**The Role of Hydrogen in Achieving Net Zero** January 3, 2023
Comments With a Focus on Commercial Reality

## Summary

Hydrogen is, by far, the most abundant molecule globally. Its application for energy is also very appealing, and we should focus a lot of attention on its industrial and commercial uses. To that end, this article was written to provide some general comments and conclusions on a recent study conducted by a group in the UK. The study was a high overview of Hydrogen's application in the UK and we will leverage this to focus on what is essential to understand to correctly engineer systems that deploy Hydrogen as an energy source for commercial use.

## Details

The House of Commons Science and Technology released a detailed report on December 19th, 2022. The report details the science and policy issues regarding using Hydrogen in our everyday lives. From vehicles we drive to heating our homes to the energy we generate for the grid, if you are interested in the state of Hydrogen as an energy source, it is highly recommended you read the full report. You can find the full report here.

The purpose of this article is to comment on the state of the technology and offer some additional clarity and realities to help tie all the science together. Overall the report is spot on and should be used to help us, especially in the UK, navigate a Hydrogen ecosystem. To tie this article to the report, specific paragraph numbers shall be noted using a "#NN" scheme.

### Some Properties of Hydrogen

Hydrogen is THE most abundant element in the universe, making up almost 75% of the visible mass of the cosmos. From the Hydrogen Fuel Cell Engines and Related Technologies: Rev 0, December 2001[1].

> *Chemically, the atomic arrangement of a single electron orbiting a nucleus is highly reactive. For this reason, hydrogen atoms naturally combine into molecular pairs ($H_2$ instead of H). To further complicate things, each proton in a hydrogen pair has a field associated with it that can be visualized and described mathematically as a "spin". Molecules in which both protons have the same spin are known as "orthohydrogen". Molecules in which the protons have opposite spins are known as "parahydrogen".*

[1] Eere.energy.gov pg. 1-2

*Over 75% of normal hydrogen at room temperature is orthohydrogen. This difference becomes important at very low temperatures since orthohydrogen becomes unstable and changes to the more stable parahydrogen arrangement, releasing heat in the process. This heat can complicate low temperature hydrogen processes, particularly liquefaction.*

This is why we generally find pure Hydrogen in an $H_2$ or $H_3$ configuration and is commonplace in the Hydrogen energy ecosystem. Furthermore, the melting and boiling points are significant to document here. Hydrogen becomes a liquid at 20 K (–423 F; –253 C) and goes solid at 14 K (–434 F; –259 C) at STP. These temperatures are very low and are regarded as cryogenic.

The boiling point for Hydrogen is clearly stated in this statement:

*The boiling point of a pure substance increases with applied pressure—up to a point. Propane, with a boiling point of –44 oF (–42 C), can be stored as a liquid under moderate pressure, although it is a gas at atmospheric pressure. (At temperatures of 70 F (21 C) a minimum pressure of 111 psig (7.7 barg) is required for liquefaction). Unfortunately, hydrogen's boiling point can only be increased to a maximum of -400 F (–240 C) through the application of approximately 195 psig (13 barg), beyond which additional pressure has no beneficial effect.*[2]

** barg = gauge pressure not absolute pressure like bar.

Another very important point to remember about Hydrogen is that the molecules are smaller than other gasses, thus, are far more susceptible to leakage, which leads to losses and intrinsic safety issues. For a good reference, see Table 1 below for specifications of Hydrogen and other fuels(gasses) we use daily.

To summarize the difference between energy content vs. density, here are some important facts to remember. And to note, a typical US semi-truck carries 125-300 gallons of Diesel.

*The energy density of a fuel is also affected by whether the fuel is stored as a liquid or as a gas, and if a gas, at what pressure. To put it into perspective:*

- *A 132-gal (500-L) diesel tank containing 880 lb (400 kg) of fuel is equivalent on an energy basis to a 2110 gal (8000 L) volume of hydrogen gas at 3600 psi (250 barg). This is a 16 times increase in volume, although the weight of the hydrogen is only 330 lb (150 kg), representing-ing a decrease in fuel weight by a factor of about 2.8.*

[2] Eere.energy.gov pg. 1-5

*• The same diesel tank is equivalent to a 550-gal (2100-L) tank of liquid hydrogen. This is a 4.2 times increase in volume.*

*• If hydrogen is stored as a metal hydride, every kilogram of diesel fuel is replaced by approximately 4.5 kg of metal hydride to maintain the same hydrogen/diesel energy equivalence. Thus the same 132 gal (500 L) diesel tank containing 880 lb (400 kg) of fuel would have to be replaced with a hydride tank containing 3800 lb (1725 kg) of "fuel" mass.* [3]

**Table 1: Specifications of important fuels and gases**

| Fuel/Gas | Vapor Density | Liquid Density | Flash Point (7) | Expansion Ratio 1:X (1) | Energy Content (3) | Energy Density (4) |
|---|---|---|---|---|---|---|
| Hydrogen | 0.00522 lb/ft$^3$ | 4.432 lb/ft$^3$ | **< –423 F** | 240-**848** (2) | **51.5-61k BTU/lb** | 0.27k Btu/cu ft (5) |
| Methane | 0.0406 lb/ft$^3$ | 26.4 lb/ft$^3$ | –306 F | 233-643 | 21.5-24k BTU/lb | 0.87k Btu/cu ft (5) |
| Propane | 0.125 lb/ft$^3$ | 30.7 lb/ft$^3$ | –156 F | 270 | 19.6-21.6k BTU/lb | 2.32k Btu/cu ft (5) |
| Gasoline | 0.275 lb/ft$^3$ | 43.7 lb/ft$^3$ | –45 F | n/a | 19-23.4k BTU/lb | **836k Btu/cu ft** (6) |
| Diesel | | | 100-125 F (8) | n/a | 18.2-19.2k BTU/lb | **843.7k Btu/cu ft** (6) |
| Methanol | | | 52 F | n/a | 7.7-8.6k BTU/lb | 424.1k Btu/cu ft (6) |
| Lead Acid Battery | | | N/A | n/a | 0.05k Btu/lb | 8.7k Btu/cu ft (6) |

(1) Ratio 1:X means X multiple going from liquid to gaseous state.
(2) When hydrogen is stored as a high-pressure gas at 3600 psig (250 barg) and atmospheric temperature, its expansion ratio to atmospheric pressure is 1:240.
(3) The range is the difference between the "heat of vaporization"
(4) Density is the measure of energy per volume
(5) Gas at 1 atm, and 60 F (15 C)
(6) Liquid state
(7) Flashpoint is the point where enough vapors are produced in the air to ignite and is different than LEL.
(8) Diesel fuel #2 as specified by ASTM D975 has a minimum flash point of 125.6°F. For diesel fuel #1, the minimum flash point is 100°F. (https://southeastpetro.com/wp-content/uploads/2015/12/Diesel-FlashPoint.pdf)

[3] Eere.energy.gov Pg. 1-17

Finally, below are two important reference images from the Hydrogen Fuel Cell Engines and Related Technologies document[4] that should be clearly understood.

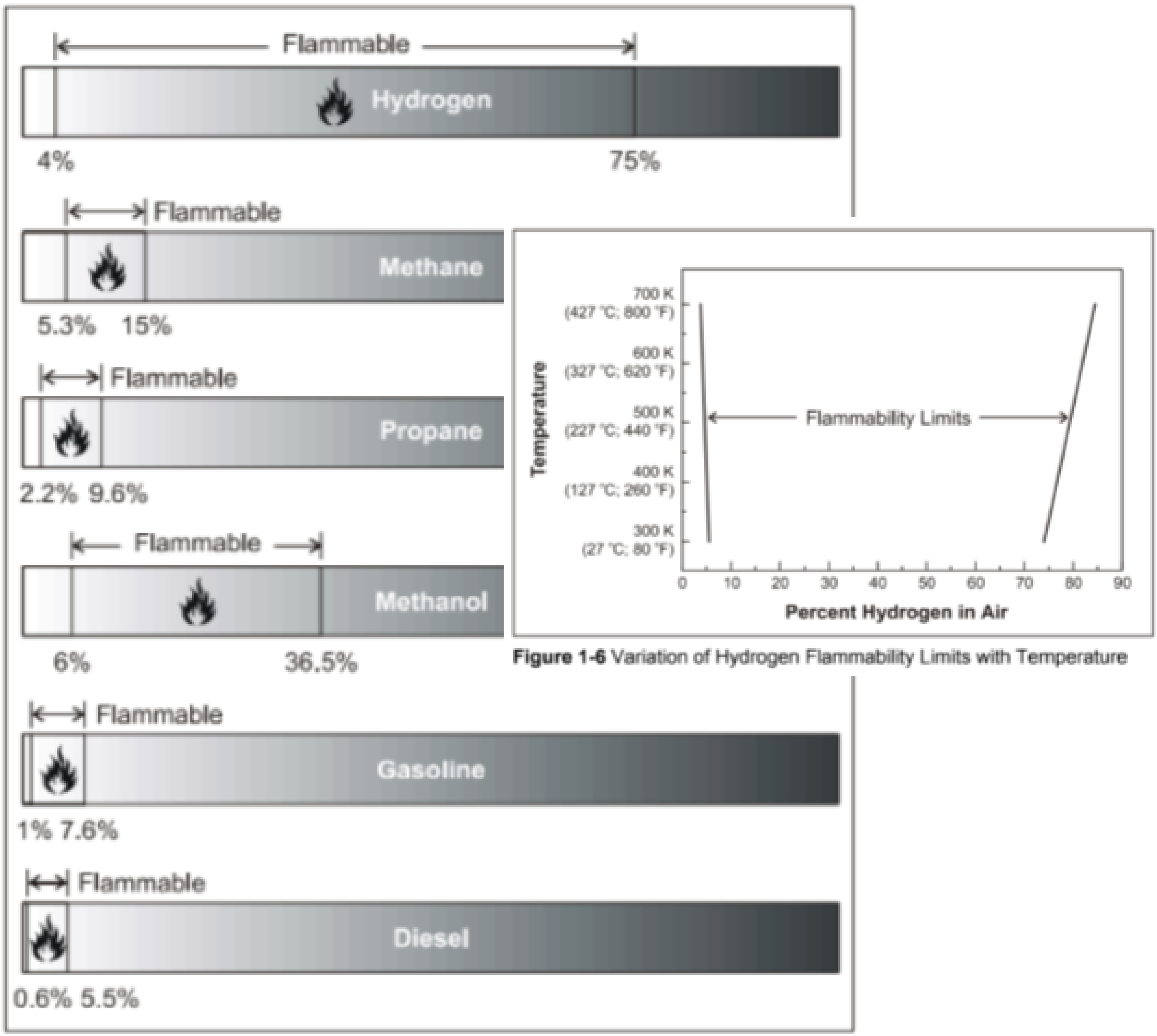


**Figure 1-6** Variation of Hydrogen Flammability Limits with Temperature

**Figure 1-7** Flammability Ranges of Comparative Fuels at Atmospheric Temperature

[4] Eere.energy.gov Pg. 1-19 and 1-20

Types of Hydrogen

Besides the properties of Hydrogen, and the differences in fuels and gases which dictate handling and design risks, the Hydrogen industry has different classes of produced Hydrogen. Four main classes of hydrogen exist in the ecosystem:

**Grey Hydrogen**: Large amounts of Hydrogen gas are produced in the production of Natural gas. These facilities do not employ Carbon Capture systems and thus are considered 'grey,' which is less desirable to our environment.

**Blue Hydrogen**: This class of hydrogen is produced with Carbon Capture systems, thus making this class better for our environment. However, as Carbon Capture technology is still early in its development and use, the total impact from these facilities is yet unknown.

**Green Hydrogen**: Hydrogen can be produced via a process called Electrolysis of water which separates $H_2O$ into Hydrogen (H) and Oxygen (O) molecules. This process is deemed very beneficial to our environment and thus is labeled green. However, electrolysis, at least from an industrial scale, is not very efficient and, again, still in its early stages of development and use. Thus its total impact on our environment is still being determined. Furthermore, we discuss Electrolysis in detail below.

**Pink Hydrogen**: Hydrogen produced from Nuclear energy.

In "*The Role of Hydrogen in Achieving Net Zero*" report, it was discussed in paragraph #44 that green hydrogen will become cheaper over time faster than blue hydrogen. This pits electrolysis against carbon capture technologies. Feldhake Consulting LLC is not a subject matter expert on Carbon Capture technologies and cannot independently verify this statement. However, we believe Electrolysis, used in the correct application, could provide very efficient and beneficial energy savings while providing cleaner by-products.

Energy Storage

The role of energy storage in our new energy ecosystem will become extremely important and vital. This is not just an issue from a power generation or utility vendor standpoint but will work itself down to commercial buildings and homeowners as well. Energy storage, managed by a Hybrid Energy system, will provide building power-supply resilience to the owner and allow the system to weather energy grid supply issues. A good system will also increase the reliability of the facility, offering easier maintenance and a lower Total Cost of Ownership (TCO).

In the report in paragraph #70, they clearly confirmed this idea when they reported on an interview with a Dr. Radcliffe. Dr. Radcliffe stated that increased energy storage would be required as we approach Net Zero while more flexible energy components (renewables etc.) are introduced and mixed in with our current system. Energy storage allows for the balance between supply and demand and can be realized when looking at the response times of different storage techniques.

For instance, batteries provide good energy conversion rates compared to other storage (ESD) techniques like Pumped hydro (PHS) or Compressed Air (CAES). However, other techniques like Chemical (STES), Supercapacitor (SCES), and Flywheel (FES) energy storage systems can provide much better response times and may provide less TCO. Below is Figure 7[5] from a Renewable and Sustainable Energy Reviews paper Showing the relationship between power rating and response times of different ESGs. Paragraph #72 confirms these statements.

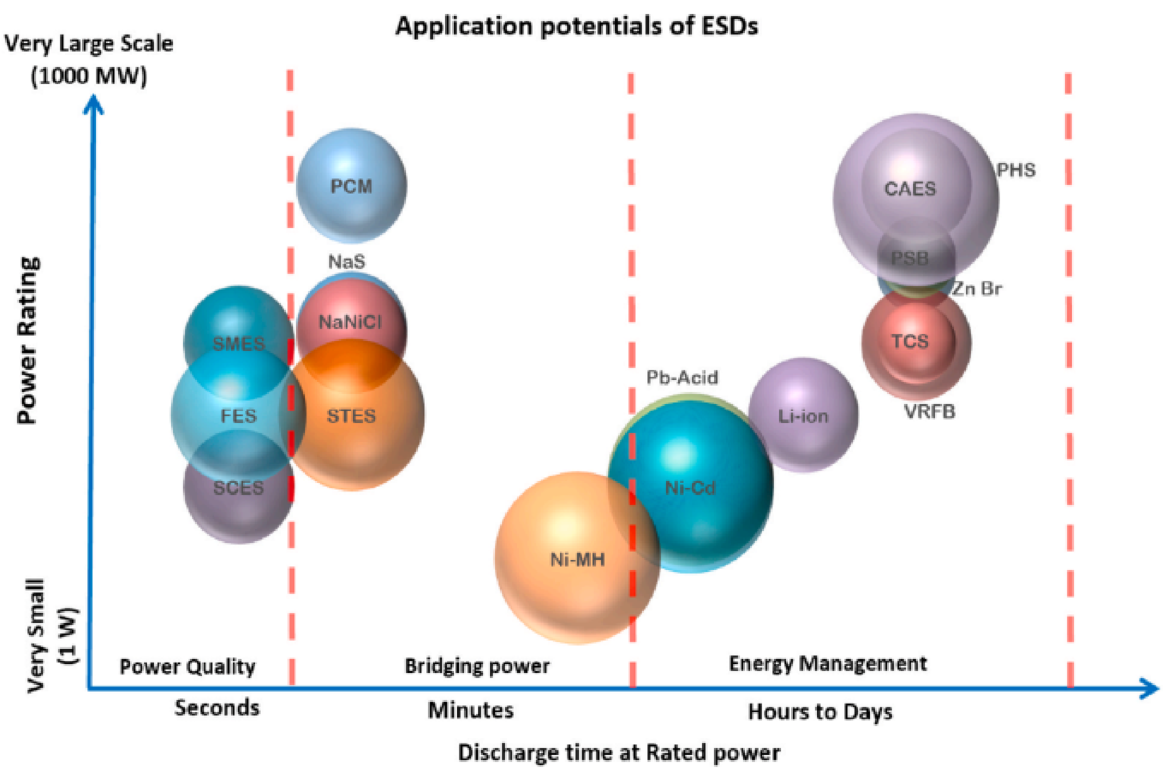


Figure 7

Another aspect of Energy Storage is grid-scale vs. commercial scale. Grid-scale, supplied by large utility companies, could economically install systems like compressed Hydrogen or pumped hydro. However, smaller commercial entities would not have access to the capital, space requirements, or technical know-how to install and thus operate these types of systems.

[5] Kebede, Abraham Alem, et al. “A Comprehensive Review of Stationary Energy Storage Devices for Large Scale Renewable Energy Sources Grid Integration.” *Renewable and Sustainable Energy Reviews*, vol. 159, May 2022, p. 112213, https://doi.org/10.1016/j.rser.2022.112213.

For instance, in order to make compressed Hydrogen work, it would need to be stored in leakproof tanks holding liquid Hydrogen at a temperature of 24 K (-250 C or -416 F). The amount of energy required for maintaining these temperatures on smaller-scale systems would outweigh the benefit it provides. Paragraph #68 confirms this belief.

A reliable energy storage system for a commercial entity would employ a Hydrid Energy system consisting of different energy sources (i.e., Grid, Solar, Wind, etc.) along with easy-to-install and operate ESDs like CAES and SCES.

## Building Heating

In one particular application for commercial use is that of building heating systems. Through a process known as Hydrogen blending in fossil fuels, boilers that operate in many of the older buildings could run cleaner and help reduce emissions and be an alternative to heat pumps. In paragraph #24, Carl Arntzen stated, "*the operation of a heat pump to heat a home was very different to that of a boiler since a heat pump uses a 'shallow temperature gradient' to heat a home.*" There are currently several projects underway that are showing some evidence that this approach could work; however, they also have shown the risks that come with the technology. In a recent post, the California Public Utilities Commission (CPUC) issued these important notes:

- Hydrogen blends of up to 5 percent in the natural gas stream are generally safe. However, blending more hydrogen in gas pipelines overall results in a greater chance of pipeline leaks and the embrittlement of steel pipelines.
- Hydrogen blends above 5 percent could require modifications of appliances such as stoves and water heaters to avoid leaks and equipment malfunction.
- Hydrogen blends of more than 20 percent present a higher likelihood of permeating plastic pipes, which can increase the risk of gas ignition outside the pipeline.
- Due to the lower energy content of hydrogen gas, more hydrogen-blended natural gas will be needed to deliver the same amount of energy to users compared to pure natural gas.

The UK study also highlighted HyDeploy, which is generating evidence on how they can support blending for the large fossil fuel network, which helps heat 83% of the buildings. You can check them out at https://hydeploy.co.uk/.

## Vehicular Transportation

Besides building heating, Hydrogen can be applied to the vehicular transportation industry. While in paragraph #94, they admit that because EVs have become dominant and successful in small passenger cars, Hydrogen would play only a small role. However, for the Heavy Goods (HGVs) (para. #101) and Busing industries (para. #103), these vehicles can apply Hydrogen engines and have success because of their fixed routes and spot fueling networks. To complete the vehicular comments, the rail network (para. #109) might be a suitable application, but plans are not progressing very clearly.

Electrolyzers and Fuel Cells

If you have never read anything about the hydrogen energy products industry, it is a large world in and of itself. There is no way to cover the entire technology spectrum in this paper, so we will summarize everything but stay true to its commercial use side. Because the industry is broken down into hydrogen creation, conversion, and delivery, along with hydrogen-to-electrical power generation. For a good analysis of the industry and the technology, you can read Fraunhofer Institute's[6] cost analysis, which can be found [here](). They have included a great map of the Hydrogen marketplace in Figure 1-1 below.

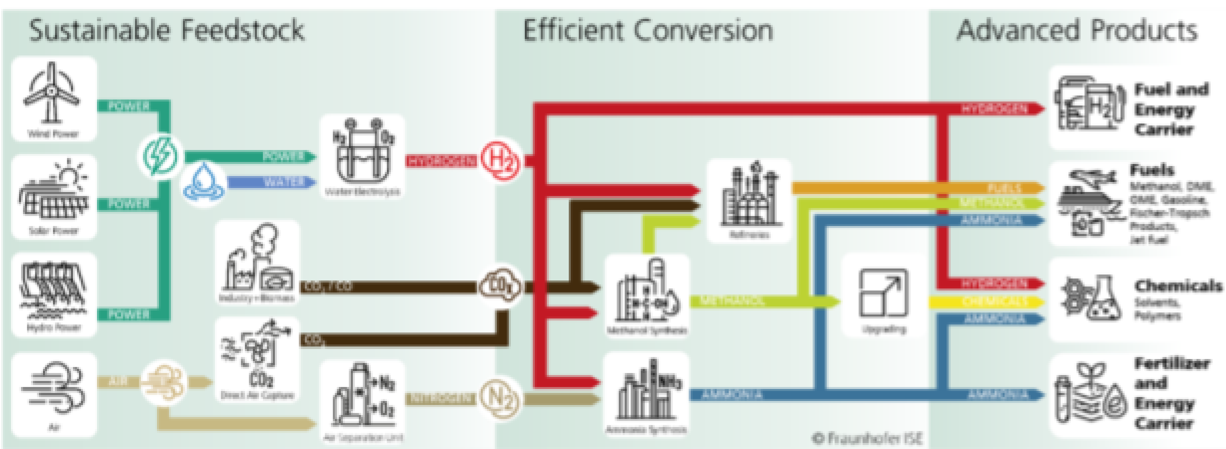


**Figure 1-1: Pathways for hydrogen in a carbon free society**

For our purposes, we need to focus on water electrolysis and fuel cell technologies. Although these two systems are identical at a conceptual level, they are vastly different in how they operate and deliver energy conversion. Briefly, an Electrolyzer converts water & electrical energy into Hydrogen and Oxygen components, while a fuel cell does the exact opposite converting hydrogen and oxygen into usable electricity. The diagram below shows the conceptual differences.

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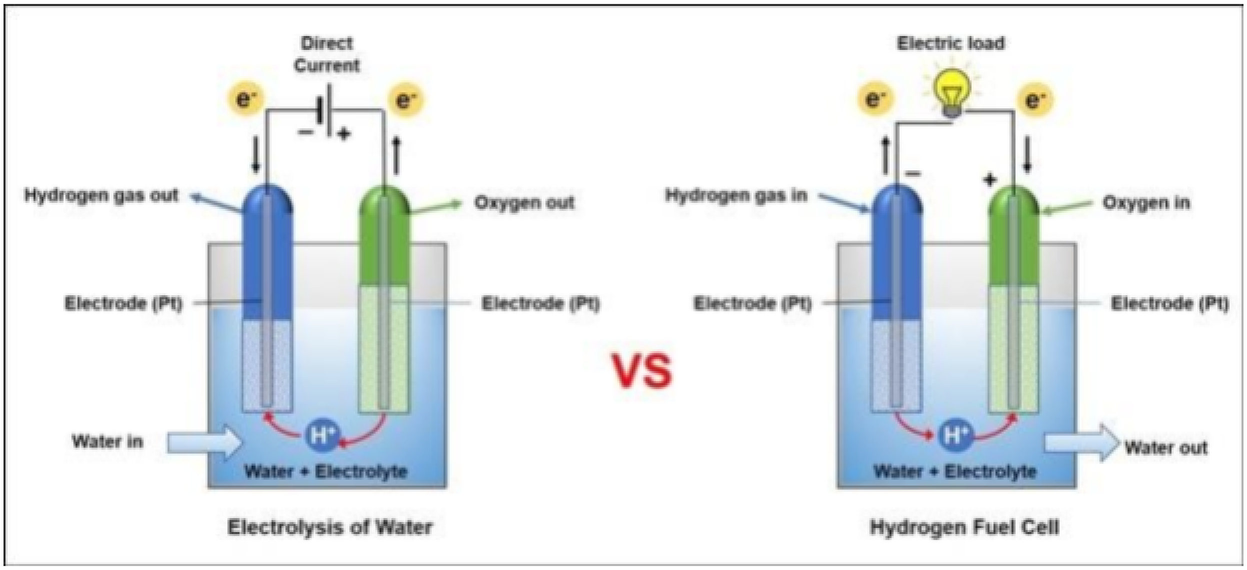
[6] COST FORECAST for LOW TEMPERATURE ELECTROLYSIS - TECHNOLOGY DRIVEN BOTTOM-up PROGNOSIS for PEM and ALKALINE WATER ELECTROLYSIS SYSTEMS. [www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/cost-forecast-for-low-temperature-electrolysis.pdf.](www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/cost-forecast-for-low-temperature-electrolysis.pdf) Accessed 27 Dec. 2022.




Electrolysis vs. Hydrogen Fuel Cells[7]

There are many vendors that provide these solutions for commercial use. PlugPower has several product lines, like the GenSure Low Power and High Power series. The Low Power fuel cells could be useful for commercial power backup and include fuel delivery services as part of the offering. Nel electrolyzers offer varying sizes of products that support industrial applications like annealing and brazing along with auto-consumption. Nel's H (up to 6 $Nm^3/h$) and S (up to 1 $Nm^3/h$) series of products could be used for any number of commercial applications, such as boiler pre-heating, for example.

Bloom Energy is another vendor that offers fuel cell technologies for commercial building projects. Their high-temperature steam electrolysis (HTSE) might be better than Plug Power's second-generation cold electrolysis technology. Per a recent TheStreet.com article, "*PEM fuel cells require roughly 52 kilowatt-hours (kWh) of electricity per kilogram of hydrogen production, solid oxide fuel cells* [HTSE] *require roughly 38 kWh/kg. That's a nearly 28% decrease in the amount of the electricity required.*"[8] Furthermore, Bloom Energy states their solution produces nearly zero Nitrogen oxides ($NO_x$) and Sulfur dioxide ($SO_2$).

For smaller applications, Parker has a full line of electrolyzers that are commonly found in labs, powered by 120VAC that are suitable for safe commercial use. These units can deliver flows at very low rates of clean Hydrogen with good purity.

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[7] Principles of the electrolysis of water and the hydrogen fuel cell (Adapted from Minnehan & Pratt, 2017)
[8] Maxx Chatsko. "Bloom Energy Has a Sneaky Advantage over Plug Power." TheStreet, TheStreet, 30 Sept. 2022, www.thestreet.com/investing/bloom-energy-solid-oxide-advantage-plug-power-pem.

Water Quality for Electrolysis

One aspect of electrolysis is to ensure the right quality water is used. Typically a DI water system is required, but this may depend on the vendor and water source. Testing the water before the specification of any unit would be the first practical step. Once the lab results come back, a water system can be specified to suit the preferred electrolysis vendor specifications.

The role of water quality is vital and should not be underestimated. Depending on the type of electrolysis, i.e., alkaline, solid oxide, or microbial electrolysis, the quality of the water will help define the necessary filtering along with PM schedules for cleaning to maintain efficiency. Typical sources of water can be found in seawater, creeks or streams, groundwater, and estuaries. Rainwater, and public utility water are possible, as well as water from cooling towers or treated wastewater.

## Conclusions

Understanding Hydrogen is very important for use in commercial applications. Combining Hydrogen systems with Hybrid Energy systems could bring value by allowing the conversion of excess renewable energy to useful forms without the need for costly intrinsic safety solutions. Hydrogen can also be applied in pin-point applications such as in boiler pre-heating or other heating applications.

The study concluded in paragraph #198:

> *198. Hydrogen has attracted a growing interest as the UK pursues its legal commitment to deliver a Net Zero economy by 2050, and we have heard a variety of views on its potential prominence in a sustainable future energy system. It has unique features as a clean-burning fuel that can be stored on long timescales with scalable production through several low-carbon means. This enables hydrogen to play a role, not only in decarbonizing our energy consumption but also in providing more resilience for our energy system and increasing the UK's energy security.*

From a commercial application standpoint, the storing of Hydrogen should be avoided unless there is space for a protected area outside the facility that provides the safe storage and handling of Hydrogen. However, any piping that leads back into the main facility should be minimally sized and protected with fire safety valves. Hydrogen piping lengths should be kept at a minimum, and use prepared hoses like the Parker Polyflex hose, a TOPS Flight hose, or even a flexible Metal hose from Hose Master. Particular attention to the fittings should also be adhered to ensure no gas leakage. Pressure testing of the gas system before putting gas on pressure is vital.

Proper intrinsic safe engineering methods should be employed to detect faults and fail systems. Gas flares should be considered for any outside storage areas; however, there are certain risks with this approach. Gas detection and alarm systems should be the first line of defense for leak issues.

Finally, because of Hydrogen's inherent properties, pin-point application of the gas should be the preference for stakeholders. This shortens the distances the gas needs to be moved, dramatically lessening the risks and costs for the owners. Systems that require fuel deliveries should have local resources and technicians to help support the owners of the facility.

If you are interested in learning more about using Hydrogen in your facility, please contact our founder at mfeldhake@fconsult.llc.

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