WHITE PAPER:
REMOTE HYDROGEN REFUELING FOR UNMANNED AERIAL VEHICLES

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1. Executive Summary

First demonstrated in military unmanned aerial vehicles (UAVs), fuel cell systems now been proven from a reliability, durability, and range perspective, opening doors to commercial and civilian applications. However, access to hydrogen fuel in remote locations where UAVs are deployed can be a challenge. One well-proven solution is on-site production of hydrogen from water through electrolysis.

By combining a PEM fuel cell propulsion module developed by Protonex with high-pressure PEM electrolysis offered by Proton OnSite, a complete hydrogen fueled solution is available to overcome the common barrier to adoption of ready access to hydrogen at remote sites.

2. Hydrogen Fuel Cell Power for Unmanned Aerial Vehicles

UAVs are innovative and versatile tools increasingly used for surveying and monitoring applications. In the future, UAVs will carry out many more tasks, such as wireless internet access and package delivery. With the growing interest in new applications, designers and system integrators are seeking alternative power sources that provide greater endurance, range, and operational flexibility.

Hydrogen fuel cells have come to the forefront as an attractive solution to these challenges. First demonstrated in military UAVs, fuel cell systems have now been proven from a reliability, durability, and range perspective, opening doors to commercial and civilian applications. Fuel cell-powered systems offer compelling value for certain UAV use cases due to improved reliability over small internal combustion engines, enhanced safety, and low maintenance operation. UAV systems powered by fuel cells operate longer than their battery counterparts, with comparable benefits of low thermal, noise signature and zero-emissions.

To learn more about the applicability of fuel cell-based propulsion in this next phase of UAV commercialization, download our white paper at http://info.ballard.com/advanced-propulsion-uavs

UAVs powered by proton exchange membrane (PEM) fuel cells require high purity hydrogen as the fuel. Commercial hydrogen supply is abundantly available. In fact, the U.S. hydrogen industry currently produces twenty million metric tons of hydrogen a year.[i] Most of this hydrogen is used for industrial applications such as petroleum refining, heat treating, and food processing.

In addition to commercial hydrogen supply, hydrogen refueling infrastructure is steadily developing, primarily located to support initial fleets and retail sales of fuel cell passenger vehicles and transit buses. The roll-out of hydrogen stations in California is tailored to match the way most people drive and get fuel: clusters of stations in commuting corridors and "connector" locations enabling travel throughout the state. By 2020, more than 100 stations are expected throughout California, with an additional network developing in the northeast United States. In support of more than 14,000 fuel cell powered lift trucks deployed at warehouses and distribution centers in the U.S., Plug Power has built 45 hydrogen stations, each distributing between 200 and 300 kilograms of hydrogen a day. [ii]

However, for fuel cell applications deployed in remote sites, the current hydrogen supply infrastructure may not be easily accessible. UAVs are often used at military forward operating bases, large agricultural and forestry plots, or are used to investigate natural disasters; all areas where reliable and affordable access to hydrogen fuel can be a challenge.

In these situations, small on-site production of hydrogen is a practical and flexible means of bridging these gaps in hydrogen infrastructure. Hydrogen fuel can be generated on-site from many sources, including natural gas or liquid hydrocarbon fuels, from hydrogen carriers such as sodium borohydride, or from water through electrolysis. The available feedstocks dictate the production process chosen, and each of these production methods has a varying cost and environmental impact.

This paper will examine specifically the production of hydrogen from water through electrolysis as a means of fueling UAVs operating in remote locations.

3. Enabling Low Cost and Reliable Hydrogen Production at Remote Sites

Water electrolysis for hydrogen production is well proven and has been used for industrial applications for more than 125 years.[iii] Electrolysis is also a promising option for hydrogen production from renewable resources in remote locations. Hydrogen is easily produced from water by electrolysis, a process which uses electricity to split water into hydrogen and oxygen (Figure 1). This reaction takes place in a unit called an electrolyzer. Electrolyzers are inherently scalable and are commercially available in small, appliance-size equipment that is well-suited for distributed hydrogen production.

There is a strong desire by platform developers of UAVs to have a "deployable" fueling capability. For both commercial and military applications, the solution must be rapidly established at a location without major infrastructure requirements and have the ability to be quickly relocated. Small UAVs, in particular, are deployable by design and are meant to be moved around quickly and easily for fast response. If the fuel source needs to move with the user, then an electrolyzer system design that addresses mobility, shock and vibe, environmental considerations, and available power is necessary. The ability to easily interface with renewable power sources and utilize reclaimed

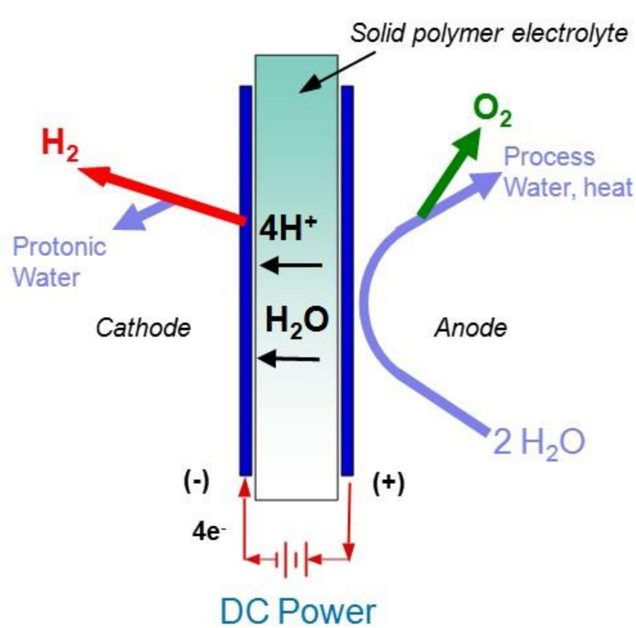

Figure 1: Electrolysis is the splitting of water to produce hydrogen and oxygen gas

water may also be design attributes of a deployable system.

In data tracked by the U.S. Department of Energy (DOE), electrolyzers have been shown to be the most reliable piece of major equipment at hydrogen fuel stations. PEM electrolyzers have high reliability with low ongoing maintenance costs and frequency. In particular, hydrogen generation system solutions that eliminate the mechanical compressor can provide added reliability, especially for smaller volume applications. This approach has been successfully achieved through the use of a high-pressure electrolyzer, to produce high purity hydrogen at fueling pressure, without the need for a mechanical compressor.

4. Deployable Refueling Concept

The deployable refueling concept is a simple adaptation of an existing small electrolyzer system commonly used for the launching of weather balloons in remote locations. Typically, electrolyzers are sited with existing infrastructure for power and water needs. The hydrogen refueling solution would be part of the ground control system of a typical UAV platform that is Group 2 (21-55 lbs) or larger. Power would be supplied by the existing generator system that runs the ground control, or power could be supplied by a vehicle auxiliary power unit (APU) or renewable energy source. An integrated water purification system would allow the use of potable water or pretreated gray water based on existing reverse osmosis and de-ionization technology. Hydrogen produced by the electrolyzer would be buffered in a lightweight composite tank and dispensed to the UAV tank via a nozzle and connector used in automotive fueling. Refueling of the onboard hydrogen tank should take no more than 15 minutes, well within the typical turn time for most existing UAVs in the Group 2 class.

Figure 2: Diagram of system components

Figure 3: 5,000 psi Electrolyzer System

Currently, there are two approaches to addressing the pressure of the electrolyzer system. Commercially available electrolyzers typically operate below 500 psi and require a mechanical compressor to boost the pressure and fill the hydrogen storage tank onboard the UAV. With this design, there is flexibility to fill tanks beyond 5,000 psi, extending the duration of flights. An alternative design in development is an electrolyzer stack that produces hydrogen directly at a higher pressure of 5,000 psi (Figure 3). A system with this design is more efficient and reliable, and could be less costly given the lower part count. Figure 2 describes this approach to the system design. The high pressure electrolyzer can also be coupled with a smaller single-stage boost compressor to achieve higher filling pressures, which will enable longer duration missions.

This deployable refueling concept is a cost effective solution to the challenge of accessing hydrogen fuel. On-site production enables the use of extended-range fuel cell powered UAVs while eliminating complicated fuel supply logistics. Siting the electrolyzer is straight forward and it easily connects with existing power generators and water supply.

5. Beyond Unmanned Aerial Vehicles

Other fuel cell applications, such as vehicles that are co-located with a fuel cell-powered UAV, can also benefit from on-site hydrogen production, especially for military users. Silent watch or idling applications usually requires the vehicle to operate without the main engine, while still operating monitoring and communication systems. A dedicated power supply allows for the reduction or elimination of acoustic and infrared signatures while still remaining mission effectiveness. Current battery systems do not provide the desired silent watch mission duration, whereas a hydrogen fuel cell can provide that capability simply by sizing the hydrogen storage appropriately.

An APU is a secondary power generator. By using a silent hydrogen fuel cell APU, you can provide an alternative power source to certain vehicle loads, thereby reducing reliance on the primary vehicle power source. These systems are already being trialed by the U.S. military. United States Special Operations have used Protonex's M-300 Fuel Cell to enable silent watch on river craft and small wheeled vehicles. In addition, the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) has collaborated with General Motors in the development of a mission-ready Chevrolet Colorado ZH2 Fuel Cell Vehicle, which will use fuel cell power for both primary propulsion and silent watch.

The director of TARDEC, Paul Rogers has said: “Fuel cells have the potential to expand the capabilities of Army vehicles significantly through quiet operation, exportable power and solid torque performance, all advances that drove us to investigate this technology further.”[iv] Military field trials of these fuel cell applications will take place in remote areas and will require a supply of high purity hydrogen. The fueling strategy developed for these types of application could be sized to support a portfolio of fuel cell-powered applications co-located in the field, gaining synergies and optimizing costs.

Electrolyzers are also used to supply hydrogen for launching weather balloons in remote parts of the world, and the U.S. Army has tested Proton OnSite’s equipment for launching tactical aerostats at remote sites. The U.S. Government purchases Proton OnSite’s electrolyzers to provide hydrogen for lifting gas at meteorological stations at some of the most remote locations in the world, including Antarctica.

6. Conclusion

Many applications for fuel cell powered UAVs will require launch sites in remote and dangerous areas where resupply of hydrogen (or other fuel types) would be extremely difficult. So while fuel cell performance on UAVs is well documented, it is the fueling solution that is the near-term barrier to deployment.

By combining a PEM fuel cell propulsion module developed by Protonex with high-pressure PEM electrolysis offered by Proton OnSite, a complete hydrogen fueled solution is available to overcome the common barrier to adoption of ready access to hydrogen at remote sites.

Manufacturers interested in opportunities for deployable packaged solutions for UAV propulsion and fueling solutions based on fuel cell systems and on-site hydrogen generation supply using electrolysis are invited to contact us today to learn more at marketing@ballard.com or sszymanski@protononsite.com.

7. About Proton OnSite

Proton OnSite is the market and technology leader in PEM electrolysis, with more than 2,700 installations around the world. For more than 20 years, Proton has been providing advanced PEM electrolysis solutions for its military and commercial customers in a variety of market sectors. Proton is proud to produce electrolyzer stacks for oxygen production on U.S., U.K., and French Navy submarine fleets. With a large range of production capacities, ranging from 200 cc/min to more than 400 Nm3/hour, Proton can offer hydrogen system solutions for virtually any requirement. Proton OnSite's vast installation base and world-class technical support coverage is unparalleled. It is that dedication to excellence that allows Proton OnSite to continue to foster a strong network of lasting relationships with customers.

To learn more about Proton OnSite, please visit www.protononsite.com.

8. About Protonex Technology Corporation

Protonex Technology Corporation, a wholly owned subsidiary of Ballard, is a leading designer and manufacturer of advanced power management products and portable fuel cell solutions. Protonex develops, tests, and manufactures portable power management products in Southborough, Massachusetts. Protonex has commercialized and deployed several products designed for end-users in military and commercial markets that are currently underserved by batteries and small generators and has received development programs from U.S. military and U.S. government organizations. Recently, Protonex's family of fuel cell propulsion systems were designated as EAR99 (Export Administration Regulations 99) compliant by the U.S. Department of Commerce, creating a path for commercial export and deployment in a variety of civilian unmanned vehicle applications.

Protonex products are protected by patents in the U.S. and elsewhere. To view the list of these patents, visit https://protonex.com/company/protonex-patents/. The list of Protonex products published on the website may not be all-inclusive, and other Protonex products not listed may be protected by one or more patents.

For more information about Protonex power managers, chargers and fuel cells please visit www.protonex.com.

9. About Ballard Power Systems

Ballard Power Systems is recognized as a world leader in the design, development and manufacture of clean energy fuel cell products. Ballard is located in Burnaby, British Columbia, Canada, where the company operates a fully equipped R&D, engineering and test facility, as well as a high-volume fuel cell manufacturing facility. Ballard's proprietary technology draws on intellectual property from our patent portfolio, together with our extensive experience and know-how, in key areas of fuel cell stack operation, system integration, and fuel processing.

There are approximately 450 employees at Ballard with half made up of Ph.D.'s, engineers, scientists, and technologists focused on developing fuel cell products primarily for motive applications and providing engineering services to key customers and markets. Ballard also has sales, R&D and manufacturing facilities in the United States and Denmark.

To learn more about Ballard, please visit www.ballard.com.

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