PROTON
THE LEADER IN ON SITE GAS GENERATION.

Proton OnSite Editorial Series

Is On-site Electrolysis Hydrogen Generation a Fit for Your Hydrogen Requirement ?

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Abstract

PEM electrolysis on-site hydrogen can be helpful to many customers. Particular benefits are evident for users requiring highly pure hydrogen, customers wishing to avoid hydrogen delivery or storage, customers in rental, remote or high security locations, and customers using hydrogen on a fairly constant basis.

Applications and Uses

Hydrogen is one of the highest volume industrial chemicals used worldwide, serving a remarkable diversity of applications that make use of its unique chemical and physical properties. Some examples are:

- As a chemical feedstock to modify the properties of petrochemicals and specialty chemicals and for use as a reducing agent to stabilize oils
- As a reducing atmosphere in thermal treatment involving metals such as heat treating, sintering, brazing, float glass manufacturing, etc.
- As a high heat, clean fuel gas in applications involving glass melting and fabrication, and thermal spray coatings
- As a protective carrier gas in semiconductor fabrication, crystal growth, welding, and CVD coatings
- As a fill gas for hydrogen-cooled electric generators; pure, low density hydrogen safely improves the efficiency of electricity production
- In hydrogen/nitrogen blends as a lower cost, high performance, environmentally advantageous alternative to helium for leak checking.

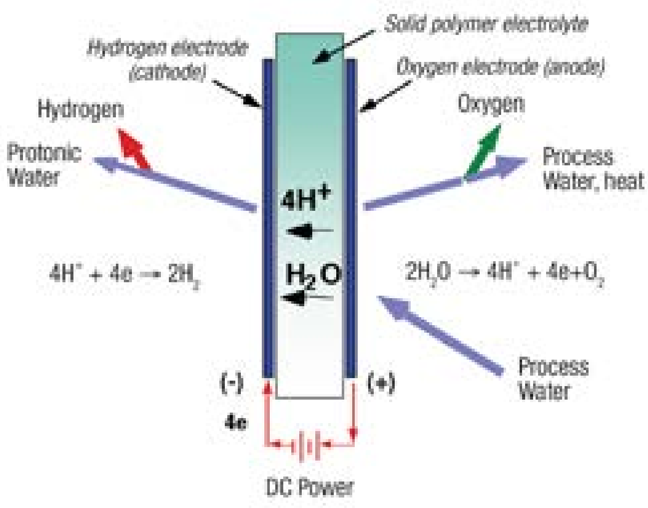
Applications for industrial hydrogen span the usage range from just 10s of scf/d (standard cubic feet per day) of hydrogen for specialty crystal growth and leak checking to well over 100 MM scf per day (million standard cubic feet per day) of hydrogen for a refinery. The wide range of usage rates have spawned a diversity of hydrogen supply approaches to suit customers' needs. Proton OnSite® makes Proton Exchange Membrane (PEM) water electrolysis on-site hydrogen generators that serve a portion of the market of small-to-medium-sized users that might otherwise be served by a form of delivered hydrogen.

Hydrogen has several characteristics that complicate delivery and storage:

- The widest flammability range of all gases (4% to 75% in air)
- Extremely low ignition energy
- The capability to leak from the tiniest openings.

Hydrogen is classified as a highly hazardous material, meaning that storage is highly regulated. National Fire Pro¬tection Association standards NFPA 55 or NFPA 2 are the relevant code documents. Generally, the more hydrogen that is stored, the greater distance that must be allowed between the hydrogen storage and other site operations — so storage of significant quantities of hydrogen takes a lot of site space. In the US, indoor hydrogen storage is gen¬erally limited to 2,999 Scf — about 10 cylinders. In certain situations, permissible indoor storage is even more limited by other factors such as the presence of other flammables or hazardous materials, seismic concerns, siting above or below ground level, or other relevant factors.

The use of hydrogen as a chemical feedstock has the highgest use rate of all industrial applications, and has always used an on-site hydrogen generation approach — making hydrogen as it is needed — to avoid the need for enormous volumes of hydrogen storage. These large chemical factories typically use heat and catalysts in reformers to liberate hydro¬gen from hydrocarbons and steam to generate enormous volumes of hydrogen relatively inexpensively to meet the high volume, 24/7, steady rate process needs. Such reformers have limited turndown range, and are large and expensive to build, own and operate. Although many organizations have tried to adapt hydrocarbon reforming for smaller uses, reforming is not yet recognized as commercial for hydrogen requirements under about 25,000 scf/hr (600,000 scf/day).



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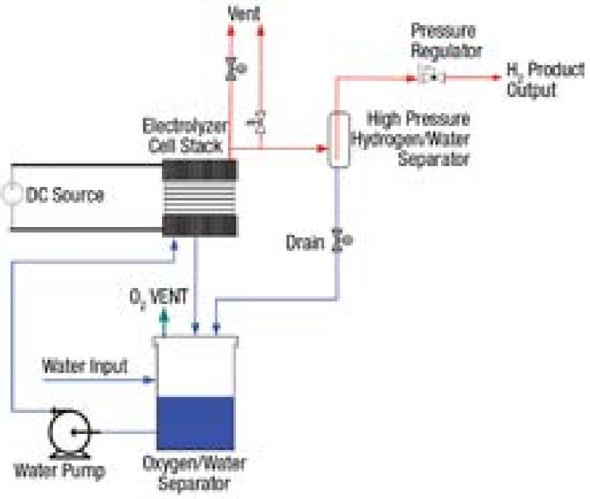
Proton Exchange Membrane (PEM) based water electrolysis hydrogen generators provide operational, safety and production cost advantages to hydrogen users that consume too little hydrogen to be served by hydrocarbon reforming. Previously, these users would have had to use delivered and stored hydrogen. Amenable users may also have additional operational requirements such as high purity, limited installation spaces, variable use rate, operation less than 24/7, and the need for fast permitting, simple installation, operation, and maintenance. PEM on-site hydrogen generators make small-to-medium flow rates of pressurized, extremely pure hydrogen at predictable costs, with near-zero hydrogen inventory, and they are able to vary production rates to suit customers' needs. PEM on-site hydrogen generation is currently best suited to industrial customers using less than about 3,000 scf/hr (~75,000 scf/day), although larger systems are being introduced that may enable larger customers to benefit in certain situations.

PEM on-site gas generation provides several attractive characteristics:

- Compact equipment requiring little safety review and no emissions permits
- Extremely high gas purity and low water content
- Near zero gas inventory
- Load following by varying hydrogen delivery rate exactly as needed
- Medium gas pressure: high enough pressure to enable surge storage load leveling
- Fast permitting, easy installation, simple operation, high reliability and minimal maintenance.

PEM on-site hydrogen generation is the right hydrogen supply solution for many customers, but it is not a universal solution. PEM on-site hydrogen provides the best economics for a customer who values many or all of the characteristics above. Customers who may prefer delivered, stored hydrogen include:

- Temporary or portable hydrogen needs.
- Intermittent hydrogen use (perhaps for a few minutes at a time, a few times per day).
- Hydrogen flow rate needs that are widely variable and cannot be predicted.
- Customers for whom hydrogen purity is not important.



The target hydrogen market for PEM on-site hydrogen competes with truck delivery of hydrogen. Historically, delivered hydrogen has been supplied to industrial users primarily by truck delivery of packaged pressurized gas cylinders or bulk hydrogen delivered and stored as a com pressed gas or cryogenic liquid. Customers using delivered hydrogen would use up to 100,000+ scf/d of hydrogen.

There are opportunities for hundreds of PEM on-site hydrogen generation systems to replace delivered hydrogen for industrial applications each year, making it possible to standardize and cost-reduce the systems for best performance at the lowest overall cost. Proton OnSite has focused on developing highly adaptable standardized systems that offer the highest possible performance in areas that matter to potential customers while saving money where possible. A large field population of near-identical units, together with a robust service capability has made it possible for Proton OnSite to utilize field performance as feedback to the design and manufacturing processes, continuously improving generator performance, reliability and price-competitiveness.

Proton OnSite's PEM on-site hydrogen generators are standardized and factory-built to meet the challenging safety and quality standards of compliance organizations worldwide. Equipment meeting these standards can be deployed worldwide with the lowest possible risk of compliance issues in any particular locale. Proton's on-site hydrogen generators are compliant with applicable UL, CSA and CE ATEX requirements.

Hydrogen Purity

PEM on-site electrolysis splits water to make hydrogen product gas that is very pure—99.9995+% or better, plus the byproduct oxygen. Hydrogen purity is extremely valuable to some customers, and less important to others, primarily based on what they use the hydrogen for. Users of delivered hydrogen pay a meaningful premium price for highly pure hydrogen – and the gas price purity premium is often much higher for smaller users, because the price of the analysis is semi-fixed, but is allocated over a delivery batch size. While the price for analysis of a liquid hydrogen trailer is allocated over the entire 1.2 MM scf of hydrogen in the trailer, the cost of analyzing a cylinder would be charged to the 200-300 scf of hydrogen in that cylinder. Essentially, users requiring a quality certification pay for three things: preparing the delivery batch (cylinder, multi-pack, or trailer) to be filled and filling it, performing the quality verification on the batch of hydrogen; and how long that quality verification takes. The primary analysis for quality verification is normally performed by gas chromatography (GC), and the more detailed the quality specification and the lower the limits of detection have to be, the longer the GC run will take. Because every fill batch must be tested if an analysis certificate is required, the forms of delivery that involve smaller batches will require correspondingly more tests for a given amount of hydrogen. Users of cylinders have the smallest batch size – as small as each cylinder. Users of tube trailer hydrogen, made and delivered in large "batches" pay relatively less, and users of liquid hydrogen pay a smaller premium still.

While US and Canada users have grown used to highly stable and predictable hydrogen quality, elsewhere in the world there can be wide variability in the quality of gaseous hydrogen from one delivery to the next, depending on where a customer is located and the source of hydrogen supply. In the US and Canada, most of the delivered gaseous hydrogen starts out as inherently pure liquid hydrogen and is transported long distances from hydrogen sources to local depots as liquid hydrogen, where it is vaporized and distributed as cylinders or bulk gas. Because the production process for liquid hydrogen excludes all but tiny amounts of impurities, virtually all industrial delivered hydrogen in the US and Canada starts out as very pure, and as long as it is carefully handled during repackaging from bulk liquid to bulk gas or cylinder gas, the degradation of quality (increase in impurities) is manageable and relatively consistent. Outside the US and Canada, most delivered hydrogen starts out as a gas, and is compressed and packaged in gaseous form, meaning that it has not undergone the cryogenic processing steps that make liquid hydrogen so pure. Hence the purity of gaseous delivered hydrogen outside of the US and Canada can vary widely between deliveries, making it critical to pay for purity analysis of every batch.

A customer in the US or Canada who contracts with their industrial gas supplier for industrial grade hydrogen as defined in the applicable CGA document (CGA G-5.3 – Commodity Specification for Hydrogen), will often get hydrogen that is much purer than what they have contracted for, because the production and distribution process is generally based on vaporized liquid hydrogen, which is inherently highly pure. Often, over time, the customer then refines their own internal process limits for hydrogen purity, assuming that the hydrogen that will be delivered will always be of the same purity that they have received in the past. Unless they have a contractual guarantee of that purity, they must be aware that they can receive a delivery of lower purity hydrogen that still meets their purchase specifications, but no longer meets their process specifications. (Under normal circumstances, the hydrogen that they get is better than what they have paid for, but there is no responsibility of the vendor that they will continue to get better hydrogen than they have paid for.) When, as happens somewhat regularly, the supplier temporarily shifts the source of hydrogen to compensate for production or distribution problems, the customer may get a load of hydrogen that meets their purchase specification, but is far less pure than the gas that they had received for many deliveries prior. Invariably the day will come when the hydrogen delivery will be the gas quality that they actually contracted for, not the superior gas quality that they've enjoyed previously for free. If you are using delivered hydrogen, is important to understand and plan for the effect on your hydrogen-using process.

A handy rule of thumb is that for delivered cylinders, every “9” of purity beyond 99.95% industrial grade purity — say 99.99% or 99.999% or 99.9999% — doubles the price per cylinder. Hence a $25/cylinder 99.95% industrial grade hydrogen can quickly become a $200 or higher cost hydrogen cylinder, driven by the need to achieve, prove, and document the required purity in the small cylinder batch size. This is particularly evident for electronic quality hydrogen.

The premium pricing of higher purity delivered hydrogen dramatically increases the cost of using it. Thus PEM on-site hydrogen generation that inherently provides premium quality hydrogen can be especially attractive to users of high purity grades of hydrogen.

Zero-Inventory Hydrogen

Proton OnSite designs its PEM on-site hydrogen systems with essentially a zero-inventory production approach. For example, a model C30 hydrogen generator, capable of delivering up to 30 Nm3/hr (1140 scf/hr or 2.7 kg/hr) of hydrogen, contains just 14 grams (6 scf) of internal hydrogen when operating at 100% of capacity. The advantages of zero inventory hydrogen supply include compliance, safety, and lessened investment in facility exhaust systems. By minimizing the size of pressurized internal vessels, Proton falls below the lowest threshold for most national and regional pressurized gas limitations.

Load-Following

PEM on-site hydrogen systems have the ability to load-follow users’ hydrogen needs from 0% delivery up to 100% of capacity by adjusting production to match the rate of hydrogen use exactly without wasting hydrogen or using extra power. Because of the specifics of electrochemical hydrogen production, the variable hydrogen delivery is achieved without sacrificing operating efficiency on turndown, shifting product quality, or wasting hydrogen.

Pressurized Hydrogen for Surge Storage Adaptability

In addition to their load-following capacity, PEM on-site hydrogen generators make pressurized hydrogen, which can be used with surge hydrogen storage to serve customers’ variable hydrogen flow rate needs that intermittently exceed the ability of ordinary load-following. In this way, a smaller hydrogen generator can be used to serve a variable rate hydrogen requirement that may sometimes exceed the capacity of the hydrogen generator. Examples of how this is helpful are:

- Torches that run intermittently but at high rates can be fed from surge storage to meet virtually unlimited flow rates for finite periods of time.
- Batch furnaces can be fed with a hydrogen generator that is sized to the average use rate, but the surge storage allows the furnace to be filled quickly.
- For semiconductor applications, the provision for a small amount of surge storage capacity prevents a pressure drop if a mass flow controller opens suddenly.

Operating Efficiency and Expandability

For many processes, smaller scale systems are lower in operating efficiency than larger systems of the same type. But due to the specifics of electrochemical hydrogen generation, modern PEM on-site hydrogen systems do not lose efficiency at smaller scale. Additionally, the systems are operable across a wide range of ambient conditions.

Proton OnSite builds its PEM hydrogen generators with a modular, expandable design that allows the hydrogen generator to be quickly expanded in capacity if additional capacity is needed to accommodate growth. For example, Proton OnSite's model C10 hydrogen generator makes up to 10 Nm3/hr of hydrogen (about 380 scf/hr). The unit can be expanded, at the customers' site and within the cabinet, to a C20 or a C30 unit, with capacity up to 30 Nm3/hr of hydrogen (about 1140 scf/hr).

Electrical Rates

Electricity rates, denominated in dollars per KWh, vary widely across the US, around the world, and even based on the specific arrangements or characteristics of a particular site. Putting aside other factors, sites with lower cost electricity find PEM on-site hydrogen more price competitive than sites that have higher electrical rates. For example, at an industrial electrical rate of $.06/KWh, a PEM hydrogen generator will make hydrogen for about $1.00 per 100 scf variable cost; whereas in higher electrical cost areas where industrial power might cost $0.12 or more per KWh, the same hydrogen would cost over $2.00 per 100 scf variable cost. Hence PEM electrolysis generated hydrogen can be less expensive in areas where electrical rates are lower.

Power plants may have particularly low electrical costs, especially for baseload plants in areas where electricity is regulated. The low electrical costs for these plants arises from the fact that electricity inside of the fence may be priced as parasitic power at its variable cost only, often resulting in electrical costs in the $0.03 to 0.04 per KWh range— even in areas where the rates for other customers may be far higher.

As more markets offer the time-of-day option for less expensive nighttime power, an entirely new option for saving money using PEM electrolysis hydrogen generation may become commercially attractive.

Portability & Ability to be Relocated

Most hydrogen applications are fixed in location for all practical purposes. For example, a power plant uses hydrogen at a fixed site for the life of the plant; a heat treat facility uses hydrogen in furnaces that are fixed in location. Some customers use hydrogen for applications that require portability, such as a hydrogen torch used for work that may require portability. The design of typical PEM hydrogen generators (e.g. weight, bulk, fixed connections) makes them most suitable for fixed use rather than situations that require portability. For portable applications, hydrogen cylinders may be a better choice.

In contrast, a PEM hydrogen generator may be the preferred solution for a customer located in a rented or temporary facility, especially for a hydrogen user that requires volumes of hydrogen of more than a few cylinders weekly. PEM on-site hydrogen is advantageous in this situation because the cost of required permanent hydrogen delivery and distribution infrastructure can be minimized or entirely avoided. Avoided costs include foundations and other infrastructure for external hydrogen storage, underground piping from hydrogen delivery/storage area to the building, and the cost of extensive building internal piping from the delivery area to the usage area within the building.

Hence, for customers in rented facilities with hydrogen uses of larger than a few cylinders weekly, it may be advantageous to use hydrogen generation that can be placed immediately adjacent to the use area, and can be moved when the customer grows and relocates to new facilities. The hydrogen generator approach will minimize the amount of invested capital spent on foundations and piping that must be left behind (and perhaps even removed at additional cost) when the customer expands or relocates.

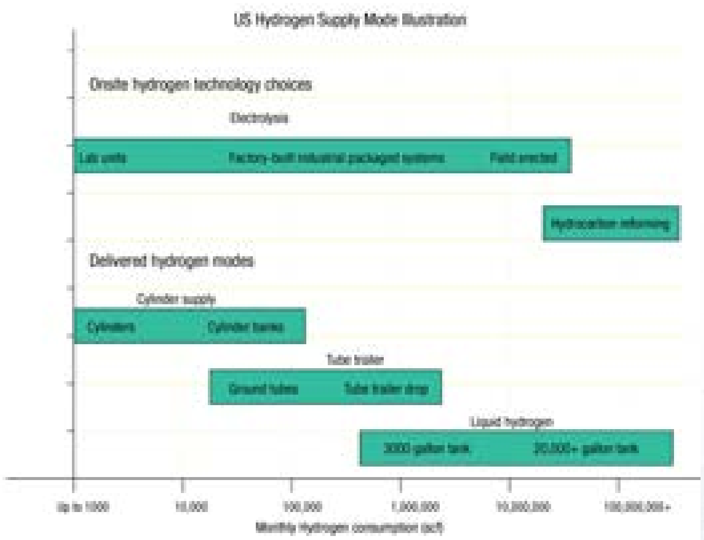
Equipment Cost Allocation and Variable vs Fixed Costs

PEM on-site hydrogen generators are capital equipment, and the cost of hydrogen produced is affected by three primary factors:

- The cost of buying and installing the hydrogen generation system, and its useful life.
- The variable cost of the energy used to generate hydrogen.
- The cost of maintenance and service.

Decision chart for delivered versus PEM on-site hydrogen

	Delivered	PEM on-site
Higher purity hydrogen		
Reduce or eliminate hydrogen inventory		
Eliminate deliveries		
Temporary hydrogen use		
Very occasional hydrogen use		
Portable hydrogen use		
Reduced piping needs		
Eliminate outdoor hydrogen		
Lower H2 unit cost as volume increases		
Ability to be relocated at low cost		
Limited access security environment		
Hydrogen storage not allowed		
More hydrogen usage hours per day		
Remotely monitor hydrogen availability		
Easily controlled hydrogen shutdown		
Consistent hydrogen quality		
Low local electricity prices		
Increasing hydrogen usage hours per day		
	Preferred	
	Less Preferred	



On average, for PEM on-site hydrogen generation, the total cost of hydrogen is about half capital (fixed) cost, and half variable cost (of which 90% is electricity, with DI water and maintenance making up the remainder). This is a higher proportion of fixed cost than is generally the case for delivered hydrogen. Hence, PEM on-site hydrogen is particularly attractive when hydrogen is used many hours per day, so the fixed cost can be allocated over more hours. Conversely, in situations where hydrogen is used relatively few hours daily, delivered hydrogen might be more economical. For customers using PEM on-site equipment, if hydrogen usage hours increase, the total cost of hydrogen from PEM on-site hydrogen generation drops rapidly as the fixed cost is allocated over more hours.

For customers using delivered cylinders for hydrogen supply, hydrogen is primarily a variable cost. The cylinder delivery charges and rental costs generally are modest, and for the smallest volume users, the facility piping for cylinders can be minimal as long as usage remains low so that the cylinders can be placed very nearby the point of use (generally permissible as long as inventory remains below 2999 scf). The price of hydrogen in the cylinders is relatively high, but for some customers it is preferable to have the flexibility to use hydrogen or not, and have the costs follow the molecules. This is particularly true of customers starting a new process, or serving requirements whose growth pattern cannot be estimated, or setting up an experimental rig – all situations where the customer cannot estimate whether they will use hydrogen in the future, or how much.

- As users' hydrogen consumption grows, the disadvantages of delivered hydrogen cylinders start to outweigh the advantages, and alternatives may become more attractive. Disadvantages of hydrogen cylinder supply include:
- Cylinder handling, and impurities entering the system on changeouts
- Cylinder gas costs, especially for better grades
- Potential runouts as each cylinder contains only a relatively small amount of hydrogen
- Cylinder accounting for deliveries and rental charges
- Potentially variable quality as suppliers refill industrial grade hydrogen cylinders on top of the heel from the previous users.

Location, Security, Access

One of the major differences between hydrogen supply approaches is the portion of the costs attributable to freight charges. Because a 150 lb gross weight hydrogen cylinder only contains a little more than 1 pound of hydrogen, the hydrogen cylinder delivery trucks are primarily hauling steel as both full and empty cylinders make up the bulk of the payload. This characteristic makes cylinder hydrogen expensive to deliver over long distances, so customers who are remote from their hydrogen origin pay a meaningfully higher price than customers situated closer to where the cylinders are filled.

We tend to think of locations such as Wyoming as being remote from a delivery standpoint, but ironically, some of the most urbanized areas in America and elsewhere are equally difficult and expensive to access due to traffic, tolls, tight delivery spaces and restricted delivery hours. For example, it can cost hundreds of dollars in tolls alone for a single delivery trip from outside New York City to a customer in NYC. That cost is borne by the users served by that delivery. Several power plants in NYC and other similar locations have adopted PEM on-site hydrogen for that reason among others.

There is generally a difference in delivery frequency (and therefore required customer inventory) between cylinder deliveries and tube trailer or liquid hydrogen deliveries. Because hydrogen cylinders will be transported in a mixed load on the same trucks (and from the same depots) that deliver other gases, it is frequently the case that cylinder trucks will deliver up to several times a week. That frequent delivery means that the customer can minimize their hydrogen inventory (advantageous). However, it also means that deliveries of hydrogen, which generally are accorded much higher scrutiny than other gases, because of the risk of safety problems arising from delivery, are a frequent interruption. Many plants, especially power plants, send an individual from the plant staff to accompany every hydrogen delivery while in the plant. Dependence on frequent, small deliveries also makes the customer more susceptible to hydrogen interruptions in cases of missed deliveries due to weather or other supply/delivery problems.

Conclusion

PEM on-site hydrogen is a hydrogen supply option that should be considered by customers using up to about 75,000 scf/d of hydrogen. Plan ahead and consider the timing requirements of your hydrogen supply contract so that you can consider making a change when you are contractually free to do so.

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