Fuel Cell Market Overview 2023

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GREEN HYDROGEN SOUTH AFRICA

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RESPONSIBLE INSTITUTIONS

Green Hydrogen South Africa (GH2SA): GH2SA is a multi-stakeholder initiative that promotes South Africa as a leading green hydrogen producer and investment destination of choice. It is led by the Investment and Infrastructure Office (IIO) within the South African Presidency and home of the South African Green Hydrogen Summit (SAGHS).

H2.SA: H2.SA is a project of the German Development Cooperation with South Africa. It is commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) and implemented by the *Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH* in close cooperation with The Presidency of South Africa. H2.SA's main objective is to promote a South African green and sustainable hydrogen economy. Working closely with its partners from Government, private sector, and civil society, H2.SA provides expertise, resources, and builds capacity for a secure and sustainable energy future that holds opportunities for all South Africans.

GIZ South Africa, Lesotho and Eswatini: The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH is a German development agency which provides services in the field of international development cooperation and international education. Its work in South Africa is carried out primarily on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ). Some of the core areas of cooperation are Climate, Energy and Just Transition. GIZ supports South Africa in developing an environmentally sustainable and secure energy infrastructure and enhancing energy efficiency.

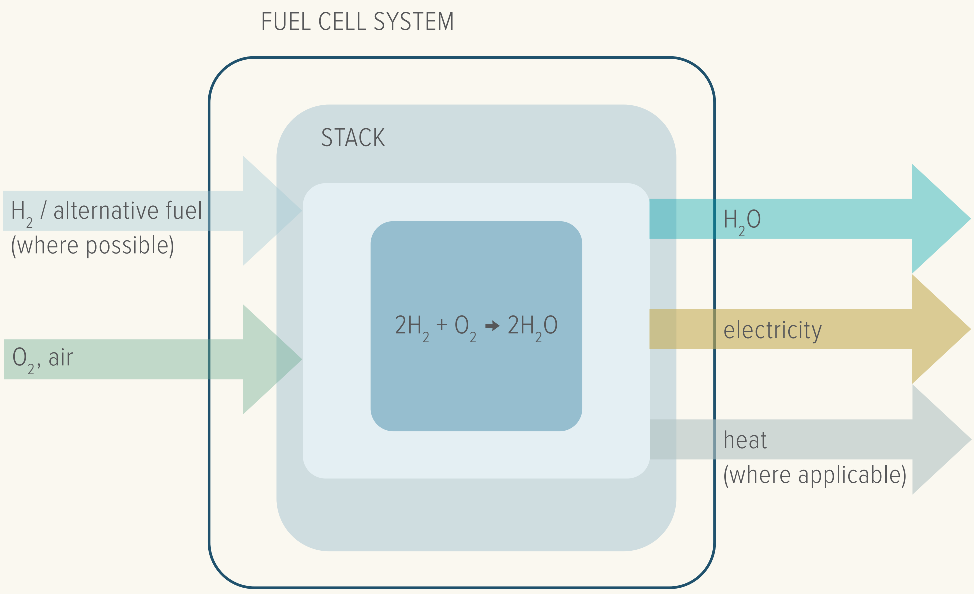
Green Hydrogen and Fuel Cells

In the context of a rapidly decreasing global carbon budget and an urgency to identify adequate solutions for decarbonizing the so-called hard-to-abate sectors, the demand for green hydrogen (H2), is steadily increasing.

The term “green hydrogen” refers to H2 produced on the basis of using renewable energy sources via electrolysis; Power to X (PtX) refers to renewable hydrogen-based products such as ammonia and synthetic jet fuels. Many offtakers (e.g. Germany, the EU, Japan) are willing to pay a premium price and to sign long-term supply agreements to stimulate the renewable H2/PtX market development.

Renewable hydrogen also offers domestic use opportunities to countries like South Africa, which are characterised by favourable solar and wind energy conditions, sufficient mineral resources and existing hydrogen value chains and industries.

A key component in hydrogen production is a fuel cell, which is an electrochemical device that converts the chemical energy from a fuel source, such as hydrogen, into electricity through a chemical reaction with an oxidising agent. Unlike conventional batteries, fuel cells continuously generate electricity as long as a source of fuel and oxidiser are supplied. Fuel cells come in various designs, but the most common type is the hydrogen fuel cell, which uses hydrogen as the fuel and oxygen from air as the oxidiser. The hydrogen and oxygen react at the electrodes of the fuel cell to produce electricity, water, and heat.



Typical fuel cell layout, adapted from the diagram which appeared in "Marktübersicht Elektrolyseure 2021" Centrales Agrar-Rohstoff Marketing-und Energie-Netzwerk (C.A.R.M.E.N. e.V.)

Fuel cells have the potential to provide a clean source of power, as they only produce water and heat as byproducts, and they can be fuelled with hydrogen produced from renewable sources. They are being developed for a wide range of applications, including stationary power generation and mobility applications.

Different Types of Fuel Cells

There are several types of fuel cells, each with its own unique characteristics and applications. Some of the most common types of fuel cells include:

- **Alkaline Fuel Cell (AFC)**: AFCs were some of the first fuel cells developed and have been used primarily for manned space missions. They are efficient and durable, but require high-purity hydrogen and oxygen, which makes them less practical for widespread commercial use.
- **Proton Exchange Membrane Fuel Cell (PEMFC)**: PEMFCs are commonly used for transportation and portable power applications due to their fast start-up time and compact design.
- **Phosphoric Acid Fuel Cell (PAFC)**: PAFCs are highly efficient and have been used in stationary power applications, such as combined heat and power systems. They can tolerate different types of fuel gases as well as blends, and are relatively tolerant of impurities in the fuel.
- **Solid Oxide Fuel Cell (SOFC)**: SOFCs operate at high temperatures and can use a variety of fuels, including natural gas, propane, and diesel. They are highly efficient and well-suited for large-scale stationary power generation, but their high operating temperature and use of ceramics make them more expensive to manufacture.
- **Molten Carbonate Fuel Cell (MCFC)**: MCFCs operate at high temperatures of 650°C and use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide matrix. They are are currently being developed for natural gas and coal-based power plants for electrical utility, industrial, and military applications.

These are some of the most common types of fuel cells, but there are many other types as well, including specialised fuel cells designed for specific applications. Please note that this section is not intended as a scientific assessment of fuel cell types but rather as a high-level overview of common technologies. Project developers should therefore do in-depth research to identify the most suitable fuel cell type for their specific needs.

Alkaline Fuel Cell (AFC)

Advantages:

- **Durability**: AFCs are highly durable and have a long lifespan, making them well-suited for demanding applications, such as manned space missions.
- **Efficiency**: AFCs are highly efficient, meaning they convert a high proportion of the chemical energy in the fuel into usable electrical energy.
- **Wide range of fuels**: AFCs can use a wide range of fuels, including hydrogen, methanol, and ethanol, which makes them flexible and adaptable for a variety of applications.
- **Operating temperature**: AFCs operate at a relatively low temperature, which makes them more durable and less expensive to manufacture than some other types of fuel cells.

Disadvantages:

- **Hydrogen purity**: AFCs require high-purity hydrogen and oxygen, which can be challenging and expensive to obtain.
- **Limited applications**: Despite their high efficiency and durability, AFCs have limited commercial applications due to their high-purity fuel requirements.

Overall, while AFCs have some notable advantages, they are not as widely used as some other types of fuel cells due to their high-purity fuel requirements. Nevertheless, they continue to play an important role in certain specialised applications, such as manned space missions.

Proton Exchange Membrane Fuel Cell (PEMFC)

Advantages:

- **Start-up time**: PEMFCs can start producing electricity within seconds, making them well-suited for applications that require quick response times, such as transportation and portable power.
- **Power density**: PEMFCs have a high power density, meaning they can produce a lot of power in a small space, making them well-suited for portable and transportation applications.
- **Efficient**: PEMFCs are relatively efficient, meaning they convert a high proportion of the chemical energy in the fuel into usable electrical energy.
- **Noise**: PEMFCs are quiet and produce no harmful emissions, making them well-suited for use in enclosed spaces.

Disadvantages:

- **Durability**: PEMFCs have a relatively short lifespan compared to some other types of fuel cells, and they are sensitive to impurities in the fuel, which can reduce their performance and lifespan.
- **Cost**: PEMFCs use critical raw materials such as platinum and are therefore relatively expensive to manufacture.
- **Fuel impurities**: PEMFCs are more sensitive to fuel impurities than other fuel cell technologies.

Despite their high costs, PEMFCs are a suitable technology for small and mobile applications due to their favorable dynamic behavior and small footprint.

Phosphoric Acid Fuel Cell (PAFC)

Advantages:

- **Stability**: PAFCs have a stable performance over a wide range of operating conditions, making them well-suited for use in a variety of applications.
- **Durability**: PAFCs are highly durable and have a long lifespan, making them well-suited for demanding applications, such as combined heat and power systems.
- **Fuel flexibility**: PAFCs can use a wide range of fuels and fuel blends, including natural gas, LPG, biogas, and renewable fuels, which makes them flexible and adaptable for a variety of applications. They are also less sensitive to fuel impurities than other technologies.

Disadvantages:

- **Cost**: PAFCs are relatively expensive to manufacture.
- **Start-up time**: Due to their relatively high operating temperature of 150-200°C, PAFCs require longer start-up times than other fuel cell technologies.

Overall, while PAFCs have some notable advantages, they are not as widely used as some other types of fuel cells due to their relatively cost as platinum is used as the catalyst. Nevertheless, they continue to play an important role in certain specialised applications, such as combined heat and power systems.

Solid Oxide Fuel Cell (SOFC)

Advantages:

- **Efficiency**: SOFCs are highly efficient, meaning they convert a high proportion of the chemical energy in the fuel into usable electrical energy.
- **Fuel flexibility**: SOFCs can use a wide range of fuels, including natural gas, biogas, and renewable fuels, which makes them flexible and adaptable for a variety of applications.

Disadvantages:

- **Cost**: SOFCs are more expensive than other types of fuel cells.
- **Durability**: SOFCs' high operating temperatures can lead to corrosion and breakdown of cell components and limit the overall number of start-ups and shut-downs.
- **Start-up time**: SOFCs need long start-up times to reach the operating temperature.
- **Maturity**: SOFCs are still under development and not widely commercially available.

SOFCs have the highest efficiency and are well suited for stationary applications such as power back-up solutions and combined heat and power. However, they are still under development and face stability issues.

Molten Carbonate Fuel Cell (MCFC)

Advantages:

- **Efficiency**: MCFCs are highly efficient, meaning they convert a high proportion of the chemical energy in the fuel into usable electrical energy.
- **Fuel flexibility**: MCFCs can use a wide range of fuels, including natural gas, biogas, and renewable fuels, which makes them flexible and adaptable for a variety of applications.
- **Combined heat and power**: MCFCs are particularly suitable for use in used for combined heat and power applications, in which the heat generated by the fuel cell is used to generate additional electricity or for other applications.

Disadvantages:

- **CAPEX**: MCFCs are relatively expensive to manufacture.
- **Durability**. MCFCs' high operating temperatures, and their corrosive electrolyte can lead to shortened cell life span due to accelerated component breakdown and corrosion.
- **Start-up time**: MCFCs need long start-up times to reach the operating temperature.
- **Maturity**: MCFCs are still under development and not widely commercially available.

Overall, while MCFCs have some notable advantages, they are not as widely used as some other types of fuel cells due to their high cost and complexity. Nevertheless, they continue to play an important role in certain specialised applications, such as combined heat and power systems.

Purpose, Context & Limitations

This market overview seeks to assist project developers with the challenging task of comparing different fuel cell manufacturers and products to select the right fuel cell for their needs. The first section provides an overview of 25 manufacturers and 70 fuel cells. The second section outlines which companies are open to delivering their products to South Africa and to servicing them there.

Both sections were compiled with significant effort and to the best of our abilities, but they are likely incomplete and may contain minor errors, as follows:

- **Section 1: List of Manufacturers** – some manufacturers and/or products may have been missed when compiling this overview. Furthermore, data sheets and even units are not standardised across manufacturers, and product ranges change rapidly, which means that data is quickly outdated.
- **Section 2: Qualitative information** – only about a third of manufacturers responded to GIZ's interview questions about their interest and intended role in the South African market.

ITEM	UNIT	EXPLANATION
Fuel cell type		Describes the type of the fuel cell which is typically defined by the separator or the environment the fuel cell operates in. Proton exchange membrane (PEM) fuel cells are typically used for mobility applications, whereas solid oxide and molten carbonate fuel cells are used for stationary cases. Other types comprise alkaline and phosphoric acid fuel cells.
Type of application		This column describes the recommended application of the fuel cell: B – Backup power M – Motive MA – Marine MH – Material handling P – Power generation
Nominal power output	[kWel]	The nominal power output gives the electricity output when the fuel cell is operated at nominal capacity and is measured in Kilowatts of electric power (kWel).
Power density	[kW/l]	The power density describes the output of electrical power per volume of the fuel cell. This can be given either for the stack or the system and is measured in Kilowatts of electrical power per litre of the system (kW/l).
Output voltage range	[V]	Here, the minimum and maximum voltage which a fuel cell system can provide is given and measured in Volts (V).
Fuel cell electric efficiency	[%]	The electric efficiency of the fuel cell describes how much of the energy content of the hydrogen (typically lower heating value) can be transformed to electricity and is measured in percent (%).
Operational input pressure (fuel input)	[bar]	The operation input pressure indicates at which pressure the hydrogen should enter the fuel cell system and is measured in Bar (bar).
Start-up time	[sec]	The start-up time describes the time which is needed to reach the nominal load and is measured in seconds (sec).
H2-quality requirements	[%]	Here, the quality of the hydrogen is specified under which the fuel cell should operate. This can be either given as a purity in percent (%) or as a reference to an industry standard.

ITEM	UNIT	EXPLANATION
Indicated life expectancy	[h]	Some manufacturers indicate the lifetime of the fuel cell in hours (h). Caution is advised, however since the values are often not proven and sometimes refer to fuel cell stacks OR systems.
Stack/system dimensions	[mm]	The dimensions of the system are typically given in length, height and width with the unit millimeter (mm).
Weight stack/ system	[kg]	The weight of the system is typically given in kilograms (kg). This measure is most important for mobile applications.
Ambient temperature condition	[°C]	Fuel cells can only operate in a safe way in a specific temperature range. The lower and upper temperature limit is given in degrees Celsius (°C).

Name	Country	Market readiness	Name	Fuel cell type	Typical application	Nominal power output [kW]	Power density [kW/l]	Output voltage range [V]	Fuel cell electrical efficiency [%]	Operational input pressure (fuel input) [bar]	Start-up time [sec]	H2-quality requirements [%]	Indicated life expectancy [h]	Stack/system dimensions [mm]	Weight stack/system [kg]	Ambient temperature condition		Website
																From [°C]	To [°C]	
Ballard Power Systems	Canada	Market ready	Fcmove-MD	PEM	M	45		140 - 280V						1 070 x 595 x 395	145			See online
			FCmove-HD	PEM	M	70		250 - 500V	57	8		SAE J2719	25 000	1 525 x 812 x 367	250	-30	50	See online
			FCmove-HD+	PEM	M	100		280 - 560V	57	8		SAE J2719 or ISO 14687 (Grade D)	25 000	1 056 x 630 x 650	260	-30	50	See online
			Fcmove-XD	PEM	M	120		520 - 750V	60	8		SAE J2719, ISO 14687 (Grade D), or GB/T 37244-2018	25 000	596 x 745 x 985	250	-30	40	See online
			FCvelocity-HD85	PEM	M	85		260 - 419V		8		SAE J2719	20 000	1 130 x 869 x 487	256			See online
			FCvelocity-HD100	PEM	M	100		357 - 577V		8		SAE J2719	20 000	1 200 x 869 x 487	280			See online
			FCgen-H2PM		B	1.7 - 60		48 - 55V DC		5		100		500 x 567 x 617 (for 5kW)	75 (for 5kW)	-20	46	
			FCWave	PEM	B, MA, P	200		350 - 720V		3.5 - 6.5		SAE J2719 or ISO 14687 (Grade D)	25 000	1 209 x 741 x 2 195	1 000	0	45	See online
Bloom Energy	United States of America	Market ready		SO		300		480V	52	0.7 - 1		99.9		5 461 x 2 642 x 2 057	15 800	-20	45	See online

TYPE: Proton Exchange Membrane (PEM) Alkaline (A) Solid Oxide (SO) Phosphoric Acid (PA) Molten Carbonate (MC)

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																From [°C]	To [°C]	
HyAxiom (recently renamed from Doosan Fuel Cell America)	United States of America	Market ready	PureCell Model 400	PA	B, P	440 - 460		480V AC	50	2.5 - 3.5			Stack: 87 600 System: 175 000	8 300 x 2 500 x 3 000				See online
		Early stage		SO	B, P	300		480V AC	57				Stack: 61 320 System: 175 200					
EKPO Fuel Cell Technologies GmbH (former Elring Klinger AG and Plastic Omnium)	Germany/ France	Market ready	NM5-EVO	PEM	M	76	3.6/4.6	201V		2.5				329 x 225 x 687				See online
			NM12 Single	PEM	M	123	4.2/6.2	215V		2.5				402 x 287 x 700				See online
			NM12 TWIN	PEM	M, MA	205	4.0/6.2	359V		2.5				472 x 437 x 640				See online
GenCell	Ireland	Market ready	GenCell FOX (ammonia)	A	B	4		48V DC			9 000	99.5 (ammonia)		3 000 x 2 000 x 2 200 to 4 000 x 2 200 x 2 400	2 500 - 3 000	-20	40	See online
			GenCell Backup Operations eXtender (BOX) (hydrogen)	A	B	5		43 - 53V DC	52	3 - 5		99.95				-20	45	See online
			GenCell REX (hydrogen)	A	B	5		-48V DC +48V DC 230V AC 130V DC		3 - 5	Immediate	99.95		2 800 x 2 250 x 2 500		-20	45	See online

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																From [°C]	To [°C]	
GenCell	Ireland	Market ready	GenCell EVOX (hydrogen or ammonia)	A	P (EV charging)													See online
Horizon Singapore HQ	Singapore	Market ready	VLS II Series	PEM		135			42 - 60		600			1 200 x 670 x 780	250	-30	45	See online
			VLS II Pro Series	PEM		110			43 - 60		360			1 050 x 680 x 660	198.2	-30	45	See online
			VL III Series	PEM		200			44 - 60		600			1 256 x 730 x 730	259.5	-30	45	See online
Intelligent Energy	United Kingdom	Market ready	IE-DRIVE P100	PEM	M	110		210 - 360V DC							240	-20	40	See online
			IE-DRIVE-HD	PEM	M	100		250 - 400V DC						1 260 x 520 x 700	275	-20	40	See online
			IE-SOAR 800 W	PEM	M	0.8		24 - 48V		0.9			1000	210 x 105 x 105	1.45	-5	40	See online
			IE-SOAR 1.2 kW	PEM	M	1.2		50 - 70V		0.9			1000	128 x 246 x 233	2.7	-5	40	See online
			IE-SOAR 2.4 kW	PEM	M	2.4		50 - 70V		0.9			1000	128 x 442 x 233	4.8	-5	40	See online
			IE-LIFT 804	PEM	B, MH, P	4		20 - 56V		0.5 - 0.7	20	99.9		450 x 300 x 500	20	5	40	See online
			IE-LIFT 1T/1U	PEM	B, MH, P	1 - 1.2		16 - 58V		0.5 - 0.7	20	99.9		196 x 294 x 294	10.4	5	35	See online

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																From [°C]	To [°C]	
Mitsubishi Heavy Industries	Japan	Market ready	Megamie 250 kW class	SO		210		200 - 220V	53		Hot: 7 200 (2h) Cold: 86 400 (24h)			3 200 x 11 400 x 3 300	33 000			
			Megamie 1 000 kW class	SO														
Plug Power Inc.	United States of America	Market ready	ProGen 15	PEM	M	15		280 - 430V		16.5		ISO 14687-2:2012		985 x 674 x 567	248	-20	40	See online
			ProGen 30	PEM	M	30		280 - 430V		16.5		ISO 14687-2:2012		1 341 x 833 x 415	257	-20	40	See online
			ProGen 125	PEM	M	125		500 - 750V		20.7		ISO 14687-2:2012		1 430 x 700 x 400	363	-20	55	See online
			GenDrive Series 1000	PEM	MH													See online
			GenDrive Series 2000	PEM	MH													See online
			GenDrive Series 3000	PEM	MH													See online
			GenSure LP-200	PEM	B	0.1												See online
			GenSure LP-1100	PEM	B	1.1												See online

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																From [°C]	To [°C]	
Plug Power Inc.	United States of America	Market ready	GenSure LP-2500	PEM	B	2.5												See online
			GenSure HP	PEM	B	1 000		480V		8.6		99.9		40' container		-30	50	See online
Robert Bosch GmbH	Germany	Market ready	FC Power Module	PEM	M	>70	0.3						20 000			-30		See online
			FC Stack		M	<132	3.6						20 000					See online
			Bosch SOFC	SO	P	10 (per unit)			60									See online
			Bosch SOFC	SO	P	50kW - MW-size			60									See online
Toshiba	Japan	Limited production	Pure Hydrogen FC System	PEM		100		210V	50	0.7 - 0.9 or 1 - 7	300			2 800 x 2 000 x 1 900	4 500			See online
Fuel Cell Energy Inc.	United states of America	Market ready	MCFC 1500	MC	P	1 400		480V AC	47					11 913 x 16 942 x 6 096				See online
			MCFC 3000	MC	P	2 800		13.8kV	47					21 311 x 16 027 x 7 772				See online
			SOFC 250	SO	P	250		480V	65					10 660 x 3 040 x 2 430				See online
TECO2030	Norway	Market ready	FCM 400	PEM	M, MA	325							35 000	1 380 x 795 x 2 125	1 390			See online
			FCC 1600	PEM	M, MA	1 600							35 000	10' container				See online

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																From [°C]	To [°C]	
TECO2030	Norway	Market ready	FCC 3200	PEM	M, MA	3 200							35 000	20' container				See online
			FCC 6400	PEM	M, MA	6 400							35 000	40' container				See online
PowerCell Sweden AB	Sweden	Market ready	PowerCellution Power Generation System 5	PEM	B, P	5		25 - 59V DC	42	0.5 - 12		ISO 14687:2019	10 000	440 x 557 x 1 218	125	5	45	See online
			PowerCellution Power Generation System 100 - 60kW	PEM	B, P	60		150 - 300V DC	45	0.5 - 12		Hydrogen ISO 14687:2019	20 000	606 x 696 x 674	212	5	45	See online
			PowerCellution Power Generation System 100 - 75kW	PEM	B, P	75		185 - 370V DC	45	0.5 - 12		Hydrogen ISO 14687:2019	20 000	606 x 696 x 674	212	5	45	See online
			PowerCellution Power Generation System 100 - 100kW	PEM	B, P	100		250 - 500V DC	45	0.5 - 12		Hydrogen ISO 14687:2019	20 000	606 x 696 x 674	212	5	45	See online
			PowerCellution Power Generation System 200 - 185kW	PEM	B, P	185		440 - 880V DC	54	0.5 - 12		Hydrogen ISO 14687:2019	20 000	730 x 900 x 2 200	1 070	5	45	See online
			PowerCellution Power Generation System 200 - 200kW	PEM	B, P	200		550 - 1 100V DC	54	0.5 - 12		Hydrogen ISO 14687:2019	20 000	730 x 900 x 2 200	1 070	5	45	See online
			PowerCellution Marine System 200 - 185kW	PEM	MA	185		440 - 880V DC	54	0.5 - 12		Hydrogen ISO 14687:2019	2 000	730 x 900 x 2 200	1 070	5	45	See online

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																From [°C]	To [°C]	
PowerCell Sweden AB	Sweden	Market ready	PowerCellution Marine System 200 - 200kW	PEM	MA	200		550 - 1 100V DC	54	0.5 - 12		Hydrogen ISO 14687:2019	20 000	730 x 900 x 2 200	1 070	5	45	See online
			PowerCellution Heavy Duty System 100	PEM	M	100		250 - 500V DC	45	8 - 12		Hydrogen ISO 14687:2019	20 000	606 x 696 x 674	212	5	45	See online
Loop Energy Inc.	Canada	Market ready	S1200	PEM	M	100		520 - 850V DC	48	14		SAE J2719 or ISO 14687 (Grade D)		1 008 x 679 x 787	300	-30	50	See online
ZEPP Solutions B.V.	Netherlands	Early stage	zepp.Y50	PEM	M, MA	50		450 - 750V DC	47			ISO 14687:2019, SAE J2719	25 000	585 x 445 x 903	180	-30	50	
			zepp.X150	PEM	M, MA	150		520 - 750V DC	51			ISO 14687:2019, SAE J2720	25 000	1 250 x 700 x 680	355	-30	50	See online
AFC Energy Ltd.	United Kingdom	Market ready	S-Series air cooled	A	P	2.5												See online
			H-Power Tower S-Series	A	P	10		60V DC 230V AC 415V AC										See online
			L-Series	A	P	40								10' container				See online
			S-Series	A	P	100												See online
HyPoint Inc. Ltd.	United states of America	Limited production	HTPEM	PEM	M	50 - 10 000										-60	60	See online

TYPE: Proton Exchange Membrane (PEM) Alkaline (A) Solid Oxide (SO) Phosphoric Acid (PA) Molten Carbonate (MC)

Name	Country	Market readiness	Name	Fuel cell type	Typical application	Nominal power output [kW]	Power density [kW/l]	Output voltage range [V]	Fuel cell electrical efficiency [%]	Operational input pressure (fuel input) [bar]	Start-up time [sec]	H2-quality requirements [%]	Indicated life expectancy [h]	Stack/system dimensions [mm]	Weight stack/system [kg]	Ambient temperature condition		Website
																From [°C]	To [°C]	
Bambili Energy Fuel Cells	South Africa	Market ready	MRFC5000	PEM	P	5 - 100												See online
Proton Motor Fuel Cell GmbH	Germany	Market ready	HyStack PM 200-24	PEM	B, M, MA, P	0.4 - 2.1		14 - 28V	47 - 67	1.5 - 7.5		ISO 14687-2/ SAE J2719		294 x 237 x 395	15.9	-35	45	See online
			HyStack PM 200-48	PEM	B, M, MA, P	0.8 - 4.2		28 - 55V DC	47 - 67	1.5 - 7.5		ISO 14687-2/ SAE J2719		294 x 237 x 489	19.3	-35	45	See online
			HyStack PM 200-72	PEM	B, M, MA, P	1.2 - 6.3		42 - 83V DC	47 - 67	1.5 - 7.5		ISO 14687-2/ SAE J2719		294 x 237 x 583	22.7	-35	45	See online
			HyStack PM 200-96	PEM	B, M, MA, P	1.6 - 8.4		56 - 110V DC	47 - 67	1.5 - 7.5		ISO 14687-2/ SAE J2719		294 x 237 x 676	26.1	-35	45	See online
			HyStack PM 200-120	PEM	B, M, MA, P	2 - 10.6		70 - 138V DC	47 - 67	1.5 - 7.5		ISO 14687-2/ SAE J2719		294 x 237 x 771	29.5	-35	45	See online
			HyStack PM 200-144	PEM	B, M, MA, P	2.4 - 12.7		84 - 165V DC	47 - 67	1.5 - 7.5		ISO 14687-2/ SAE J2719		294 x 237 x 861	32.9	-35	45	See online
			HyStack PM 200-168	PEM	B, M, MA, P	2.8 - 14.8		98 - 193V DC	47 - 67	1.5 - 7.5		ISO 14687-2/ SAE J2719		294 x 237 x 957	36.3	-35	45	See online
			HyStack PM 400-72	PEM	B, M, MA, P	3.1 - 21.3		42 - 83V DC	47 - 68	3 - 7		ISO 14687-2/ SAE J2720		436 x 279 x 580	46	-35	45	See online
			HyStack PM 400-96	PEM	B, M, MA, P	4.1 - 28.4		56 - 110V DC	47 - 68	3 - 7		ISO 14687-2/ SAE J2720		436 x 279 x 673	55	-35	45	See online
			HyStack PM 400-120	PEM	B, M, MA, P	5.1 - 35.5		71 - 137V DC	47 - 68	3 - 7		ISO 14687-2/ SAE J2720		436 x 279 x 768	64	-35	45	See online

TYPE: Proton Exchange Membrane (PEM) Alkaline (A) Solid Oxide (SO) Phosphoric Acid (PA) Molten Carbonate (MC)

Name	Country	Market readiness	Name	Fuel cell type	Typical application	Nominal power output [kW]	Power density [kW/l]	Output voltage range [V]	Fuel cell electrical efficiency [%]	Operational input pressure (fuel input) [bar]	Start-up time [sec]	H2-quality requirements [%]	Indicated life expectancy [h]	Stack/system dimensions [mm]	Weight stack/system [kg]	Ambient temperature condition		Website
																From [°C]	To [°C]	
Proton Motor Fuel Cell GmbH	Germany	Market ready	HyStack PM 400-144	PEM	B, M, MA, P	6.2 - 42.6		85 - 165V DC	47 - 68	3 - 7		ISO 14687-2/ SAE J2720		436 x 279 x 860	73	-35	45	See online
			HyStack PM 400-168	PEM	B, M, MA, P	7.2 - 49.7		99 - 193V DC	47 - 68	3 - 7		ISO 14687-2/ SAE J2720		436 x 279 x 954	82	-35	45	See online
SolydEra SpA/GmbH	Italy/ Germany	Market ready	BLUEGEN BG-08	SO	P													See online
			BLUEGEN BG-15	SO	P	0.5 - 1.5			57					1 200 x 550 x 1 014	250			See online
			BLUEGEN PRO90	SO	P													See online
			SolydEra S15	SO	P													See online
			SolydEra E100	SO	P													See online
CERES	United Kingdom	Market ready	SteelCell	SO	P													See online
			SteelCell	SO	M													See online
Nuvera Fuel Cells LLC.	United States of America	Market ready	E-45-HD	PEM	M	45		170 - 290V DC		12 - 15		SAE J2719/ ISO 14687-2		1 000 x 600 x 500	187	-30	45	See online
			E-65-HD	PEM	M, MH	59		180 - 270V DC		12 - 15		SAE J2719/ ISO 14687-2		1 000 x 600 x 500	190	-30	45	See online

TYPE: Proton Exchange Membrane (PEM) Alkaline (A) Solid Oxide (SO) Phosphoric Acid (PA) Molten Carbonate (MC)

Name	Country	Market readiness	Name	Fuel cell type	Typical application	Nominal power output [kW]	Power density [kW/l]	Output voltage range [V]	Fuel cell electrical efficiency [%]	Operational input pressure (fuel input) [bar]	Start-up time [sec]	H2-quality requirements [%]	Indicated life expectancy [h]	Stack/system dimensions [mm]	Weight stack/system [kg]	Ambient temperature condition		Website
																From [°C]	To [°C]	
Baltic Fuel Cells GmbH	Germany	Market ready	LEV stack 22	PEM	Stack only	0.2		9 - 22V DC		1 - 4		100		155 x 85 x 95	1.65	5	62.5	See online
			PEM stack 40	PEM	Stack only	0.04		2 - 4V DC		0.25 - 0.35		100			0.6	5	55	See online
			PEM stack 200	PEM	Stack only	0.2		10 - 22V DC		0.25 - 0.35		100		145 x 85 x 95	1.4	5	55	See online
			PEM stack 300	PEM	Stack only	0.3		15 - 30V DC		0.25 - 0.35		100		175 x 85 x 95	1.7	5	55	See online
			SuSy500	PEM	Subsystem	0.45		24 - 45V DC		2 - 10		100		244 x 155 x 180	4			See online

TYPE: Proton Exchange Membrane (PEM) Alkaline (A) Solid Oxide (SO) Phosphoric Acid (PA) Molten Carbonate (MC)

Fuel cell manufacturer feedback

The above fuel cell market overview comprises a large number of companies and products; however, not all of those are available in South Africa. In order to understand the potential engagement of international fuel cell manufacturers in South Africa, and to assist South African project developers in identifying potential suppliers, we posed several key questions to the manufacturers about their business strategies.

Not all manufacturers gave feedback, but the following information provides a snapshot of their interest and intention to do business in South Africa.

1. Do you already sell fuel cell hardware in South Africa or are you considering to enter the market?

Several manufacturers such as **Ballard Power Systems** and **HyAxiom**, expressed their interest in exploring opportunities in fuel cell business in South Africa. Few manufacturers indicated that they had an active presence in South Africa. **Plug Power Inc.** is selling FC hardware in South Africa, and **Ballard Power Systems** has been involved in some projects in South Africa on an individual basis.

As the only FC manufacturer with South African roots, **Bambili Energy** has a strong natural interest in supplying FCs to the market. **Robert Bosch GmbH** does not yet sell any hardware in South Africa, but Bosch has a head office based in Midrand, Gauteng, and a manufacturing facility based in Brits, North West.

Companies such as **HyAxiom, Proton Motor Fuel Cell GmbH, SolydEra SpA**, and **TECO 2030** are not currently active in the South African market. However, if there are business opportunities, some manufacturers are willing to explore these. **Proton Motor Fuel Cell GmbH** is open to opportunities, if the customer has a European affiliation or is working jointly with a strong European partner.

2. Are you supplying full fuel cell systems or components such as stacks?

Robert Bosch GmbH aims to produce a solid oxide fuel cell (SOFC) ready for series production after 2024, and to sell it as a full fuel cell system. However, the supply of components, such as stacks by Robert Bosch GmbH, is not planned.

TECO 2030 intends to supply both stacks and complete fuel cell systems and solutions. **SolydEra SpA** is very interested in entering the South African market with their fuel cell modules.

HyAxiom sells their PAFCs as full fuel cell systems. Likewise, they intend to sell their SOFC as full system as well.

3. Do you offer maintenance services in South Africa? If so, directly or via local partners?

Ballard Power Systems is interested in sales, maintenance services, and integration services. **HyAxiom** emphasised that the maintenance of fuel cells needs skilled technicians with experience. They would service directly until they could develop local partners to build knowledge and experience. **SolydEra SpA** indicated their interest in maintenance and service partners, once they brought their products onto the local market.

4. What segment of the South African market is particularly interesting to you?

Ballard Power Systems does not currently have a local office or sales representative located in South Africa. Having integrated a mining truck for Anglo American, the mining and heavy transport sectors would be particularly interesting for Ballard Power Systems.

HyAxiom does not have business in South Africa, but would consider exploring business opportunities for electrolysers (PEMEL) and stationary fuel cells (PAFC and SOFC). **Plug Power Inc.** is interested in the Petro-chemical, mobility, industrial, power/energy, mining sectors. **TECO 2030** could be interested if there is sufficient demand in the market. **SolydEra SpA** is interested in markets worldwide.

SolydEra SpA is very interested in servicing the local market combined heat and power (CHP) manufacturers or system integrators.

5. How do you intend to cooperate with local partners?

Manufacturers such as **Plug Power Inc., Proton Motor Fuel Cell GmbH**, and **Robert Bosch GmbH** indicated that local cooperation with partners is generally desirable. However, the cooperation depends on the application, and mainly relates to installation, servicing and testing. Some offer strategic investments in their holding or licensing models. **TECO 2030** suggested that some parts of system assembly could be relocated to a strategic partner in South Africa.

Ballard Power Systems emphasised that their stack business requires a significant development programme for the balance of the plant, and therefore requires a large investment into R&D infrastructure, multi-year development schedules, product certification and staff resources. The FC system integration can be done by OEMs or third-party integrators and requires experience and capability in electric drives, battery energy storage and energy management, power electronics, hydrogen storage tank systems and controls. In general, where an integrator or third party is not involved, Ballard handles the service directly.

HyAxiom would consider cooperating with local partners, under the condition that they are well qualified with strong credentials and experience in South Africa. HyAxiom can further explore localisation opportunities with local partners to manufacture and sell products locally, and as well as, throughout the Sub-Saharan African region. HyAxiom would seek credible partners with experience in power project development or EPC or servicing of power generation assets.