Backup Power and Off-Grid Primary Power Fuel Cell Systems: Two Years Later

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***Abstract* - In 2008, ReliOn presented a paper discussing hydrogen delivery and storage options for fuel cells delivering backup and off-grid primary power. As fuel cells become a more widely deployed solution for telco backup, the delivery and storage of hydrogen remains key. In addition, the attention paid at both the corporate and government level to fuel cells as alternative energy solutions increases. In late 2008, The U.S. Department of Energy released a Funding Opportunity Announcement, targeting Market Transformation for stationary fuel cells for communications backup. One specific requirement of this program is the capability to provide 72 hours backup on compressed hydrogen. ReliOn has been at the forefront of hydrogen supply alternatives and infrastructure strategies since the company was established in 1995. In 2009, U.S. DOE issued multiple awards under the Market Transformation sub-topic. ReliOn was awarded a program to deploy 200 fuel cells with 72 hours backup. The majority of these sites will incorporate a field-refillable hydrogen storage module, placing into service both the storage solution and delivery model discussed in our 2008 paper. Driven by the prospects of this program, further development of market-ready options has occurred, and the industry is in the first phases of a nation-wide deployment of 72 hour backup solutions based on hydrogen fuel cells. This paper provides an overview of the program and preliminary status update, focusing on the storage and fueling solutions presented two years ago, and the influence these specific programs have had in stimulating the emergence of bulk hydrogen delivery for stationary backup applications.**

The value of the Market Transformation program is three-fold: it provides a one-time cost offset to accelerate commercial deployment of a large number of fuel cell backup systems; it requires long run time on compressed hydrogen; and it requires deployment over a short period of time. The benefit of the cost offset is the strong incentive for telecommunications companies to make the near-term investment in a medium-size deployment. This creates a critical mass, with corporate attention paid to the endeavor. Previously, attention was limited to forward-looking leaders at the regional market level, with minor discretionary spending authority. The benefit of the requirement to have long run time with compressed hydrogen drives the development and production of storage modules and delivery infrastructure by again creating a critical mass of units, generating attention from a major gas supplier with the capabilities, and now the potential business opportunity, to bring both storage and delivery to the stationary backup market. The short deployment time requirement (two years) ensures that the previous two critical mass exercises are achieved quickly, avoiding the typical delays that the vagaries of budgets, management, and intense competition introduce to the successful completion of any large, strategically important yet tactically less critical, program.

Field refill of fixed vessels in hydrogen storage cabinets and ground storage modules is now becoming a reality in many locations throughout the United States. 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. Options of high pressure hydrogen delivery and storage continue to develop, though their deployment and commercial availability are still in the future.

I. DOE Program Structure: Market Transformation

The U.S. Department of Energy (U.S. DOE) has historically focused on research and development, providing funding to commercial and academic communities for the development of higher-risk technologies. Recently, the U.S. DOE has begun funding "market transformation" activities, with the objective of assisting with the non-technical barriers that have typically delayed or obstructed the commercialization of those higher-risk technologies.

The market transformation program that is the topic of this paper is an indirect result of U.S. DOE's awareness of the unique and specific requirements of the telecommunications industry, specifically the deployment of fuel cells for backup power, with a requirement of 72 hours on compressed hydrogen. The program provides partial cost reimbursement to encourage deployment beyond the "onesy-twosy" typical trial, with the objective "to increase the number of commercially available fuel cell systems, expand practical user operating experiences, generate volume for the fuel cell supply chain, increase private equity confidence, and validate performance. Furthermore, this topic seeks to increase market pull for existing and new-generation fuel cell power systems."[1]

This paper discusses two of the U.S. DOE-awarded programs: one with a wireless telecommunications company as prime contractor, and one with a fuel cell company as prime contractor. Between the two programs there are two wireless carriers, two fuel cell companies, one gas supplier, and myriad subcontractors. The two programs combined include the deployment or upgrade of over 500 fuel cell systems providing backup to cell sites, all of which will incorporate bulk refueling to achieve the required 72 hours backup capacity.

In return for their cost contribution, U.S. DOE requires that data on installation and operational costs, and operational data be supplied periodically. The data, to be collected from a representative sampling of sites each quarter, consists of run-time, power delivered, and fuel consumed. Other data as collected by the commercial fuel cell system, with minimal or no extraneous data acquisition equipment, may also be included.

The wireless carriers that are participants in this program are already familiar with fuel cells, and between the two have deployed hundreds of systems across the country since 2004. All of these systems use cylinder gas, known in the industry as packaged gas, for fuel management. In a packaged gas application, fuel is delivered in cylinders, and the cylinders are exchanged full for empty. This model has some challenges: cylinders are heavy and awkward to move, making cylinder exchange challenging in some installations; due to their weight (~140lbs), cylinders must be relatively small to be physically manageable, and thus their storage capacity is limited (~261 scf per cylinder), therefore many cylinders are required; and full cylinders are often exchanged with a partial fill, since the end-user may choose to replenish the site to full backup duration capacity after one or more outages that may not have consumed all the fuel. This last issue is one more of perception, since a major factor of fuel replenishment is the actual delivery, not just the fuel cost itself.

II. Typical Site Development Process

Site development for this program is divided into three phases: site selection, equipment installation, and equipment operation. All sites selected for these programs are cellular telecommunications sites. The sites vary from suburban to rural to remote. This section emphasizes site selection, as equipment installation and operation are straightforward.

A. Site Selection: Typical Site

Sites are selected based on numerous criteria: appropriate power levels, site access for refueling, and feasibility of site acquisition. Each criterion must be met for the site to be viable.

B. Power Levels

Power levels less than 10kW are a requirement of this program, and this is a reasonable power level for non-programmatic reasons. First, hydrogen-fueled fuel cell systems are more cost-effective at 10kW and below; the cost-performance of conventional diesel generator systems becomes very difficult to overcome in excess of 10kW. Second, the ability to achieve 72 hours of run-time (a program requirement, and a desirable feature for the market) is more costly in terms of storage capability as the power level increases.

C. Site access for refueling

With the introduction of bulk refueling as an alternative to packaged gas, the site must have sufficient access for a delivery truck. The requirements account for the size of the truck, as well as the operational requirements of the gas provider. With respect to truck size, the site or its surrounding environment must allow the truck to get close enough for its hose to reach the storage unit, and then navigate away from the site. Drive-thru access, or a turning radius of 50 ft. or more is required for large articulated tube trailers. Any access gates must be wide enough to accommodate the truck. Road conditions must accommodate the weight of the tube trailer, in some cases in excess of 85,000lbs GVW. Operational requirements of the gas companies preclude stationing the truck during refueling operations under overhead lines, or parking across public sidewalks. There are also limitations with respect to safe ingress and egress from sites on narrow, hilly, or windy roads that drivers require to ensure they can safely enter and leave the site while considering local traffic.

The gas company was engaged as part of the site survey team to ensure that all selected sites met their access requirements. This project demonstrated the importance of early involvement with the gas company for site selection.

In recognition of many of these limitations and based on their direct experience assisting with site selection, the participating gas company is developing a new truck configuration better suited to facilitating delivery to a broader population of sites.

D. Site Acquisition

After the completion of site selection based on power level and fueling access criteria, the site acquisition process begins. Site acquisition includes permitting and any required lease amendments. In some instances, site acquisition may disqualify a site from final selection.

Permits are required for the installation of almost any type of equipment, and require documentation to be filed with numerous stakeholders. Building permits are required from the local authorities, and include reviews of compliance with structural, electrical, and aesthetic codes. Building permits may include recommendations for changes that are not required in other jurisdictions, particularly aesthetic. Permits

[1] U.S. DOE Funding Opportunity Announcement DE-PS36-08GO98009, dated 5/27/2008

from the local fire marshal or authority having jurisdiction (AHJ) are required for the installation of any equipment that uses or contains a flammable or hazardous material, and may also result in recommended changes. These recommendations may increase the cost to install the system at a particular site.

Permits take many weeks to secure, and the ability and timing to secure permits varies greatly from jurisdiction to jurisdiction. In some cases, the increased costs may disqualify the site from actual deployment. Alternatively, the fact that fuel cell equipment has zero emissions and a quiet acoustic footprint may alleviate permitting requirements that in other cases would disqualify a conventional diesel generator.

Lease amendments require the site owner (who often-times is not the wireless carrier) to approve the installation and may involve negotiating lease terms for the new space on the site. The terms and requirements vary considerably from owner to owner. For example, some site owners define any area within the radius of the "setback" required for the presence of fuel as leased space. Others only define the space as the actual footprint, including door-swing, of the equipment. Some site owners are looking for ways to offer more services to their tenants, and are evaluating centralized backup power for all tenants. These owners are significantly less interested in approving lease amendments for individual tenants' backup equipment, regardless of the fact that few tenants are comfortable or willing to delegate backup power to the site owner.

Changes and inconsistencies in codes between jurisdictions add to the challenges. For example, NFPA 55, a standards document that defines requirements for the use and storage of compressed flammable gases, is used as a reference in some jurisdictions, and as legal code in others. Furthermore, NFPA 55 evolves separately from the legal code, so it may be possible that current NFPA standards define requirements differently than a legal code that adopted a previous NFPA standard. For a specific example, NFPA 55 (2006) defined setbacks for compressed flammable gas based on the quantity of gas. NFPA 55 (2010) now defines setback distances based on the pressure at which the gas is stored, and the diameter of the piping through which the gas can escape, with no limit on quantity. The selection of which version of the same standard can lead to significantly different interpretations when determining siting requirements.

To add to the mix, on November 18, 2009, the Federal Communications Commission (FCC) issued a declaratory ruling establishing deadlines for state and local zoning authorities to act on wireless tower siting requests. In the declaratory ruling, the FCC adopted the following rules regarding the time periods for state and local zoning authorities to act on wireless siting applications:

A state or locality must act on wireless facility siting requests under Section 332(c)(7)(B) within (1) 90 days from submission of the request for collocations, and (2) 150 days from submission of the request for all other wireless facility siting applications.

If a state or local zoning authority fails to act within the relevant time frame, the applicant may file a claim for relief in any court of competent jurisdiction within 30 days of the failure to act.

The FCC declaratory ruling is already under fire from local jurisdictions who claim that the FCC is overstepping its regulatory jurisdiction.

It should be noted that these challenges are not unique to fuel cells. Permitting and lease amendments for any new power-generating equipment involves similar steps, with the same agencies, and bear the same risks of timely approval. These observations should be familiar to anyone deploying new equipment, particularly backup generators. The introduction of a novel technology and fuel merely adds a level of unfamiliarity for the stakeholders; it doesn't change the rules.

E. Equipment Installation

The fuel cell equipment and fuel storage are cabinetized and configured for outdoor environments. Installation involves straightforward trenching for conduits, pad placement (or pouring), cabinet placement, and electrical and fuel plumbing connections. Cabinets are typically craned into place. The hydrogen storage module (HSM) (see Section III) weighs 6,300lbs, and therefore requires access to a crane with an appropriate lifting capacity.

Once the equipment cabinet and HSM are placed, conductors are installed between the DC bus within the fuel cell cabinet and the site radio equipment DC bus. If the site has an alarm aggregator, relay outputs from the fuel cell system can be connected to provide monitoring of basic alarm functions. Ethernet, if present on the site, can be connected as an option to monitor higher level functions and provide remote access for human interface by operators.

F. Equipment Operation

The fuel cell equipment operates self-autonomously in a backup mode. Two operating modes are available: low voltage start and contact start. Low voltage start mode monitors the DC bus voltage, and at a user-settable threshold, starts the fuel cell system. This allows the operator to set up the site to ride through short outages on batteries only, without consuming fuel. Contact start allows the operator to set the system to start on an explicit command, typically by connecting it to a "loss of AC" relay, or to a rectifier-fail alarm contact. The two modes can be set simultaneously to capture either type of event.

The ReliOn fuel cell systems are provided with an exercise function that is user-configurable. By exercising the system periodically, the system remains in a conditioned state, ready to deliver power regardless of the time between actual power outages. Furthermore, a periodic exercise is for all intents and purposes a complete operation of the system, and any potential faults will be communicated during this exercise, allowing the user to respond in a timely fashion. This is preferable to having the potential faults only realized during an actual outage.

III. STORAGE AND DELIVERY

A. *Storage Development*

As mentioned previously, fuel cells have already been deployed in hundreds of cell sites as a backup power solution. The advancement in functionality comes from the ability to deploy a larger fuel storage solution, coupled with delivery of non-packaged fuel.

Beginning in September 2008, coincident with ReliOn's earlier paper[2] on bulk refueling, the development of a hydrogen storage module (HSM) was initiated. The objective was to achieve a small footprint, relatively low cost solution using mature technology that was straightforward to acquire. In that paper, the characteristics of various storage solutions was discussed in detail. One particular solution incorporating larger commercial steel cylinders was chosen as the most attractive option, based on small footprint, quantity of hydrogen stored, technology readiness, and cost.

A variety of storage cylinders were evaluated, including standard DOT-approved steel cylinders, conventional ground storage cylinders, and composite cylinders. From a purely volumetric standpoint, larger cylinders are more effective than smaller cylinders. However, the realities of siting within an existing cell site preclude this option, at least with respect to steel. Ground storage cylinders are typically a minimum of 10-12 feet in length, and often much larger, and therefore were rejected due to their large size.

Composite cylinders continue to be touted as a viable storage solution, due to their light weight and potentially higher pressure capabilities. However, these benefits come with a 3x price per unit stored hydrogen. U.S. DOT steel cylinders in standard sizes can be purchased for $0.78 per scf stored ($400 for 513scf cylinder) while composites cost $2.60 per scf ($2,500 for 962 scf cylinder). Furthermore, these benefits cannot be fully realized in the ground storage application being deployed. First, light weight is convenient for the actual installation process, but once installed, is irrelevant. Arguments exist for using composite cylinders for rooftop installations, and the industry anticipates a time when this will be a viable solution. For now, the challenge of how exactly to fuel a rooftop fixed storage system remains. Secondly, the high pressure capability can only be leveraged if there is a delivery mechanism to exploit the higher pressure capability. High pressure refueling is currently limited to demonstration programs: very few vehicles are available that can deliver 5,000 psi or greater. Even within this program, the majority of vehicles available can only refuel to 2,400 psi. A program to deploy a small fleet of higher pressure vehicles that will service 3,000 psi and higher is underway as a direct result of this program. A third challenge with composite cylinders is that current regulations do not adequately address composite cylinders for ground storage. Most composite cylinders that are in use for hydrogen storage are permissible in very specific applications as defined by special permits issued by the U.S. Department of Transportation. The American Society of Mechanical Engineers (ASME) is another standards organization responsible for pressure vessels. The ASME has been considering composite pressure vessels for ground storage, and has published code cases describing a particular configuration, steel cylinders with cylindrical composite wrapping of the cylinder, acceptable for ground storage. As of the writing of this paper, no supplier was identified that had a cylinder available that was fully qualified to the ASME code case. Most building and fire codes require that a cylinder bear a U.S. DOT or ASME certification.

All codes permit the use of U.S. DOT certified cylinders, and therefore DOT3AA cylinders were selected. The typical DOT3AA cylinder is a 2,400psi cylinder with a capacity of 261 standard cubic feet (scf). Though this is the standard industrial gas cylinder, a system capable of serving 3.5kW for 72 hours would require 32 cylinders. To minimize footprint, a larger, higher pressure cylinder was selected. The cylinder of choice is a 3,000psi cylinder with a capacity of 513.8 scf. It should be noted that the majority of this increased capacity is because the larger cylinder is 80 liters wet volume, vs. 44 liters. An additional 20% capacity is realized due to the higher pressure.

The HSM developed for deployment in this program is based on a production cylinder with U.S. DOT certification and these specifications:

- DOT 3AA 3000
- 3,000 psi/513.8 SCF/1.2kg H2 stored = 16kWhr per cylinder
- 2,400 psi/411 SCF/0.97kg H2 stored = 13kWhr per cylinder
- 80 liters wet volume
- 64 inches tall (at the neck) x 11.25 inches diameter
- 270 lbs.

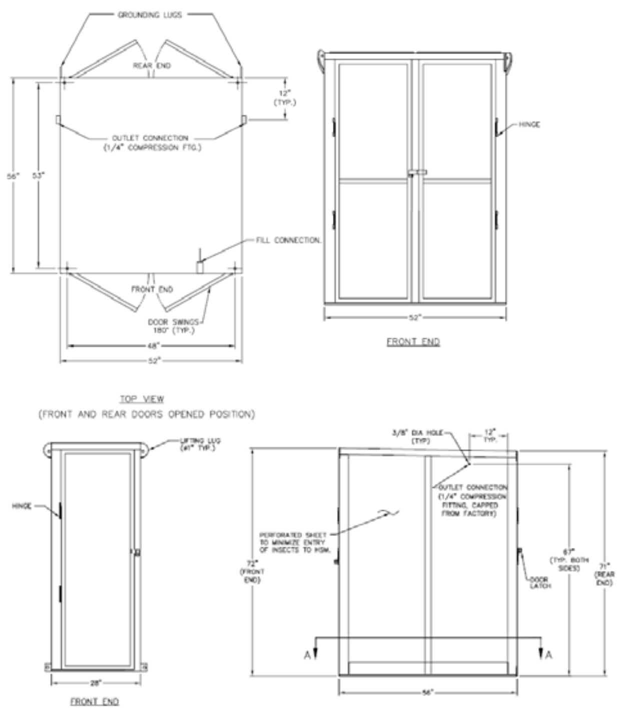
The program requirements for 72 hours, combined with the practical aspects of mechanically designing a module, drove the design to a 16 cylinder version and an 8 cylinder version. Originally, a 24 cylinder version was envisioned, but the weight of 6,500 lbs. of cylinders plus the required structure to carry that 6,500 lbs. made the 24 cylinder version impractical from a manufacturing and installation standpoint. Therefore, an 8-cylinder "secondary" module was developed to meet the requirements originally defined for 24 cylinder version. The specifications for the two versions are listed below:

16 cylinders = 8160 scf = 19.3kg = 256 kWhr = 72 hours @ 3.56kW

8 cylinders = 4080 scf = 9.6kg = 128 kWhr = 72 hours @ 1.78kW

[2] Hydrogen Delivery and Storage Options, Cohen/Snow, IEEE Intelec 2008 Proceedings

When used together, 24 cylinders will serve 72 hours @ 5.34kW.



The 16-cylinder HSM includes all valving, refueling connection, and pressure gauges to support refueling. Since the 8-cylinder is used primarily as a secondary add-on storage, the redundant refueling connection and pressure gauge are not installed. The 8-cylinder can be supplied with all refueling components for smaller loads, or where 72 hours is not a requirement.

The HSM is configured with a port, installed behind lockable doors, that interfaces with a quarter-turn mating connector for gas transfer. This port is similar to the quick-connect fitting used in the automotive industry to fill fuel cell vehicles. The particular mechanical features of this port ensure that it can only mate to the proper fill pressure. The use of a dedicated fill port provides the benefit of faster refueling and reduces the risk of system leaks. Faster fueling is accomplished because multiple heavy cylinders do not need to be moved by hand, and multiple high-pressure gas connections do not need to be disconnected then reconnected. System leaks are reduced because only one connection is made and disconnected, and this connection does not hold pressure during normal operation, as it is upstream of a manual valve that is closed once the fueling operation is complete.

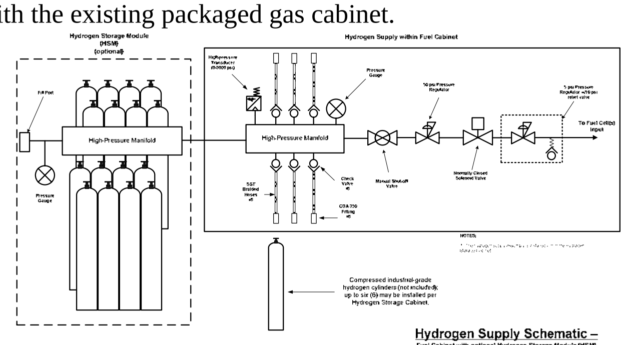
B. Installation Options

The HSM is being installed in two different configurations: stand-alone, as the only fuel storage, and hybridized with packaged gas. In the stand-alone application, the HSM is the only fuel storage. These sites are committed exclusively to the bulk-refueling model, and represent 60% of the sites. Within these HSM-only sites, 20% are planned as retrofits to existing sites, where the current packaged-gas cabinets will be removed and replaced with an HSM. The remaining 80% of sites will be new installations, with a fuel cell cabinet and an HSM.

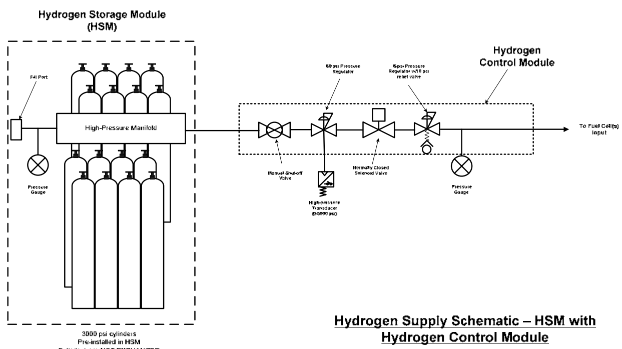
Forty percent of the sites will be configured as hybrid storage systems, combining an HSM and a packaged gas cabinet. In this configuration, the HSM is plumbed into a manifold in parallel with standard packaged gas cylinders, contained within a fuel storage cabinet integrated with the fuel cell equipment cabinet. The packaged gas cylinders are plumbed through check-valves, and are normally left with their cylinder valves closed. The closed cylinder valves prevent the packaged gas cylinders from draining during normal system operation, saving them for emergency activation if a bulk fueling truck cannot reach the site for any reason. The check-valves allow the packaged gas cylinders to be exchanged while the system is operational, preventing the release of gas when a cylinder is disconnected during cylinder exchange. This configuration allows the end-user the option of cylinder exchange in the rare case a refueling truck cannot reach the site.

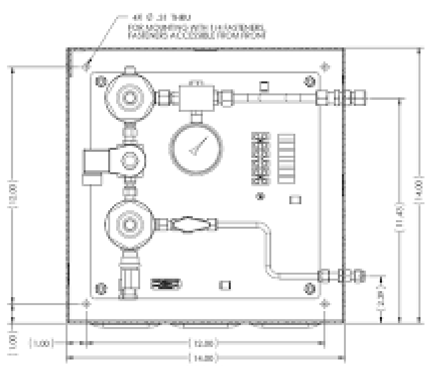
C. Fuel Control

Since the HSM is designed to be generic, and not unique to any particular fuel cell manufacturer, external pressure regulation and control are required to meet the particular requirements of the specific fuel cell system. For the systems installed as hybrid configurations, the fuel control is integral with the existing packaged gas cabinet.



For the stand-alone HSM, a fuel control module is required. ReliOn is providing a hydrogen control module to support its fuel cells being installed with a stand-alone HSM. Analogous designs are expected to be supplied by each fuel cell vendor. The hydrogen control module is a small enclosure (7” x 14” x 14”) mounted to the side of the HSM. The hydrogen control module contains the same components as those within the standard packaged gas fuel cabinet: manual ball valve, high-pressure regulator (50psi output), normally closed solenoid, low-pressure regulator (6psi output), and pressure gauge. In the case of the packaged gas fuel cabinet, the pressure gauge is installed to measure and display cylinder pressure. Since the HSM has its own pressure gauge at cylinder pressure, the hydrogen control module has the pressure gauge installed to measure and display final output pressure to the fuel cells.





As previously described, 20% of the HSM-only sites will be retrofits to existing sites, and will have their existing packaged gas cabinets removed. For these sites, the hydrogen control components will be recovered and installed in a field-built hydrogen control module.

E. HSM Cylinder Re-certification

The HSM requires only minimal maintenance. Inspections are a routine element of the refueling operation. Each time the system is refueled, the delivery operator will inspect the system for leaks. Since the cylinders are not exchanged, and the individual cylinder connections are not disturbed, the likelihood of leaks developing is small.

In packaged gas scenarios, the gas company typically rents or leases the cylinders to the end-user, and maintains ownership of the cylinders. Therefore, the gas company is the responsible party for periodic recertification of the cylinder as a pressure vessel. When ownership is by the end-user, recertification is a maintenance consideration. U.S. DOT requires that cylinders undergo periodic testing or inspection. The specific requirements are defined in 49CFR§180. The particular size of cylinders used in the HSM, and their configuration in a fixed-manifold system, requires that they be hydrostatically tested every 5 years. Inspection requires field-disassembly of the HSM, exchanging inspected cylinders for the cylinders due for inspection, re-assembly, and leak-check. Cylinder inspection itself is less than $20 per cylinder, so the majority of cost is the labor to dis-assemble, re-assemble, and leak-check, and the transportation from the site to the certified testing house. Based on shipping costs of an effectively packed truck, and estimates of 8 hours labor (2 persons for 4 hours) at a burdened rate of $75, we estimate the recertification costs to be less than $1,500 per HSM, borne every 5 years. It is anticipated that a seed-stock of either new or newly inspected cylinders would be planned so that a site is visited once and the cylinders are exchanged, rather than servicing a site by removing its cylinders, testing them, and then reinstalling.

Complete exchange and swap-out of the HSM as an assembly was considered and rejected, based on the heavy lifting requirements and subsequent rental and access permissions necessary to execute a complete "forklift" exchange.

IV. TRUCK DEVELOPMENT

Bulk delivery of hydrogen is a common industry practice. Industries such as petroleum processing, metal treatment, food oil processing (hydrogenation), power generation (turbine cooling) and semiconductor manufacturing use hydrogen as a process gas. Hydrogen is delivered either as compressed gas, or as a liquid. These end-users are typically located in industrial areas, with access for large vehicles, and closely monitored facilities. Serving wireless cell sites with bulk delivery requires adapting the delivery infrastructure to meet the characteristics of a cell site: unattended, smaller access routes, and urban, suburban, rural, and remote locations.

The wider deployment of fuel cells with refillable storage has stimulated the evolution of delivery trucks to serve this emerging market. The first evolution phase adapts existing trucks with capabilities to reach the HSM. The smallest existing hydrogen trailer is a “mini-tube” trailer.

This type of trailer consists of numerous steel tubes plumbed to a common manifold. To facilitate access to the HSM, trailers in the local markets are being retrofitted with extended hoses with a quick-disconnect fitting that mates with the HSM. With this new hose, the trailer can be up to 75 feet away and still service the site. Even with 75 ft. service distance, certain sites may not be appropriate for this trailer. The trailer and towing rig may weigh up to 65,000lbs, making access on soft roads challenging. The articulated trailer makes navigating narrow or winding roads difficult. Another solution is desirable to expand access to a greater population of candidate sites. A model similar to conventional propane delivery is an attractive approach: a single, light-weight chassis truck.

A small fleet of single-chassis "short trucks" is in development to reach this new market for bulk refueling. To reduce the gross vehicle weight (GVW), composite cylinders are being deployed. Though rejected for this project as too expensive for the refillable ground storage, they are ideal for mobile applications because of their light weight and higher pressure. Light weight reduces the GVW of the vehicle, resulting in better fuel economy and lower operating costs. Higher pressure means a greater percentage of fuel can be offloaded, since transfill operations rely on pressure-equalization. A higher pressure delivery vehicle filling a lower pressure receiving vessel can deliver more of its payload. When installed on a single non-articulated chassis, the new vehicle has the added benefit of physically being able to access previously challenging sites with soft roads or narrow, winding access.

B. 3rd Party Service

Another delivery option being evaluated would introduce the capability of third party service providers to deliver hydrogen fuel for the "last mile". Variations on this option include trailers, truck-mounted modules, and dedicated trucks. Trailers have already been developed for "last mile" by numerous composite cylinder manufacturers, and deployment would only require acquisition and retrofitting with a compatible hose and fitting. However, existing trailer designs are "ball-hitch" type, and some sites are not well-suited to an articulated trailer with a low hitch due to ground clearance issues. These trailers could be modified to be "fifth wheel" mounted, providing greater clearance, though they still retain the challenges of being an articulated vehicle, and furthermore require a tow vehicle with a "fifth wheel" hitch in the bed. Non-trailer options under investigation include a storage module that is either permanently installed on a "short truck", or is temporarily fixed to a flat-bed chassis when required for fuel delivery. This allows the truck chassis to be used for other services when fuel delivery is not required. Since these systems are for backup, with 72 hours of runtime on site, they may only require fueling 1-3 times per year. This makes the justification for a dedicated truck challenging unless the truck can serve a large enough population of sites to keep it relatively well-utilized. The value of this implementation is that the chassis is available for services beyond hydrogen fueling. In early stages of deployment, particularly in backup applications, hydrogen is needed when it's needed, but when all is full and well, the module can be removed and stored separately, allowing the rolling chassis to be deployed for other operations/services.

C. Business Model

A third party is an ideal candidate when they already are a service provider to the carrier. As such, hydrogen refueling services are an incremental addition to an existing business model, rather than a new model that must be self-sustaining in and of itself. The justification to develop and purchase a hydrogen delivery vehicle depends on the financial and operational requirements of the stakeholders, and is an important factor since a short truck with composite cylinders may cost $300,000 or more, depending on capacity and features. Three business models for acquisition of the vehicle for third party refueling of cell sites are considered here; the service provider, the carrier (end-user), and the fuel cell company or companies.

3rd Party acquires vehicle

For a third-party to justify purchase of the vehicle, they must recoup their costs in service over their business's required ROI period (depreciation of asset). This is highly dependent on the particular service agreement they have with their end-customer, the owner of the fuel cell. One service model provides for a fixed revenue stream to the service provider, in exchange for guaranteed service. This model may well justify the investment, particularly since there is likely a long-term commitment between the carrier and the service provider. An alternative service model is on a call-by-call basis, with service delivered on request. This is harder to justify, as the revenue stream to the service provider is intermittent and unpredictable, and there is no long-term commitment. This can be mitigated if the third party can negotiate with multiple carriers to provide hydrogen refueling. In some cases, the third party may have the opportunity to serve as a "last mile" provider directly for the gas supplier, expanding the gas supplier's ability to serve their customers, and opening up opportunities for the service provider beyond their historical customer base.

Carrier acquires vehicle

Since the carrier, particularly in the early stages of deployment, is the sole consumer of hydrogen, they may choose to invest in a vehicle to ensure they have supply under adverse conditions that may not be optimally served by the gas company. The carrier therefore may choose to invest to reduce the risk of fuel supply. In this model, the carrier's chosen third party service provider, more likely than the carrier themselves, would be the operator of the vehicle. This is of benefit to the carrier, as they are guaranteed access to the vehicle, and is of benefit to the service provider, as it reduces their investment.

Fuel Cell Company (or Companies) Acquire the Vehicle

A model in which the fuel cell company (or a partnership of companies) acquires the vehicle has been discussed in some circles. The justification is that the fuel cells require hydrogen, and therefore the fuel cell companies should facilitate fueling to expand the market. Further analysis shows the fallacy in this logic. Market pressures continue to drive prices down, forcing manufacturers to identify ways to reduce cost. Taking what small margins do exist and investing them not in further development of product but in fueling infrastructure would be akin to an automobile manufacturer getting into the petroleum business. Just as the automotive industry collaborates with the petroleum industry to a certain extent, the fuel cell companies are working with various gas providers to develop stronger fueling infrastructure, and have been particularly influential in the gas industry's progress in developing hydrogen storage modules and last mile refueling options.

V. Operational Deployment

A. *First Fill and Commissioning*

The operational deployment of the refueling model requires coordinated planning to get the most leverage out of the available resources. The initial fill is considered part of the installation and commissioning, and therefore must coordinate fueling and installation. Where hybrid systems (HSM with packaged gas) are installed, the systems can be installed and fully commissioned with packaged gas. The benefit is that multiple sites can be brought online and checked, and then the HSM can be filled at a later date. This allows full utilization of a fueling truck, which may be able to service 4-6 sites on one load. Where the HSM is the only fuel source, the site must be fully fueled to complete commissioning; this simply means that the fueling truck must be scheduled to service sites after installation, but prior to commissioning. This will take close coordination between installers, the gas company, and commissioning of the site (which may or may not be coincident with the completion of construction/installation).

B. *Subsequent Refills*

Once commissioned, sites will have at least 72 hours of runtime, depending on real-world loads and operating conditions. Most sites are expected to experience multiple short outages rather than one long outage. These multiple short outages, in addition to the normal self-exercise function of many fuel cells, will slowly consume the fuel, reducing the runtime capacity. The carrier must determine the minimum acceptable backup runtime available and schedule refueling accordingly. This may be managed in-house, where the carrier monitors the system and notifies the gas company for service.

The fuel cell systems typically monitor fuel pressure as a standard function. ReliOn's systems can be user-provisioned to notify on two different pressure levels. Notification is by either a dry contact closure, or by SNMP. In some instances the gas company has the capability to monitor the fuel level, allowing them to respond without intervention by the end-user. This is a typical industrial gas end-user model, and is an option for the carrier depending on the carrier's service contract with the gas provider.

Regardless of the method of notification, the optimal use of the refueling vehicle will involve coordinating multiple deliveries from a single truck deployment, similar to initial fills. This may warrant servicing sites that haven't reached a low fuel notification, yet can be topped off.

VI. Path Forward

The program started in September 2009, with the early phases focused on developing an overall project plan, site surveys and identification, and site acquisition. Construction began in Winter 2010, and entering the spring of 2010, site selection has been completed on 180 sites, with 8 sites having been constructed and fully commissioned. A total of 510 sites will be completed over the next two years, involving two carriers and two fuel cell companies, with support from a gas company. The sites are in clusters across the continental U.S., ranging from cold northern to hot southern latitudes.

Fueling trucks are being modified to service these sites. Five existing mini-tube trailers already have or will be modified with hoses, and straight trucks are under construction and will be deployed in the fourth quarter of 2010.

The "market transformation" objective of the U.S. DOE program is being met with a wide deployment of multiple vendors' fuel cells, across multiple carriers, in multiple regions across the continent, and with a new fueling model.

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