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Green Hydrogen



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REV0524

Green hydrogen production and usage cycle



Hydrogen electrolyzer market is poised to grow at a CAGR of 26% from 2024 to 2032

Market trends and drivers

The hydrogen electrolyzer market was valued at 588M USD in 2023 and is expected to exceed 4.4B USD by 2032. Main growth drivers for hydrogen electrolyzer are lower cost of renewable energy and greater demand for green hydrogen.

The medium-capacity electrolyzer serves a wide range of industrial applications such as chemical manufacturing, refining, and metallurgy.

Medium capacity electrolyzers convert surplus electricity from renewable sources into hydrogen for energy storage grid balancing and power-to-gas applications.

The global hydrogen electrolyzer market is segmented into solid oxide electrolyzers, alkaline water electrolyzers, and polymer electrolyte membrane (PEM) electrolyzers. PEM electrolyzers are known for their high efficiency and fast response time, making them suitable for applications such as transportation, energy storage, and grid balancing.

The hydrogen electrolyzer market is fragmented due to the presence of local and global players. North America held around 29% of the market share in 2023 and is anticipated to grow to almost 30% by 2032.

Global electrolyzer market revenue share (%)





Littelfuse solutions for green hydrogen value chain





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AC-coupled hydrogen electrolysis



AC-coupled hydrogen electrolysis



	Technology	Product series				
	High-speed Fuse	PSX, PSR, L70QS, L75QS				
	Arc Flash Relay	<u>AF0025, AF0100,</u> <u>AF0500, PGR-8800</u>				
	Ground Fault Monitoring	<u>SE-601, EL731</u>				
	Surge Protection Device	<u>SPD2</u>				
		Phase Control Thyristors				
	Press Pack Thyristors OR Press Pack Diodes OR Press Pack IGBTs OR	Rectifier Diodes				
		High-Power IGBTs				
	Press Pack Sonic Diodes OR	HP Sonic FRD Diodes				
	Stacks and Assemblies	Power Stacks				



Potential Littelfuse products for AC-coupled hydrogen electrolysis



	Technology	Function in application	Product series	Benefits	Features			
1	High-speed Fuse	Provides high current limiting short circuit protection to protect high-value sensitive power semiconductor devices, personnel, and surrounding high-value assets	<u>PSX, PSR,</u> L70QS, <u>L75QS</u>	High current-limiting; low watts loss; low l ² ts; high breaking capacity	IEC and UL compliant; available in a variety of mounting types; indication and microswitch accessories for remote monitoring; AC and DC rating included on all product labelling or marking; CE marked			
	Arc-Flash Relay	Significantly reduces the incident energy from an arc-flash event by detecting the light from an arc and providing an immediate trip signal (within <1 or <5 ms)	<u>AF0025, AF0100,</u> <u>AF0500, PGR-8800</u>	Arc energy reduction lessens potential for personnel injury and allows personnel to wear lower-rated PPE; ensures smallest downtime from equipment damage after an arc flash; provides always-on protection	Microprocessor-based relays with redundant circuitry; protection is enabled <50 ms after power is applied; point and fiber sensors with continuous self-check; one-, two-, or four-zone protection; plug-and-play installation with minimal configuration; breaker failure detection			
	Ground Fault Monitoring	Monitors connection between live conductors and ground (earth), opening the circuit in the event of a fault to ground to help prevent inadvertent electrocution of personnel	<u>SE-601, EL731</u>	Limits fault current to 25 mA on ungrounded systems, ensuring detection of faults and reduction in point-of- fault damage; adjustable trip settings to suit system requirements	Rich feature options, including sensitive pickup levels as low as 1 mA, Modbus TCP, Ethernet IP, and Profibus network communications options, on-screen metering, programmable output contacts, and temperature sensor, monitoring			
	Surge Protection Device	Reduction of overvoltages caused by switching transients and lightning strikes	<u>SPD2</u>	Clamps overvoltages to maintain acceptable levels, reducing damage to other circuit components and reducing downtime and maintenance	DIN rail mountable; VDE/IEC and UL compliance, reducing inventory needs			
	Press Pack Thyristors OR Press Pack Diodes OR Press Pack IGBTs OR Press Pack Sonic Diodes OR Stacks & Assemblies	Power conversion AC-DC	Phase Control Thyristors	Low conduction loss; maximum current rating and lowest thermal resistance for the package size	Comprehensive ranges of standard phase-control thyristors; voltage ranges from 400 to 6500 V			
			Rectifier Diodes	Low conduction loss; low thermal impedance with high overload capacity; designed to survive even the most arduous applications	Comprehensive range of rectifier diodes offers class- leading performance and reliability; blocks voltages from 200 to 6.8 kV			
			High-Power IGBTs	Free from wire and solder bonds, which all but eliminates the mechanical fatigue associated with conventional modules	Offers a range of class-leading devices with voltage ratings of 1.7 kV (900 V DC link), 3.3 kV (1.8 kV DC link), 4.5 kV (2.8 kV DC link), and 6.5 kV (3.6 kV DC link)			
			HP Sonic FRD Diodes	The wide safe operating area (SOA) makes these ideal as freewheeling diodes for snubberless IGBT and IGCT applications or any application that require a fast, low- loss diode	World-leading class of ultra0fast and ultra-soft recovery diode available from -1.7 to 6.5 kV in current ratings from 270 to 4200 A			
			Power Stacks	Custom options available; UL recognized and meets the requirements of the European Union Directive; surge suppression and fusing provides reliable, safe operation	Standard configuration high-power stacks provide fast off-the-shelf solutions for single and multiphase rectifiers in a wide range of power ratings			



Power conversion example for electrolysis:

Click the product series in the table below for more info

Classic approach of Thyristor-controlled B12C driven by a dedicated transformer





Advantages of Phase Control Thyristors versus wide bandgap solutions (SiC MOSFETs)

Thyristor and efficiency

• For example, N1718NC200



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- V_f@500 A: 1064 mV
- V_f@1000 A: 1148 mV
- Estimated losses per bridge at 1000 A: 1000 A·1148 mV+2 ·(500 A ·1064 mV) →2212 W
- Overall losses: 4423 W
- Overall efficiency: 99.8%





Reduction in size and resources per kW installed



Classical approach:

SiC-MOSFETs, liquid cooling 42 AC-DC units, 60 kW each \rightarrow 2.5 MW 97% efficiency \rightarrow 60 kW losses 20 kW_{el} chiller needed

~0.6 m³

B12C-stack, forced-air cooling One unit →2.5 MW 99.7% efficient 0.6 kW for fans

Thyristors instead of SiC-MOSFETs means:

- Reduced complexity
- Enhanced efficiency
- Superior lifetime
- Lower build volume
- Lower cost, faster ROI
- Far lower TCO

Power conversion example for electrolysis:

Click the product series in the table below for more info

B6U rectifiers followed by IGBT-based choppers









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DC-coupled hydrogen electrolysis



DC-coupled hydrogen electrolysis



	Technology	Product series				
	High-speed Fuse	<u>PSX, PSR, L70QS, L75QS</u>				
	Arc Flash Relay	<u>AF0025, AF0100,</u> <u>AF0500, PGR-8800</u>				
	Ground Fault Monitoring	<u>SE-601, EL731</u>				
	Surge Protection Device	<u>SPD2</u>				
	Press Pack Thyristors	Phase Control Thyristors				
	OR Press Pack Diodes	Rectifier Diodes				
	OR Press Pack IGBTs	High-Power IGBTs				
	Press Pack Sonic Diodes OR	HP Sonic FRD Diodes				
	Stacks and Assemblies	Power Stacks				
	High-speed Fuse	PSX, PSR, L70QS, L75QS				
2	Press Pack IGBTs	High-Power IGBTs				
	Stacks and Assemblies	Power Stacks				



Potential Littelfuse products for DC-coupled hydrogen electrolysis



	Technology	Function in application	Product series	Benefits	Features			
1	High-speed Fuse	Provides high current limiting short circuit protection to protect high-value sensitive power semiconductor devices, personnel, and surrounding high-value assets	<u>PSX, PSR, L70QS,</u> <u>L75QS</u>	High current limiting; low watts loss; low I ² ts; high breaking capacity	IEC & UL compliant; available in a variety of mounting types; indication and microswitch accessories for remote monitoring; AC and DC ratings included on all product labelling and marking; CE marked			
	Arc-Flash Relay	Significantly reduces the incident energy from an arc-flash event by detecting the light from an arc and providing an immediate trip signal (within <1 or <5 ms)	<u>AF0025, AF0100,</u> <u>AF0500, PGR-8800</u>	Arc energy reduction lessons potential for personnel injury and allows personnel to wear lower-rated PPE; ensures smallest downtime from equipment damage after an arc flash; provides always-on protection	Microprocessor-based relays with redundant circuitry; protection is enabled <50 ms after power is applied; point and fiber sensors with continuous self-check; one-, two-, or four-zone protection; plug-and-play installation with minimal configuration; breaker failure detection			
	Ground Fault Monitoring	Monitors connection between live conductors and ground (earth), opening the circuit in the event of a fault to ground to help prevent inadvertent electrocution of personnel	<u>SE-601, EL731</u>	Limits fault current to 25 mA on ungrounded systems, ensuring detection of faults and reduction in point-of- fault damage; adjustable trip settings to suit system requirements	Rich feature options, including sensitive pickup levels as low as 1 mA, Modbus TCP, Ethemet IP, and Profibus network communications options, on-screen metering, programmable output contacts, and temperature sensor monitoring			
	Surge Protection Device	Reduction of overvoltages caused by switching transients and lightning strikes	SPD2	Clamps overvoltages to maintain acceptable levels, reducing damage to other circuit components and reducing downtime and maintenance	DIN rail mountable; VDE/IEC and UL compliance, reducing inventory needs			
	Press Pack Thyristors OR Press Pack Diodes OR Press Pack IGBTs OR Press Pack Sonic Diodes OR Stacks and Assemblies	Power conversion AC-DC	Phase Control Thyristors	Low conduction loss; maximum current rating and lowest thermal resistance for the package size	Comprehensive range of standard phase-control thyristors; voltage ranges from 400 to 6500 V			
			Rectifier Diodes	Low conduction loss; low thermal impedance with high overload capacity; designed to survive even the most arduous applications	Comprehensive range of rectifier diodes offers class- leading performance and reliability; blocks voltages from 200 to 6.8 kV			
			High-Power IGBTs	Free from wire and solder bonds, which all but eliminates the mechanical fatigue associated with conventional modules	Offers a range of class-leading devices with voltage ratings of 1.7 kV (900 V DC link), 3.3 kV (1.8 kV DC link), 4.5 kV (2.8 kV DC link), & 6.5 kV (3.6 kV DC link).			
			HP Sonic FRD Diodes	The wide safe operating area (SOA) makes these ideal as freewheeling diodes for snubberless IGBT and IGCT applications or any application that require a fast, low- loss diode	World-leading class of ultra-fast and ultra-soft recovery diode available from -1.7 kV to 6.5 kV in current ratings from 270 to 4200 A			
			Power Stacks	Custom options available; UL recognized and meets the requirements of the European Union Directive; surge suppression and fusing provides reliable, safe operation	Standard configuration high-power stacks provide fast off-the-shelf solutions for single and multiphase rectifiers in a wide range of power ratings			



Potential Littelfuse products for DC-coupled hydrogen electrolysis



	Technology	Function in application	Benefits	Features			
2	High-speed Fuse	Provides high current-limiting short circuit protection to protect high-value sensitive power semiconductor devices, personnel, and surrounding high-value assets	<u>PSX, PSR, L70QS,</u> <u>L75QS</u>	High current limiting; low watts loss; low l ² ts; high breaking capacity	IEC and UL compliant; available in a variety of mounting types; indication and microswitch accessories for remote monitoring; AC and DC rating included on all product labelling/marking; CE marked		
	Press Pack IGBTs <i>OR</i> Stacks and Assemblies		<u>High-Power IGBTs</u>	Free from wire and solder bonds, which all but eliminates the mechanical fatigue associated with conventional modules	Offers a range of class leading devices with voltage ratings of 1.7 kV (900 V DC link), 2.5 kV (1.25 kV DC link), 3.3 kV (1.8 kV DC link), 4.5 kV (2.8 kV DC link), and 6.5 kV (3.6 kV DC link).		
		Power conversion DC-DC	Power Stacks	Custom options available; UL recognized and meets the requirements of the European Union Directive; surge suppression and fusing provides reliable, safe operation	Standard configuration high-power stacks provide fast off-the-shelf solutions for single and multiphase rectifiers in a wide range of power ratings		



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Local resources supporting our global customers

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Littelfuse global labs & manufacturing footprints

	Country	untry Manufacturing facility a			Lab deta ils		Quality certifications			
Location			Global labs and testing	Product technology		IS O 9001	ISO 14001	IATF 16949	AS/EN 9100	Miscel lane ous
Beverly	United States	۲	۲	Gate Drivers and SSRs		۲	۲	۲		
Brownsville	United States	۲		Carling Technologies		۲	۲	۲		
Champaign	United States		۲		High Power					
Long Beach	United States	۲		High Power (Discrete, Module), Stack		۲				
Milpitas	United States	۲	۲	MOSFETs and IGBT	Material/Application/Reliability	۲				
Mount Prospect	United States		۲		Semiconductor/Material/Application					
Matamoros	Mexico	۲	۲	Temperature sensors	Product Eval. & Reliability	۲	۲	۲		
Matehuala	Mexico	۲		Carling Technologies		۲	۲	۲		
Muzquiz	Mexico	۲		Commercial vehicle products			۲	۲		
Piedras Negras	Mexico	۲	۲	Fuses and Relays	Materia I/Application/Reliability	۲	۲	۲		
Rockfalls	United States	۲		Hartland Controls		۲				
Round Rock	United States	۲	۲	SiC MOSFET/SiC Schottky Diode	Application/Reliability	۲				
Bremerhaven	Germany	۲		Wire hamesses (aerospace)		۲	۲		۲	
Bremen	Germany		۲		Product Eval./Reliability/Application					
Chippenham	United Kingdom	۲		High Power (Discrete, Module), Stack		۲	۲			ISO 45001
Dole	France	۲	۲	C&K Switches and Interconnects			۲	۲	۲	ISO 50001
Exeter	United Kingdom	۲		Carling Technologies		۲		۲		
Lampertheim	Germany	۲		Medium power (Diode, Thyristor, IGBT)		۲	۲	۲		ISO 50001, OHSAS 18001
Legnago	Italy	۲	۲	CVP products	Product Eval./Reliability/Application	۲	۲	۲		ISO 45001
Kaunas	Lithuania	۲	۲	Sensors	Product Eval./Reliability/Application	۲	۲	۲		ISO 45001
Dongguan	China	۲	۲	Varistors	Product Eval./Reliability/Application	۲	۲	۲		UL certified
Hong Kong	China	۲		Carling Technologies		۲		۲		
Huizhou	China	۲		C&K Switches		۲	۲	۲		
Hanoi	Vietnam	۲		C&K Switches		۲	۲			
Kanpur	India	۲		Wire hamesses (Aerospace)		۲	۲		۲	
Kunshan	China	۲		PolySwitch®		۲	۲	۲		
Lipa City	Philippines	۲	۲	Module (Bipolar IGBT/MOSFET)	Product Eval./Reliability/Application	۲	۲	۲		UL/TUV certified
Shanghai	China	۲	۲	PolySwitch®, Hartland Controls	High-Power/Material/Reliability/Application	۲	۲	۲		UL/TUV certified
Suzhou	China	۲	۲	Fuse and Sensor	Product Eval./Reliability/Material	۲	۲	۲		
Tsukuba	Japan	۲	۲	Circuit protection	Product Eval./Reliability/Material/Application	۲	۲	۲		ISO 45001, UL/TUV certified
Wuxi	China	۲	۲	Diode, Thyristor, TVS Diode	Semiconductor/Material	۲	۲	۲	EN 9001	ISO 45001, IECQ
Zhongshan	China	۲		Carling Technologies		۲	۲	۲		



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Safety

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Our engineers partner directly with customers to help speed up product design and meet their unique needs

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Our global customer service team is with you to anticipate your needs and ensure a seamless experience

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We help customers in the design process to account for requirements set by global regulatory authorities

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High-volume manufacturing that is committed to the highest quality standards



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