable Freeze-Thaw Cycles	TBD
Relative Humidity Range	TBD
Shock and Vibration	Designed to withstand normal shipping shock and vibration in standard Ballard packaging.

2.9. Stack Weight and Dimensions

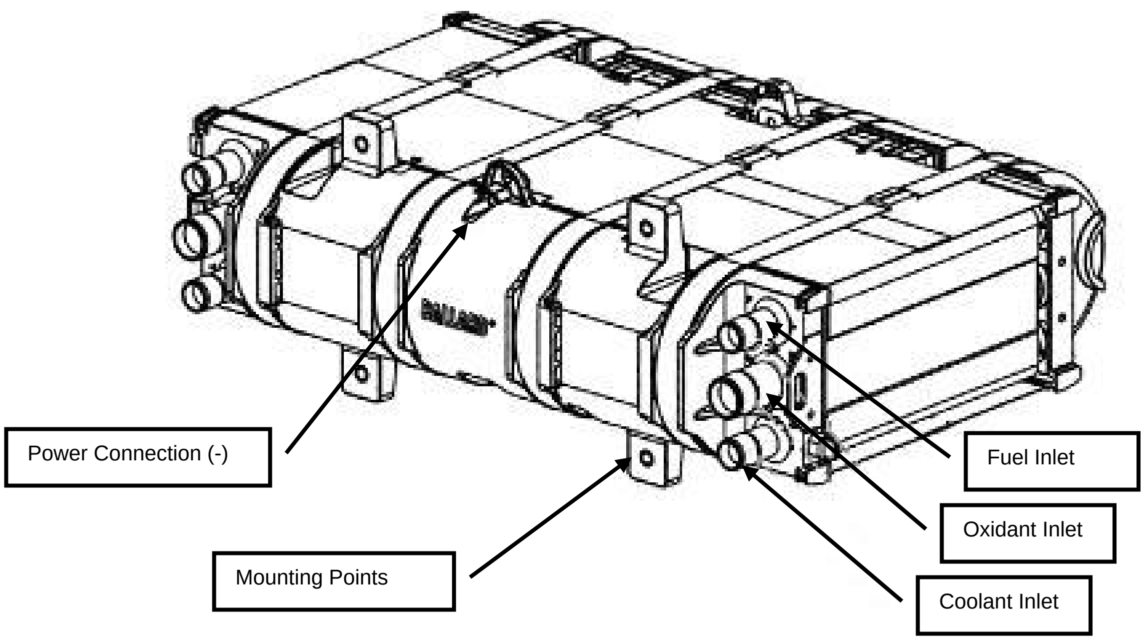
Table 9: Weight and Dimensions

Stack Length	Height	Width	Dry Mass
27 cells: 233 mm 120 cells: 473 mm	180 mm	490 mm	27 cells: 8.3 kg 120 cells: 22.2 kg

All dimensions are nominal. Refer to the corresponding stack interface drawing (DRW5113912) for details.

2.10. Mechanical and Electrical Interfaces

Figure 4 – Physical Interfaces



The fluid inlets and outlets are tube stub with beads designed for rubber tubing with hose clamps. Hose barb outer diameter is ¾” (19.3 mm) for fuel and coolant, and 1” (25.65 mm) for oxidant. The stack is designed for co-flow fluid streams (all fluids flow in the same direction, from inlet side of stack to outlet side).

The power connections require an interfacing lug with two ¼” (6.6 mm) holes spaced ¾” (19.3 mm) apart (for example: Panduit LCD6-14B-L, LCD2-14B-Q, LCD4-14B-L). The hardware is designed for M6 nut and bolt for connection between the buss plate and the interface lug. Cable size should be 6 AWG to 1 AWG dependant on maximum current to be drawn. The connectors should be tin-plated, and copper compression lugs with standard barrel should be used. It is preferred to install the stack as a floating (non-earth bonded) component.

Mounting points are 6.8 mm diameter through-holes and are intended for use with M6 nominal bolt size. Anode side (fluid inlet/outlet side) mounting points are located both on the top and bottom of the stack; cathode side (spring cap side) mounting points are on the bottom of the stack only for use in the flat orientation.

See stack integration guide (MAN5100304) for detailed installation instruction.

2.11. Stack Degradation Rate and Lifetime

There are generally two key life-limiting failure modes that will prevent the stack from performing as required in a given application: voltage loss and fuel leakage. Voltage loss is seen as a steady degradation in maximum power. Fuel leakage will lead to both an increase in fuel consumption, and H2 emissions in the air exhaust stream.

While the definition of specific failure criteria will differ depending on the application, Ballard has used the following End-of-Life (EOL) criteria to measure stack lifetime:

Average cell voltage at 135 A drops to less than 600mV

OR

Anode leakage rate into the Cathode increases to more than 10 cc/min per cell (tested with nitrogen at 0.5 barg).

Lifetime depends primarily on the number of on/off cycles that occur with an air-filled anode. Other factors, such as the number of operating hours, are less significant.

The design target for the lifetime of a FCGen® -1310 stack is 8000 hours and 1250 on/off cycles with air on the anode before reaching End-of-Life (EOL).

For non-cycling applications the stack is expected to meet 20,000 hours of operation provided less than 300 on/off cycles have been performed.

The stack is design to last TBD years calendar time including storage.

If lower voltage or higher leakage are acceptable in the application, of if a more benign duty cycle is used, the FCgen® -1310 stack will be able to be operate beyond these limits.

The stack can be refurbished by replacing MEAs and seals (termed a stack “recore”).

2.12. Recoverable Performance Losses

Reversible performance losses over time may occur due to a variety of reasons. Most often these losses are caused by prolonged periods of non-use or contaminants in the air or fuel gas streams. Acceptable recovery methods include operations at reduced air stoics, current pulsing, addition of air bleed on the fuel, air bleed pulsing or air purging of the fuel circuit within the stack.