

Hydrogen Delivery and Storage Options For Backup Power and Off-Grid Primary Power Fuel Cell Systems

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Abstract - As fuel cells become a larger percentage of telecom backup power packages, the delivery and storage of hydrogen is key. ReliOn has been at the forefront of hydrogen supply alternatives and infrastructure strategies since the company was established in 1995. This work has included fuel reforming and chemical production R&D programs, metal hydride testing, electrolyzer investigations, high pressure storage evaluations and conventional packaged gas and bulk gas distribution infrastructure. ReliOn continues to support customers with assistance in securing commercially mature, cost-effective and available hydrogen distribution and storage solutions. This paper focuses on hydrogen delivery, distribution and storage options which are available today or are expected to become cost-effective and commercially viable in the near future. Current fueling solutions include hydrogen cylinder distribution and exchange services provided by national or regional gas suppliers and/or third party service providers. Near term alternatives under development involve field refill of fixed vessels in hydrogen storage cabinets, ground storage modules or composite pressure vessels. This option—patterned on bulk gas deliveries to industrial users—can provide extended run time, reduce labor requirements and transport logistics, and decrease hydrogen wastage. Other options include high pressure hydrogen delivery and storage; and additional bulk hydrogen delivery systems under development. Discussion will be added regarding alternate methods for providing hydrogen which are not yet seen as commercially mature.

I. INTRODUCTION

ReliOn has been at the forefront of hydrogen supply alternatives and infrastructure strategies since the company was established in 1995. This has included fuel reforming and chemical production R&D programs, metal hydride testing, electrolyzer investigations, high pressure storage evaluations, and conventional package gas and bulk gas distribution infrastructure. ReliOn continues to support customers with assistance in securing commercially mature, cost effective, and available hydrogen distribution and storage solutions. This paper focuses on hydrogen delivery,

distribution, and storage options which are available today, or are expected to become cost effective and commercially viable in the near future.

Why focus on hydrogen? Compressed hydrogen is the only viable alternative for immediate commercial deployment of small (<10kW) stationary backup power systems requiring high reliability, primarily because there is very low risk of a fueling system failure. Though worthy of continued development, advanced and emerging alternatives such as methanol, diesel, and propane reforming; chemical hydride production; and water splitting are best suited for prototype or funded field demonstrations. These approaches—often scaled down industrial technologies, or an early launch of prototypes—appear not to be commercially feasible, cost effective, or reliable enough for network deployment for critical back-up or small scale primary power. (Large scale fuel cell systems providing primary power, running on natural gas, have proven to be viable. However, they have not been practically scaled down to the sub-10kW range).

II. THE CURRENT MODEL: CYLINDER DISTRIBUTION AND EXCHANGE

The fueling model presently serving stationary distributed fuel cell installations is based primarily on conventional steel cylinders installed in a hydrogen cabinet immediately adjacent to the fuel cell generator. Today, this model is the most realistic and cost effective hydrogen fueling solution for customers requiring reliable and uninterruptible power. Hydrogen gas cost in conventional cylinders is typically between \$8 and \$10 per 100 SCF (approximately \$2.50 to \$3.50 per kWh), plus delivery, hazmat, and rental charges. Business case studies confirm that financial consequences and loss of subscriber loyalty resulting from disruption of service events far exceed the cost of ensuring power security.

Under the existing fueling model, network operators have the added assurance that cylinder distribution of hydrogen is available nationwide from a number of packaged gas

providers in a competitive market. Codes and safety standards are well understood, and continued availability of hydrogen does not depend on development of new distribution models that could be delayed by commercial or regulatory uncertainties.

As of early 2008, ReliOn has shipped over 1.6 MW worth of fuel cell systems to customers. In nearly all of these installations, conventional steel cylinders are transported by packaged gas suppliers, maintenance personnel, or third party service providers to the fuel cell location and installed in the ReliOn hydrogen cabinet. These are standard industrial gas cylinders, widely available in 44 L and 49 L (liters of water volume) capacities, and are commonly designed, certified, and marked according to U.S. Department of Transportation (DOT) requirements published at 49 CFR 178 Subpart C. The 3A or 3AA specification marked on the cylinder is followed by the rated service pressure. Service pressures of 2,015 psig and 2,400 psig are the most common; although ultra high pressure steel cylinders are available with service pressures up to 6,000 psig. According to filling requirements published at 49 CFR 173.302a, cylinders in hydrogen service (a Division 2.1 flammable gas) may not be filled to a pressure in excess of its marked service pressure, even if a '+' stamp appears adjacent to the pressure test mark.

When delivered at fill pressures of 2,200 to 2,400 psig, a 49 L (3AA-2400) cylinder will provide 7.5 to 8.2 kWh of electrical energy (hours of run time at 1 kW of load) with a ReliOn T-series fuel cell system. Upon depletion, empty cylinders are exchanged for full, and the empties are returned to the gas supplier for refill. In some cases it is also beneficial to store spare cylinders at the network operator or third party service provider maintenance facilities. The storage locations are selected to serve fuel cell locations in a network region. This strategy ensures cylinders are available in reserve during emergency call outs, providing an additional layer of operating security.

In addition to steel, aluminum cylinders are also available from many gas suppliers for transport and storage of hydrogen. These are generally certified for pressurized transport and storage of hydrogen under DOT 3AL requirements. Being significantly lighter, aluminum cylinders are easier to transport and install. However, service pressure ratings and gas capacities available in aluminum cylinders are generally lower than for steel. Common service pressure ratings for DOT 3AL cylinders are 2,015 psig and 2,216 psig. Although most gas suppliers only have 16 L and 30 L aluminum cylinders in their inventories, the largest aluminum cylinder shown in manufacturer's listings is a 46 L size. This cylinder would provide an equivalent fuel cell run time of 6.5 kWh. On an equivalent energy basis, aluminum cylinders are 20% lighter than steel cylinders but are up to 4 times higher in purchase or lease/rental costs. Apart from the cost penalty, aluminum cylinders effectively allow a greater quantity of hydrogen to be transported in a company service vehicle (as opposed to the gas supplier's delivery truck) in the event of an emergency or special delivery. The federal

statute for placarding of vehicles, including the weight limit, is 49 CFR 172.504, paragraphs (b) and (c). This U.S. federal DOT code requires placarding the vehicle when over 1,001 lbs of hydrogen gas including the container is transported. Generally, state drivers' licensing laws require a Class 3 Commercial Drivers License, with Hazmat Endorsement when vehicle placarding is necessary. This 1,001 lb threshold translates to about 6 steel 49 L cylinders. Up to 10 aluminum 46 L cylinders could be transported under the same weight limit, giving about 56 % additional hydrogen as compared to steel cylinders.

Disadvantages to the conventional (steel or aluminum) cylinder distribution include:

- Labor costs associated with handling and exchanging cylinders;
- Gas supplier's company policy may not permit them to perform installation and hook-up of gas cylinders inside of customer cabinets;
- Credit not given for partial gas content in returned cylinders; and
- Energy density in 2,400 psig cylinders is relatively low, requiring a large investment in cylinders and cabinets to achieve extended run times or to serve high power loads.

III. FIELD REFILL OF FIXED HYDROGEN STORAGE

An alternative to cylinder exchange is a hydrogen delivery and storage model in which bulk or mini-bulk hydrogen vehicles deliver fuel to fixed tanks serving the fuel cell. This concept, sometimes called the "Field Bump" model, is patterned on the large scale industrial hydrogen business model in which a vehicle such as a tube trailer delivers bulk gas to fixed storage vessels (such as ground storage modules or Hydрил® tubes). Examples of bulk gas transport are conventional tube trailers (ranging in capacity from about 25,000 SCF to 140,000 SCF), hydrogen fueler trailers (approx. 20,000 – 60,000 SCF), and truck or trailer-mounted high-pressure composite cylinders (currently under development).

The Field Bump model is expected to reduce labor requirements and transport logistics associated with individual 150 lb steel cylinders, reduce hydrogen wastage, and ultimately increase available run time between site fueling visits. Refueling schedules will be based on projected usage and low-fuel alarm response. Hydrogen service fees and hydrogen gas cost for field refueling will depend primarily on fuel cell system installation density in given market regions and available bulk transport vehicles. In some cases, hydrogen gas cost could be significantly less expensive than conventional cylinder gas and associated cylinder rental costs.

Implementation of the Field Bump model requires a 3 phase approach: validate refill capability (including hardware and logistics), identify and deploy refillable storage, and establish dependable refill delivery infrastructure.

A. Phase I: Validate a Refillable Hydrogen Cabinet

A refillable hydrogen cabinet requires storage vessels and a means to fill them from a transport vehicle. Two fill models are being evaluated by both gas suppliers and fuel cell manufacturers; industrial gas trans-filling, and SAE automotive-type refueling. The primary difference is in fittings, hose location and purge venting, and pressure and temperature monitoring.

ReliOn, with support from Air Products and Chemicals, Inc. (APCI), has tested a Refillable Hydrogen Cabinet based on our standard 6-cylinder fuel storage cabinet currently in widespread commercial use. This cabinet is based on the industrial gas trans-fill approach. To accomplish refilling of DOT cylinders with the cabinet, ReliOn added modifications to the standard cabinet including a refueling connection, check valve, a purge and vent control valve, and vent line designed in accordance with NFPA 55 and CGA G-55. ReliOn's standard hydrogen cabinet contains six (6) 49 L steel cylinders for a total gas storage of 3.6 kg (equivalent to 1,566 SCF), providing about 48 kW-hr of fuel cell run time.

The results of the refill tests on the modified cabinet validated the industrial trans-fill approach. Several fill tests were conducted to demonstrate safe and controllable fills through the fill valve, check valve, and manifold system. Hydrogen was delivered to the ReliOn cabinet from a 2,400 psig tube trailer provided by APCI. The tube trailer was connected to the fill fitting on the cabinet through a flexible hose and industry standard CGA-type fittings. Each fill test began with an initial cylinder pressure of about 150 psig. Several thermocouples and temperature indicators were attached to the manifold and the cylinders to measure and record temperature as a function of fill rate. (After each fill operation, the valve to the tube trailer was closed and the cylinders were vented through the cabinet manifold to the vent stack to allow for additional fill cycles.) A key objective of the demonstration was to determine the highest rate of fill that could be achieved while limiting the effects of compressive heating of the gas contained in the cylinders and manifold system. Standard gas industry practice does not allow maximum cylinder temperature to exceed 130°F (54°C) anytime during fill operations. Figure 1 shows pressure and temperature data recorded during one of the fill tests. As shown, the cylinders in the cabinet were filled from a starting pressure of 150 psig to a final pressure of just under 2,400 psig in about 6 minutes. Ambient temperature during this test was 82°F. One cylinder was in direct sunlight and had an indicated surface temperature of 100°F at the beginning of the fill test. Maximum cylinder temperature recorded near the end of the fill operation was 111°F.

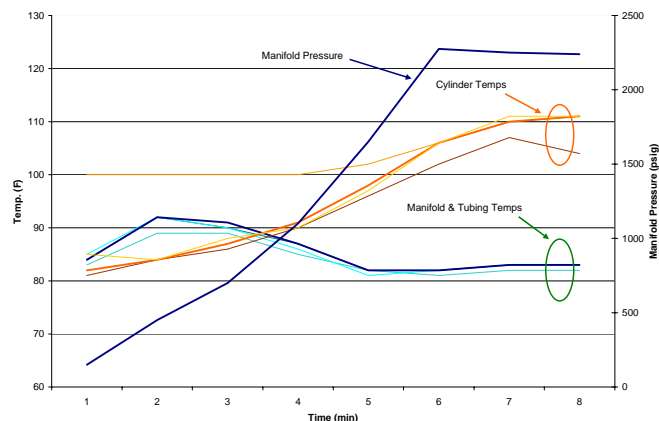


Figure 1. Pressure and Temperature Data From Fill Test of ReliOn Refillable Hydrogen Cabinet

B. Phase II: Identify and Deploy Refillable Storage

Once the refilling process itself has been validated, the next phase is to identify alternatives for a refillable hydrogen cabinet designed around pressure vessels appropriate for storing compressed hydrogen. Existing commercial storage vessels include high pressure steel cylinders and ground storage modules. Composite cylinders are in early commercialization, with wider deployment limited by cost and codes and standards. Standard pressure (3,000 psig) composite cylinders are a near-term option. High pressure (up to 10,000 psi) composite cylinders are hindered by high cost and limited access to high pressure fueling vehicles.

i. High Pressure 3000psi Steel Cylinders

A prototypical storage cabinet is based on 3,000 psi DOT 3AA steel cylinders. Due to the larger size of these higher pressure cylinders, this storage cabinet design is larger than the current 6-cylinder fuel storage cabinet. At a service pressure of 3,000 psig, this cabinet can provide total hydrogen storage of 3,083 SCF, staying within the NFPA 55 defined volume of 3,500 SCF or IFC defined 4,226 SCF for minimum setback distances. This option will provide fuel cell run times of about 96 kW-hr when filled to 3,000 psig and about 78 kW-hr when filled to 2,400 psig.

Where site conditions and setback distances allow a larger volume of hydrogen storage, a larger cabinet version incorporates twelve (12) DOT 3AA-3000 cylinders, and will fit within a 4 foot by 4 foot space. At a service pressure of 3,000 psig, this cabinet can provide total hydrogen storage of 6,166 SCF. This option will provide fuel cell run times of about 192 kW-hr when filled to 3,000 psig and about 156 kW-hr when filled to 2,400 psig.

Capital cost estimates on an equivalent pressure and run time basis for the Refillable Hydrogen Cabinet may be as much as 15% less than the existing 6-cylinder fuel storage cabinet (cylinder exchange model) with a net present value allowance for rented cylinders.

ii. Ground Storage Modules

Another hydrogen storage option commercially available today is based on DOT or ASME certified steel pressure vessels (Hydril tubes) and generally referred to as ground storage. Examples of ground storage tubes are shown in Figure 2. Ground storage tubes and tube modules are available on a sale or rental basis from bulk gas suppliers to customers and are used primarily for storage at industrial facilities, including the following:

- Metals manufacturing;
- Utilities;
- Petroleum refining and chemical process industry;
- Glass manufacturing; and
- Pharmaceutical and edible fats and oils hydrogenation.



Figure 2. Examples of DOT and ASME Ground Storage Tubes
Sources: Weldship (top); Fibatech (bottom)

Ground storage tubes are available from most suppliers certified to either DOT or ASME pressure vessel requirements. As with 3A, 3AA, and 3 AL package gas cylinders, DOT- certified and stamped ground storage tubes are required to be tested and re-certified every 5 to 10 years depending on the specifics of use. DOT design and certification requirements for ground storage tubes are similar to package gas cylinders but are specifically tailored for tubes installed horizontally and supported at the ends. Common DOT specifications are 3AX and 3AAX for large ground storage tubes. ASME stamped pressure vessels do not require follow-up testing and re-certification unless the tubes or threaded connections have been modified or repaired. Ground storage tubes designed and certified to ASME requirements can add a 15 to 20% premium to the cost of a similar sized DOT tube.

Ground storage tubes and tube modules could be well suited for back-up power, or in some cases off-grid primary power fuel cell sites where space is available and site

conditions allow access by tube trailers for re-fueling. These vessels can be installed directly on a concrete foundation without the need for additional enclosures or weather protection. Tubes are generally available at service pressures from 2,400 to 4,000 psig, with some designs usable up to 10,000 psig. At 2,400 psig, available capacities range from 2,350 SCF for single 6'-8" x 24" tube to 6,090 SCF for single 18'-6" x 22" tube. Corresponding run times are 74 – 190 kWh per tube. At 4,000 psig, available capacity is 9,794 SCF for single 20' x 24" tube to provide 308 kWh of run time.

Although capital costs can be high for such large storage solutions, total investment can be shown to be about 3% - 13% less than conventional 3AA steel cylinders and a standard hydrogen fuel cabinet on an equivalent pressure and run time basis for larger installations.

iii. Composite Pressure Vessels

Composite pressure vessels have been available for many years and have found widespread use in the aerospace and breathing pack applications. Composite pressure vessels are manufactured in a multi-layer configuration with inner gas containment constructed of plastic, resin, or aluminum. Pressure containment is accomplished by an over-wrap of glass fiber or carbon fiber, usually embedded in resin, and sometimes with an outer protective coating. Composite vessels are starting to appear in hydrogen fuel cell and compressed natural gas (CNG) vehicle applications under special DOT permits, commonly referred to as NGV2 (based on the ANSI/NGV2-2000 specification).

Although there is a large amount of interest in the application of composite pressure vessels to stationary and distributed fuel cells, and a corresponding level of attention in the bulk gas industry for transport of large gas volumes in lighter weight trucks and trailers, the availability of cost effective and certified containers suitable for these applications has been limited to date. Composite cylinders are not included in DOT cylinder specifications for hydrogen transport or storage at the point of use. Therefore, composite cylinders are only allowed in service by obtaining a special permit from DOT in accordance with 49 CFR 107 Subpart B. Obtaining the required DOT special permits to use composite cylinders in these applications can be very time consuming, sometimes requiring months or years for approval.

ASME has developed preliminary composite cylinders standards under Section X of the Boiler and Pressure Vessel Code, but the design and use requirements are extremely conservative, effectively imposing a significant cost burden on this option for now. ASME's Boiler and Pressure Vessel project team on hydrogen tanks is addressing high pressure gas storage in metal and composite tanks. The work plan includes a proposed new article KD-10 to Section VIII-3, a code case on composite tanks for Section VIII-3, and a revision to code case 2390 on metal lined composite reinforced circumferentially wrapped pressure vessels under Section VIII-3. Transport tanks may also be included in Section XII.

The Compressed Gas Association (CGA) has published a position statement (PS-26-2007) that supports the use of NGV2 Type 3 and Type 4 carbon fiber, fully wrapped composite storage vessels for permanently installed storage systems in gaseous hydrogen fueling stations, and sets requirements for their use. Though the CGA document specifically references refueling stations, its basic assumptions and parameters appear to be applicable to any permanently installed storage system.

Legislation in some other countries, such as Transport Canada standards, have allowed for earlier adoption of composite vessels in stationary storage and transport operations.

There are at least four manufacturers of composite pressure vessels in North America:

- Structural Composites Industries
- Quantum Technologies
- Lincoln Composites
- Dynetek Industries, Ltd.

In addition to their product lines serving the aerospace, breathing pack, and small specialty industries, these companies are producing fuel tanks for automotive and transit bus applications under a special DOT exemption for these applications. Composite vessels currently in use for automotive and transit bus applications have service pressure ratings ranging from 3,000 psig (200 bar) to 10,000 psig (700 bar). The stationary and backup power fuel cell industries will continue to see the benefits of the work that is being done for the automotive industry in terms of hydrogen delivery.

Outside of aerospace, CNG vehicle, and fuel cell vehicle demonstration programs, the availability of composite pressure vessels for stationary fuel cells is very limited. Structural Composites Industries (SCI) currently offers two Type III (aluminum liner with carbon fiber over wrap) composite vessels with DOT special permit status for hydrogen transport and storage. SCI's smaller tank will contain 2 kg of hydrogen, or about 800 SCF at a nominal service pressure of 4,000 psig. Installation of 22 of these tanks in a mobile hydrogen fueler is shown in Figure 3. Their larger vessel (about 10 ft long by 17 in. diameter) will contain 8 kg (about 3,200 SCF) at a nominal service pressure of 6,250 psig.



Figure 3. 2 kg (800 SCF) Composite Pressure Vessels Mounted In Hydrogen Mobile Fueler Service
Source: SCI Composites

Depending on pressure rating, vessel size, and order quantities, these composite vessels can range from about \$375 to \$1,400 per kg of hydrogen capacity. These costs are from 1.5 to 4 times the cost of conventional DOT steel cylinders, neglecting the cost of module assembly. With the increasing cost of steel, these costs are becoming more attractive, particularly at the lower pressures (3,000 psig). Due to their significant weight advantage, composite cylinders appear very well suited for transport of compressed hydrogen from the gas supplier to distributed stationary fuel cell sites.

In Canada, national and provincial codes have developed more quickly to allow greater use of composite pressure vessels in CNG, stationary fuel cell, and hydrogen transport applications. Dynetek Industries, Ltd. of Calgary, Canada has developed several vessels potentially applicable for fixed hydrogen storage and for gas delivery. Examples of hydrogen storage configurations are shown in Figures 4 and 5.



Figure 4. Dynetek 5,000 psi (350 bar) Composite Pressure Vessels In Fixed Storage Service
Source: ReliOn



Figure 5. Dynetek Composite Vessel Hydrogen Storage Cabinet Concept
Source: Dynetek

iv. High Pressure Hydrogen Storage

The full potential for fiber reinforced composite pressure vessels in stationary storage service will be realized when they can be utilized in high pressure applications. At pressures of 5,000 psig, 6,000 psig, and up to 10,000 psig (700 bar), high capital costs are offset by increased energy storage in a given volume and weight in both fixed and transport service. However, high pressure storage at the fuel cell site is restricted today not only by the development pace of relevant codes and certification standards, but also by the availability of high pressure delivery vehicles, and the practical limitations of installing compression equipment at fuel cell sites.

High pressure hydrogen storage in back-up power and distributed primary power fuel cell systems is currently limited by the ability of bulk delivery vehicles to deliver and pressurize small storage systems. Bulk delivery vehicles available in the market today (tube trailers and mobile hydrogen fuelers) do not carry on board compressor equipment. Therefore in order to fully charge the fixed receiver at the delivery site and scavenge the maximum percentage of hydrogen from the delivery vehicle, large industrial sites are often equipped with a stationary compressor station. Typical compression equipment is shown in Figure 6. These systems are priced at between \$50,000 and \$100,000 and, although cost effective for large industrial users of commodity hydrogen, are clearly not feasible for installation at a back-up power or distributed primary power fuel cell site. Bulk gas transport vehicles also use pressure equalization and cascade fill procedures to deliver hydrogen to fixed receivers. These techniques are suitable for smaller industrial receiver volumes (typically less than 50,000 SCF) and for receiver pressures up to 3,000 psig.



Figure 6. 3,000 psi Hydrogen Compressor
Permission: Pdc Compressors; Source: ReliOn

Automotive and transit bus hydrogen tanks are currently filled to between 3,000 and 10,000 psig. Temporary or demonstration filling stations generally utilize cascade fill techniques from high pressure mobile fuelers. Larger and more permanent hydrogen and compressed natural gas filling stations include gas compression equipment to fully charge the auto or bus tanks. In these stations, the source of hydrogen can be a bulk gas transport vehicle, local ground storage filled from a bulk gas transport vehicle, pipeline hydrogen or natural gas, steam methane reformer (SMR) producing hydrogen from pipeline natural gas, or electrolyzer producing hydrogen from water. Hydrogen produced at the filling station from either a SMR or electrolyzer process is sometimes referred to as “forecourt hydrogen.” When the source of hydrogen is a bulk transport vehicle or ground storage tubes, the compressor at the filling station is used to fully charge the auto or bus tanks and scavenge a greater percentage of gas from the bulk gas storage before this vessel itself must be refilled. For pipeline gas or forecourt hydrogen, the compressor is used only to maintain fill pressure to the vehicle receiver.

C. Phase III: Bulk And Mini-Bulk Hydrogen Delivery

Once the refill operation and storage vessels have been addressed, the infrastructure that delivers the hydrogen must be nurtured. Current models are based on leveraging existing industrial gas models using tube trailers operating at standard pressures (~2,400 psig), while demonstrations are being fielded using high pressure (up to 10,000 psig) trailers.

i. Tube Trailers Operating At Standard Pressure

The most common bulk gas delivery vehicles available today are 22 ft and 44 ft tube trailers. These are available from a number of bulk gas providers (Air Products, Praxair, Airgas, Linde, etc.) with some variation on size, tube configuration, and gas delivery plumbing. Typical trailer capacities are 85,000 SCF and 112,000 SCF at 2,400 to 2,800

psig, with some versions available at higher pressures depending on design. Tube trailer pressure vessels are constructed from high strength carbon steel and are typically certified to either DOT 3AX or 3AAX requirements. Examples of tube trailer designs are shown in Figure 7.



Figure 7. Standard and Jumbo Hydrogen Tube Trailers
Source: Weldship

End user categories typically served by tube trailer hydrogen deliveries are large industrial hydrogen gas consumers, such as:

- Metals manufacturing;
- Utilities;
- Petroleum refining and chemical process industry;
- Glass manufacturing; and
- Pharmaceutical and edible fats and oils hydrogenation.

Common tube trailer hydrogen delivery models are “drop and swap”, pressure equalization fill of ground storage tubes, or fill of ground storage tubes using stationary compressor at customer site. In the “drop and swap” model, the depleted trailer is removed and a full trailer is parked and attached to a product delivery stanchion.

In a pressure equalization fill delivery, ground storage tubes at customer site are filled from the tube trailer until pressures are equilibrated. This leaves a significant amount of hydrogen on board the tube trailer when returned to the supplier’s fill plant. Ground storage tubes with a total volume of no more than 50% of the tube trailer can be brought up to full service pressure using a cascade delivery method. No pump or compressor is used; so again only about 50% of product on trailer can be off-loaded. In many cases, a stationary compressor (see Figure 6) is installed at the

customer’s site near the ground storage tubes. Although this requires an additional capital expenditure, or monthly rental cost, a much higher percentage of product on trailer can be off-loaded due to scavenging by the pump, thereby lowering delivery costs.

Tube trailer gas cost varies widely depending on region, distance from supplier fill plant, and amount of gas off-loaded per delivery. Regular deliveries of industrial gases at large volumes are typically priced at less than \$4 per 100 SCF, plus freight, rental, and hazmat charges. For hydrogen delivery volumes compatible with the ReliOn Refillable Hydrogen Cabinet (between 4 and 15 kg, or about 1,600 to 6,100 SCF), initial gas costs are estimated to vary widely from \$5 to \$20 per 100 SCF depending on service model, delivery frequency, and distance from gas supplier’s fill plant.

ii. Mobile Hydrogen Fueling Trailers at High Pressure

Mobile hydrogen fuelers are being developed and promoted by bulk gas suppliers in the U.S. and Canada under federal, state, and provincial funding and internal corporate development and demonstration programs. These trailers are being used to support fuel automotive and transit bus test and demonstration programs and similar moderate to high usage applications such as warehouse lift truck demonstrations. Mobile hydrogen fueling trailers have been developed and built by Air Products, Quantum Technologies, and Dynetek, among others. Example mobile hydrogen fuelers are shown in Figures 8 and 9.



Figure 8. Air Products 50 kg Mobile Hydrogen Fueler
Source: Air Products



Figure 9. Air Products 150 kg Mobile Hydrogen Fueler
Source: Air Products

Air Products probably has the largest inventory of mobile hydrogen fuelers with about 19 units built under a program originally initiated by the 2005 DOE California Hydrogen Infrastructure Project. The Air Products fleet currently consists of one 50 kg and two 60 kg prototype mobile fuelers, based on 16 ft enclosed utility trailers (see Figure 8), and sixteen large trailers (shown in Figure 9). Hydrogen storage vessels on the smaller trailers are based on 2 kg composite vessels manufactured by Structural Composites Industries (SCI). Hydrogen vessels are filled to a nominal pressure of 5,000 to 6,000 psig for delivery to a fueling station.

Air Products also maintains a fleet of sixteen 23 ft fifth wheel type trailers containing 150 kg (60,000 SCF) at a nominal pressure of up to 6,600 psig. Hydrogen is typically off-loaded from these vehicles either to fixed receivers at hydrogen filling stations, or directly to fuel cell vehicles using a cascade delivery technique. Both the smaller and larger mobile hydrogen fuelers could potentially be used to deliver hydrogen to distributed stationary fuel cells.

As the 8 kg and similar or larger composite pressure vessels become available from SCI, Quantum, Dynetek and other developers, a greater number of small and medium sized delivery vehicles are expected to be developed. Both trailer and truck-mounted options are being considered, not only by bulk gas suppliers, but also by third party providers such as generator fueling and service companies, gas field service companies, and others. All-wheel drive trucks equipped with a chassis-mounted composite pressure vessel skid will allow hydrogen delivery to more remote installations where fuel cells are backing up communications equipment. These types of vehicles are currently in use to deliver inert gases and transport CNG from small natural gas well heads.

IV. CONCLUSIONS

A key enabler to accelerating the deployment of hydrogen fuel cells in backup power and primary off-grid installations is to move from fuel storage exchange to refilling as a standard option. This requires a 3-phase approach, involving

numerous stakeholders, including gas suppliers, storage system manufacturers, and code officials.

First, the refill operation must be standardized; filling equipment and operating procedures must be common across vendors and gas suppliers, and gas suppliers must have a compelling business case for refueling stationary sites. Numerous fuel cell vendors and gas suppliers are currently working on developing viable refill options.

Second, newer storage technologies using advanced composite pressure vessels need to be brought closer to commercial viability from a cost and codes consideration. This is secondary to the refill operation and delivery, because if the fuel can't be delivered, the storage method is irrelevant.

Third, high pressure storage must become more ubiquitous for longer run times. Codes and standards must evolve to allow the use of high pressure cylinders for stationary applications, not just mobile applications, and gas suppliers must have a business case based on wide deployments to justify the investment in fleets of high pressure mobile refuelers.

These fueling solutions will expand the continued deployment of zero-emission, quiet, reliable hydrogen fuel cells for stationary backup and off-grid primary power.