Electrical Safety Across the Hydrogen Market

White Paper

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In this white paper Emerson explores the current use of hydrogen in industrial processes, as well as its role in the global transition to the net zero economy of tomorrow. We provide insights into market opportunities and challenges, the latest processing technologies, and best practices in safety. We also address how Emerson can help industry stakeholders as they face mounting pressure to scale up hydrogen production.

The Hydrogen Market

According to the International Energy Agency, hydrogen represents "the biggest innovation opportunity" to reduce carbon dioxide (CO_2) emissions and usher in net zero by 2050. Hydrogen's ability to replace fossil fuels without releasing CO_2 when consumed has led to new applications being explored on numerous fronts. In California, for instance, there are currently 15,000 hydrogen fuel cell vehicles on the road. Operators of power plants are discovering new ways hydrogen can supplement or replace natural gas. Bolstering these initiatives, the U.S. Department of Energy in 2023 announced

Emerson's extensive portfolio of Appleton brand hazardous location electrical products optimize the efficiency of hydrogen-based technology while controlling costs and maintaining the highest standards for safety. Hydrogen is extremely combustible and can explode in confined spaces. Consequently, correctly certified explosionproof electrical equipment is required at every point across the value chain, upstream and downstream, as defined in the NFPA 70 National Electrical Code (NEC Article 500) and ATEX EN60079-10, among others. For the purposes of this white paper, we will concentrate on NEC requirements for hydrogen, specifically Class I, Division 1 or 2, Group B.

As a global leader, Emerson is helping OEMs with all types of hydrogen fuel production solutions, including building electrolyzers, fuel cells and fueling equipment to drive energy transformation and decarbonization. Partnering with Emerson means you can expect innovative, precise and reliable Appleton products designed specifically for hazardous locations. In addition, our extensive offerings in ASCO, Fisher, Micro Motion, Rosemount and TESCOM brand measurement and control products provide precise process control, optimized production, and desired purity. Emerson technology is backed by global support from industry experts who understand your expectations relating to reliability, safety and cost.

an investment of $7 billion to launch seven Regional Clean Hydrogen Hubs to accelerate the commercial-scale deployment of low-cost, clean hydrogen.

While green innovations hold great promise, hydrogen as an alternative energy represents only a small sliver of current overall consumption. Of the 120 million metric tons (MMT) of hydrogen consumed worldwide in 2022, the vast majority was concentrated in the traditional sectors of petroleum refining and chemical processing. Each year approximately 55% of hydrogen goes into the creation of ammonia for fertilizer. Another 25% goes to petroleum refining hydro-desulfurization and hydrocracking operations, 10% to produce methanol, and the remaining 10% to treating metals, flat glass manufacturing, chemical synthesis of plastics, and the manufacturing of semiconductors. Gaseous hydrogen is also utilized as a coolant for generators due to its high thermal conductivity.

Owing to government support for green hydrogen's adoption and its continued consumption by traditional industries, the hydrogen market is set to witness impressive growth over the coming decades. In financial terms, the global hydrogen industry was valued at $155.9 billion in 2022 yet is expected to register $292.0 billion by 2032. McKinsey forecasts a fivefold rise in hydrogen demand to six hundred million metric tons annually by 2050 if bottlenecks in permitting and access to capital are resolved.

Hydrogen Color Codes

Different methods of producing hydrogen are often referred to by certain colors:

- Brown hydrogen — Produced from the gasification of coal. Releases large quantities of CO_2.
- Gray hydrogen — Steam refined methane production. Releases large quantities of CO_2.
- Blue hydrogen — Steam refined methane production with carbon capture and storage. Releases around 10% CO_2 emissions.
- Green hydrogen — Hydrogen produced by electrolysis, powered by renewable energy sources like wind and solar. Release of emissions is close to zero.
- Yellow hydrogen — Hydrogen produced by electrolysis, powered by existing grid sources like coal and natural gas. Releases typical CO_2 emissions associated with power production, but cam be limited by relying on production overages.
- Pink or Purple hydrogen — Hydrogen produced by electrolysis, powered by nuclear energy. Release of emissions is close to zero, but nuclear waste is produced.
- White Hydrogen — Hydrogen mined from underground sources. The CO_2 emissions come from the mining process.

Hydrogen Production Methods

Hydrogen is the simplest and lightest of all Earth elements, consisting of only one proton and one electron. It is also the most abundant element in the universe, yet rarely is it in its pure state. Because of hydrogen's high reactivity, it quickly

Appleton Brand Products with Hydrogen Certifications


Contender™ LED Series Luminaires


AE Series Disconnect Switches


GTRS Conduit Outlet Boxes


Contender 4/4X Control Station

bonds to elements such as carbon, fluorine, oxygen, or nitrogen. To produce hydrogen, it must be separated from the other elements in the molecules where it occurs. Technologies enable the separating of hydrogen gas from its companion substances in purities in the order of 99.999%.

In the United States, steam methane reforming (SMR), or steam refining, accounts for 95% of hydrogen produced. The SMR process is a reaction between a methane source, such as natural gas, and high-temperature steam (+700 to +1,100 °C or +1292 to +2012 °F). In a final process step called pressure-swing adsorption (PSA), impurities are removed from the gas stream, leaving essentially pure hydrogen. Coal gasification, a procedure combining coal with oxygen and steam at high pressures, produces another 4%, while water electrolysis yields 1%.

Although SMR is highly cost-effective, it requires fossil fuels as feedstock and to generate heat. In fact, for every kilogram of hydrogen produced in SMR, seven kilograms of CO_2 are released into the environment. Carbon capture and storage techniques (CCS) seek to trap the CO_2 released by SMR and store it in the ground, converting "gray" to "blue" hydrogen.

Like SMR, electrolysis relies heavily on fossil fuels. The only way the process is CO_2 neutral — that is, it produces almost no greenhouse gases or other pollutants — is when renewable energy sources are employed, such as geothermal, hydro, wind or solar. Because this "green" hydrogen approach is considerably more expensive than hydrogen sourced from fossil fuels, it constitutes less than 0.04% of all hydrogen produced globally.

One promising new technology is so-called "pink" or "purple" hydrogen made thermochemically in nuclear reactors. The US Department of Energy predicts that a single 1000-megawatt reactor could produce up to 150,000 tons of clean hydrogen annually.

Hydrogen Storage

There are numerous methods to store hydrogen.

GAS: One of hydrogen's main characteristics is its low volumetric energy density. Hydrogen gas takes up four times more space than natural gas, and therefore is often compressed for storage and transportation. As a compressed gas, hydrogen is stored and transported in cylinders made of thick-walled aluminum, steel, or composite materials capable of withstanding high pressures of 5000 to 10000 psi, or within vacuum insulated tanks.

CRYOGENICS: Alternatively, hydrogen can be liquefied at cryogenic temperatures (-253 °C or -423 °F), although liquefaction is both energy-intensive and technically complex.

ABSORPTION: Another storage option is to chemically bind hydrogen with solids or liquids able to absorb it. Palladium, for instance, can absorb nine hundred times its own volume of hydrogen. Other alternatives are magnesium, aluminum, and certain alloys. The most promising carrier is probably ammonia, a mixture of nitrogen and hydrogen.

CAVERNS: Lastly, hydrogen can be stored in unique conditions below ground. Bulk storage of uncompressed hydrogen has proven viable in salt caverns, and to a lesser extent in porous sandstone or shale, or in engineered cavities. Salt is very dense, preventing hydrogen leakage, and is the most common underground storage method. Locating a suitable geological formation near the point of generation is one of many difficulties with this approach.

Hydrogen Transportation

If hydrogen is not consumed at its point-of-origin ("captive" production), bulk hydrogen must be transported to its point-of-use by railcar, barge, or over the road in gaseous tube trailers or in cryogenic liquid tanker trucks. Long-distance pipeline investments have been made by merchant producers in areas where there is a significant, steady demand for hydrogen. In the United States, there are approximately 1600 miles of active pipeline for hydrogen transportation, 90 percent of which is located along the Gulf Coast of Texas, Louisiana, and Alabama, serving refineries and ammonia plants. Pipelines are the least expensive method of transporting hydrogen. As demand for hydrogen grows, one potential transportation solution is to modify a portion of the 300,000 miles of existing natural gas distribution infrastructure in the United States to hydrogen delivery.

The Cost of Unplanned Downtime

Due to the adverse conditions of mining operations, electrical equipment must not only be properly certified, but well-built both electrically and mechanically. If it is not, unplanned downtime is the consequence. As the mining industry continues to mature and commodity prices remain low, the negative impact of unplanned downtime on the bottom line will only increase. This is one reason a typical mine spends 35 to 50 percent of its annual operating budget on preventive maintenance and repairs. ①

Mining, metals, and other heavy industrial companies lose 23 hours per month of production time to machine failures at an average cost of $187,500 (USD) per hour. This amount can go much higher depending on the time it takes to get the equipment fixed, as well as the size of the mining company, and the number of machines that failed, malfunctioned, or are no longer operational. A standard mine works 24/7 throughout the year, for years to decades, so even short intervals of unplanned downtime can have significant financial impacts. ①

The best starting point for mine operators to maximize machine uptime and availability is to specify the most reliable electrical equipment available. This is the proactive approach, focusing on avoiding issues instead of trying to repair them.

Hydrogen Fires and Explosions

When developing electrical systems for a hydrogen application, engineers must be aware of its associated dangers and the need for proper hazardous area classification. Make no mistake — there are serious safety concerns when hydrogen is released in sufficient concentrations, a situation made more precarious because hydrogen is both colorless and odorless.

Hydrogen's wide flammability range (4% to 74%) means the energy needed to ignite it can be very low, like that generated by a small spark or an electrostatic discharge. Another danger is that hydrogen flames burn at extremely high temperatures (500° C or 932° F) yet mostly outside of the visible light spectrum, making these fires both extremely destructive and nearly impossible to initially detect. Furthermore, at concentrations of 18.3% to 59%, hydrogen will explode. Blast waves from a hydrogen explosion have resulted in very serious damage to surrounding buildings and led to multiple injuries and deaths. Explosive forces vary depending on several factors, such as the quantity of gas, the presence of any other materials, and the conditions under which the explosion occurs, including container geometry.

Hydrogen explosions are classified as being either deflagrations or detonations.

Types of hydrogen combustion — Deflagration versus Detonation ②

- Deflagrations are combustion explosions in which there is subsonic flame propagation through the hydrogen-oxidant (typically hydrogen-air) mixture.
- Detonations are combustion explosions in which there is supersonic flame propagation through the hydrogen-oxidant (typically hydrogen-air) mixture, such that shock waves are generated. Detonations are frequently more destructive than deflagrations.
- Deflagrations can sometimes accelerate when the flame propagates across repeated small obstacles or through long pipes to produce deflagration-to-detonation transition (DDT). DDT does not occur in hydrogen concentrations near the flammable limits and is more likely to occur in large equipment or piping, or in very large hydrogen releases in a partially confined area.

Appleton Brand Explosionproof Products

AJBEW Cast Junction Boxes

PlexPower™ Factory Sealed Enclosed Circuit Breakers

A-51™ LED Factory Sealed Luminaires

U-Line™ Factory Sealed 20 Amp Plugs and Receptacles

- Deflagration venting per NFPA 68 Explosion Protection by deflagration venting is not an effective explosion protection measure when DDT occurs; it is effective for deflagrations.
- Detonation prevention and detonation pressure loads for gas mixtures in piping are described in NFPA 67 Explosion Protection for Gaseous Mixtures in Pipe Systems.

Hydrogen has one safety advantage over other flammable fuels: hydrogen is 14 times lighter than air and rises six times faster than natural gas, which means that it disperses rapidly when released. Unless leaking hydrogen is contained by a roof or some other structure, it will quickly disburse before it reaches a flammable concentration. The laws of physics prevent it from lingering near a leak unlike heavier gases such as propane or gasoline fumes. For that reason, hydrogen explosions and fires are most likely to occur in confined, poorly ventilated spaces where hydrogen is processed or stored in large quantities.

Mitigating Hydrogen Risks

Depending on the jurisdiction where the hydrogen facility is located, a set of codes will outline the specific requirements for electrical equipment installed. Codes help ensure uniformity of safety requirements and give local inspectors and safety officials the information they need to approve systems and installations. In North America, electrical systems installed in hydrogen applications follow the National Electrical Code (NEC), Article 500. The NEC is incorporated into most state and local jurisdiction regulations and therefore carries the weight of law.

Currently there are two systems used by the NEC to classify these types of hazardous areas: the Class/Division system and the Zone system. The Class/Division system is used predominately in the United States and Canada, whereas the rest of the world generally uses the Zone system.

In Article 500, 502, and 503 the NEC details the Class/Division system, and in Article 506, the alternative Zone system is described. Hazardous locations per the Class/Division system are classified according to Class, Division, and Group, whereas hazardous locations per the Zone system are classified as Zones and Groups. In addition, within both systems, various protection techniques and methods are employed to reduce or minimize potential risks.

Hydrogen Classification

Products intended for installation in hazardous locations must be listed or certified for that specific Class, Division, and Group. Article 505 of the NEC covers the Zone classification system for hazardous locations, which is based on the International Electrotechnical Commission (IEC) hazardous location classification system for flammable gas, and introduces IEC based protection techniques. Within both classification systems, similar protection techniques and methods are employed to reduce or minimize potential risks, see chart 1. Class I, II and III, Division 1 as well as Zones 0 and 20 represent areas where there is a hazard present continuously or frequently during normal operations in sufficient quantities to produce an explosive mixture. Class I, II and III, Division 1 as well as Zones 1 and 21 represent areas where a hazard may likely be present during normal operations in sufficient quantities to produce an explosive mixture. Class I, II and III, Division 2 as well as Zones 2 and 22 represent areas where a hazard is not likely to occur, but may accumulate infrequently in sufficient quantities, to cause a hazard for only short periods of time.

Applying due diligence in the classification, design and installation per the applicable code will render hydrogen no more dangerous than any other material.

CHART 1 — AREA CLASSIFICATION — NEC/CEC/ATEX CLASS/DIVISION/GROUP/ZONE

		NEC®/CEC			IEC/CENELEC		
Material Type	**Inflammable Material**	**Class**	**Division**	**Group**	**Zone**	**Group**	**Sub-division**
Gases and Vapors	Acetylene	I	1 or 2	A	0, 1 or 2	II	C
Gases and Vapors	Hydrogen	I	1 or 2	B	0, 1 or 2	II	B + H_2
Gases and Vapors	Ethylene, Propylene oxide, Ethyl oxide, Butadiene	I	1 or 2	C	0, 1 or 2	II	B
Gases and Vapors	Propane, Cyclopropane, Ethyl ether, Ethylene	I	1 or 2	D	0, 1 or 2	II	A
Gases and Vapors	Methane, Acetone, Benzene, Butane, Propane, Hexane, Paint solvents, Natural gas	I	1 or 2	—	0, 1 or 2	I	—
Dusts	Metals	II	1	E	20, 21 or 22	III	C
Dusts	Conductive (Carbonaceous)	II	1 or 2	F	20, 21 or 22	III	C
Dusts	Nonconductive (Grain)	II	1 or 2	G	20, 21 or 22	III	B
Fibers and flyings	Combustible (Wood, paper or cotton processing)	III	1 or 2	—	—	III	A

Emerson Solutions for Hydrogen

Emerson provides one of the world's widest selections of explosionproof LED luminaires, power distribution panels, enclosures, fittings, junction boxes, cable glands, and connectors for facilities processing, handling, storing, or consuming hydrogen. Certified to global standards Appleton products ensure reliable and safe operation of electrical systems in explosive environments. Whether the geography of your hydrogen operations require ATEX, ATEX/IECEx, NEC or CEC certification, Appleton's regulatory involvement, technical expertise and range of solutions solve the challenges of hydrogen safety Robust engineering also means a longer service life and reduced downtime. Appleton equipment is suitable for Gas Group B (Class/Division) or IIC (Zone) locations, providing Increased Safety Ex e or Ex d protection.

- *Enclosures: Appleton enclosures and boxes withstand extreme pressures resulting from an internal explosion and contain them sufficiently to prevent ignition of the surrounding explosive atmosphere.*
- *LED Lighting: Appleton explosionproof LED luminaires guarantees both worker safety and cost-effective energy efficiency. Our LED luminaires are renowned for optimal dispersion of light and minimal maintenance requirements with the strength to withstand the effects of corrosion, weather, and harsh operating conditions.*

In Conclusion

The primary challenge for hydrogen production is reducing its cost to make the resulting hydrogen competitive with the cost of conventional fossil fuels. Emerson brands are poised for the global green energy transition to hydrogen from supplying solutions for electrolyzer plants to fueling stations.

Footnotes

1. “Green hydrogen: Energizing the path to net zero. Deloitte’s 2023 global green hydrogen outlook,” April 2024, Deloitte

2. Pacific Northwest National Laboratory (DOE Office of Energy Efficiency and Renewable Energy)

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