Procurement and Application of Hydrogen Storage Technologies



Hydrogen Transport Trailer

Prepared for the

U.S. Department of Energy Office of Electricity Delivery and Energy Reliability

Under Cooperative Agreement No. DE-EE0003507 Hawai'i Energy Sustainability Program

Subtask 3.3: Hydrogen

Submitted by

Hawai'i Natural Energy Institute School of Ocean and Earth Science and Technology University of Hawai'i

September 2014

Acknowledgement: This material is based upon work supported by the United States Department of Energy under Cooperative Agreement Number DE-EE0003507.

Disclaimer: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference here in to any specific commercial product, process, or service by tradename, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Table of Contents

| Section Title | Page # | | |
|--|--------|--|--|
| 1. Introduction | 1 | | |
| 2. Description | 1 | | |
| 2.1 General | 1 | | |
| 2.2 Specifications | 2 | | |
| 2.3 Approvals | 2 | | |
| 2.4 Major Components | 3 | | |
| 2.5 Pictures | 16 | | |
| 3. Commissioning | 17 | | |
| 3.1 Ownership, Registration & Licensing, Insurance | 18 | | |
| 3.2 Purging | 18 | | |
| 4. State & Federal Regulations | 20 | | |
| 4.1 State of Hawaii | 20 | | |
| 4.2 Federal Hazardous Materials Regulations | 20 | | |
| 4.3 Drivers License Requirements | 20 | | |
| 4.4 Insurance Requirements | 21 | | |
| 4.5 HazMat Training | 21 | | |
| 5. Operations | 22 | | |
| 5.1 Transporting the HTT | 22 | | |
| 5.2 Bill of Lading | 22 | | |

List of Figures and Tables

| Figure Number and Title | <u>Page</u> # |
|---|---------------|
| Figure 1: MCBH Hydrogen Station & GM Equinox FCEV | 1 |
| Figure 2: Hydrogen Transport Trailer | 1 |
| Figure 3: Trailer Deck | 3 |
| Figure 4: Structural Frame with Cylinders Mounted | 4 |
| Figure 5: Structural Frame – FEA Analysis | 5 |
| Figure 6: Dynetek (Luxfer) Type 3 Cylinder Design | 5 |
| Figure 7: Bracket Neck Mounts – Sliding (left), Fixed (right) | 6 |
| Figure 8: End Plug Block with PRD and Vent Line Attached | 7 |
| Figure 9: Manual Valve with Integrated PRD | 7 |
| Figure 10: Thermally Activated PRD | 8 |
| Figure 11: Hydrogen Gas Receptacle | 8 |
| Figure 12: Hydrogen Gas Receptacle Location in Control Panel | 9 |
| Figure 13: Inlet/Outlet Assembly | 10 |
| Figure 14: Control Panel Valves and Pressure Gauges for "A" & "B" Banks | 10 |
| Figure 15: PRD Vent Stacks | 11 |
| Figure 16: Safety Relief Valve and Vent Stack | 12 |
| Figure 17: HTT-223 Filling & Defueling System | 12 |
| Figure 18: P&ID Diagram of the Filling Interface Control Panel | 13 |
| Figure 19. Filling Interface Panel Parts List | 13 |
| Figure 20: Schofield Filling Control Panel | 14 |
| Figure 21: P&ID Diagram of the Defueling Interface Control Panel | 14 |
| Figure 22. Defueling Interface Panel Parts List | 15 |
| Figure 23: MCBH Defueling Control Panel | 15 |
| Figure 24: Example of Bill of Lading | 23 |

Table Number and Title

| Table 1: HTT-233 Specifications | 3 |
|---|---|
| Table 2: Dynetec (Luxfer) Cylinder Specifications | 6 |

Page _____

1. Introduction

Under funding from the Office of Naval Research (ONR), the Hawai'i Natural Energy Institute (HNEI) is installing 350/700 bar "Fast Fill" hydrogen dispensing systems for fueling General Motors (GM) Equinox fuel cell electric vehicles (FCEVs) at Marine Corps Base Hawaii (MCBH) – see Figure 1. The current electrolyzer produces 12 kg of hydrogen per day. Depending on the operational tempo and number of vehicles being operated, this production rate may not keep up with the demand. The hydrogen supply is being augmented using a hydrogen transport trailer funded by US DOE, delivering hydrogen supplied from other hydrogen production sources. This report presents: (1) the design, (2) commissioning, (3) operational experiences, and (4) lessons learned in providing a mobile hydrogen delivery and storage system.



Figure 1: MCBH Hydrogen Station & GM Equinox FCEV

2. Description

In this section, we present an overview of the trailer design and specifications.

2.1 General

The Hydrogen storage trailer HTT-223 shown in Figure 2, is a transportable storage unit for compressed high pressure gaseous hydrogen. The storage unit is comprised of 16 lightweight carbon fiber composite storage cylinders with a total hydrogen carry capacity of 70 kg at a service pressure of 223 bar (3,234 psi).



Figure 2: Hydrogen Transport Trailer

The cylinders are mounted onto a protective steel frame designed to withstand impacts of 8g in any direction. The frame is constructed of A500 high strength steel tubing and is mounted on a 4,500 kg (9,900 lb) capacity flat-deck utility trailer measuring 2.44 m wide x 6.1 m long (8' x 20'). The trailer is approved to US DOT regulations to transport hydrogen on US public roads. The outer skin of the trailer consists of 3.175 mm (1/8" thick) AA5052 aluminum sheeting to protect the cylinders from the road environment.

The cylinders, manufactured by Dynetek Industries (now Luxfer), have U.S. Department of Transport (DOT) approval with a service life of 15 years. Each cylinder has an internal water volume of 260 liters and requires a hydrostatic retest every 5 years. All the cylinders are equipped with thermally activated pressure relief devices (PRDs) mounted at both ends for fire protection. The PRDs, when activated by high temperature, release the cylinder contents into stainless steel vent manifolds that release the escaping gas into the air from stacks in the roof of the trailer.

The cylinders are connected through a manifold and can be separated into 2 banks of eight cylinders each. Each cylinder is also furnished with its own shut-off valve. These cylinder valves, when closed, isolate each cylinder from the manifold piping, but do not interfere with gas flow through the manifold. Note that if the cylinder valve on any single cylinder or combination of cylinders is left open, the manifold lines will be pressurized to the cylinder pressure(s). The manifold pressure is displayed on the gauges mounted in the control panel. To see an individual cylinder pressure, each cylinder valve can be opened and closed one at a time so as to display the cylinder's pressure on the manifold gauge.

2.2 Specifications

The HTT-233 specifications are provided in Table 1.

2.3 Approvals

The HTT-223 is approved to Federal Department of Transportation (DOT) regulations under a US DOT special permit - DOT-SP13173. In addition, Powertech labs provided a Test Certificate signed and stamped by a Professional Engineer certifying:

- The Hydrogen Transport Trailer is designed for hydrogen use;
- The cylinders used are manufactured by Dynetek Industries (now Luxfer) in accordance with DOT Special Permit 13173;
- A finite element analysis (FEA) was performed on the structural framework to demonstrate the ability of the framework to protect the cylinders from damage due to front, rear, or side impact, and rollover; and
- The FEA report is on file with the US DOT.

| Description | HTT-233 |
|-----------------------------|--|
| Nominal Weight (Empty) | 4,150 kg (9,140 lbs) |
| Nominal Capacity @ 15°C | 70 kg of Hydrogen Gas |
| Dimensions | Length – 6.1 m (20') Width - 2.44 m (8') Height – 2.5 m (8' 3') |
| Operating Temperature Range | -40°C to +85°C |
| Storage cylinders | 16 – "Type 3" carbon composite cylinders Dynetek Model V260TDG233G5N-TC/DOT cylinders 260 litres water volume each |
| Cylinder Service Pressure | 223 bar (3,234 psi) |
| Trailer Capacity (GVW) | 4,500 kg (9,900 lbs) |
| Frame | Steel box tubing |
| Cladding | Aluminum |
| Service Life | 15 years |
| Approval | DOT-SP 13173 |
| Retest | Hydrostatic every 5 years |
| Test Pressure | 5/3 of the marked service pressure (5,390 psi) |

Table 1: HTT-233 Specifications

2.4 Major Components

The following paragraphs describe the major components and systems comprising HTT-223:

2.4.1 Trailer

The trailer shown in Figure 3 is manufactured by Rainbow Trailers and is designed and approved to haul equipment on public roads. This vehicle conforms to all applicable US Federal Motor Vehicle Regulations in effect on the date of manufacture (January 2011).



Figure 3: Trailer Deck

The main features of the trailer, as specified by the manufacturer, include:

- 9,900 lb GVW;
- 4,950 lb spring axles with electric brakes;

- ST 225/75R15D radial tires, spare wheel & tire;
- Stake pockets;
- 5,000 lb drop leg jack;
- 5/16" coupler; and
- 7-prong RV plug with wiring enclosed in poly conduit.

2.4.2 Structural frame

The cylinder-mounting frame assembly shown in Figure 4 safely secures and houses the high-pressure cylinders, components and plumbing. The neck mount brackets used to hold the cylinders are securely mounted to the steel structural frame. The frame is designed to attach to the trailer deck using 8 bolts mounted to the base of the frame. The entire assembly was designed to withstanding acceleration loads of 8g in each of the principal directions. A finite element stress analysis (FEA) was performed on the frame as modeled in Figure 5 to verify these loads. An aluminum skin covers the top and four sides of the frame. The skin is designed to protect the frame and the internal components from most environmental conditions and road debris.



Figure 4: Structural Frame with Cylinders Mounted



Figure 5: Structural Frame – FEA Analysis

2.4.3 Storage Cylinders

The Dynetek cylinders are a "Type 3" pressure vessel design, consisting of a seamless aluminum liner with carbon fiber / epoxy reinforcing over-wrap as shown in Figure 6. They have a service pressure of 223 bar (3,234 psig). The cylinders have a maximum service life of 15 years and require a hydrostatic retest every 5 years per DOT SP-13173.



Figure 6: Dynetek (Luxfer) Type 3 Cylinder Design

The cylinder specifications are provided in Table 2.

| Part Number | W260TDG223G5N |
|---|---------------------------------------|
| Quantity | 16 |
| Nominal Weight | 96 kg each (211.2 lb) |
| Nominal Internal Volume (water content) | 260 liters (9.18 cubic feet) |
| Nominal Capcity@15°C (hydrogen) | 4.27 kg (50.9 scm) |
| Overall Length at Zero Pressure | 2800 mm (110.2 in.) |
| Service Pressure @15 °C | 223 bar (3,234 psi) |
| Operating Temperature Range | -40 °C to +85 °C (-40 °F to +185 °F) |
| Cylinder Certification | DOT SP 13173 |
| Service Life | 15 years from the date of manufacture |
| | |

Table 2: Dynetec (Luxfer) Cylinder Specifications

2.4.4 Mounting Brackets

The aluminum neck mount brackets shown in Figure 7 secure the cylinder and additional components linked to the cylinder to the frame. The lightweight brackets are custom designed to hold the cylinders at one end (Bracket Neck Mount-Fixed) while allowing for cylinder length expansion on the other end (Bracket Neck Mount-Sliding). The brackets are designed to withstand an acceleration of more than 8g in each of the principal directions.



Figure 7: Bracket Neck Mounts – Sliding (left), Fixed (right)

2.4.5 End Plug Block

The End Plug Block mounts directly into the threaded port in each of the 16 cylinders. Each end plug block houses a thermal pressure relief device (PRD). Figure 8 shows an end plug block complete with a PRD attached, along with the PRD vent line.



Figure 8: End Plug Block with PRD and Vent Line Attached

2.4.6 Cylinder Valve

The cylinder valve is shown in Figure 9. This manual valve mounts directly into the cylinder port. The valve can control the flow in and out of the cylinder. A Pressure Relief Device (PRD) is installed into the manual valve.



Figure 9: Manual Valve with Integrated PRD

2.4.7 Pressure Relief Device (PRD)

The thermally activated pressure relief device (PRD) is shown in Figure 10. If temperatures exceed $110^{\circ}C \pm 3$, then the PRD will activate and vent gas out of the cylinder via the PRD vent lines. The vent lines from each end of each bank of 8 cylinders are manifolded together into a single vent stack.



Figure 10: Thermally Activated PRD

2.4.8 Fittings

The fittings utilized in the system are designed and tested for high-pressure hydrogen gas use applications. Installation follows Swagelok specifications and has been completed by trained personnel.

2.4.9 Hydrogen Gas Receptacle

The hydrogen gas receptacle (plug) is of the quick-connect type as shown in Figure 11. The HTT is filled and de-fueled through this receptacle. The receptacle is installed in the control panel (see Figure 12).



Figure 11: Hydrogen Gas Receptacle



Figure 12: Hydrogen Gas Receptacle Location in Control Panel

2.4.10 Tubing

All tubing is made from AISI 316 stainless steel and offers excellent hydrogen gas compatibility and corrosion resistance. Bends are incorporated into specific areas of the tubing to absorb any relative motion of the tubing connections due to thermal expansion, deflection or vibration. For the high pressure system, the tubing is assembled using Swagelok fittings.

2.4.11 Inlet/Outlet Line assembly

The high-pressure line supplies hydrogen gas from the hydrogen gas receptacle to the cylinders. Through this single line, the cylinders can all be filled or de-fueled.

The cylinders can be separated into 2 banks of eight cylinders, each bank with its own manifold (see Figure 13). The 2 banks are isolated by means of the control valves labeled "Bank A" and "Bank B" on the control panel (see Figure 13). Having both control valves open at the same time will cause the pressures in the 2 manifolds to equalize.

Each cylinder is also furnished with its own manual cylinder valve, allowing each cylinder to be isolated from the manifold piping. Note that when a cylinder valve is closed, gas can still flow to and from other cylinders through the manifold attached to the valve.

If any single cylinder or combination of cylinders is left open, the manifold piping will be pressurized to the cylinder pressure(s). The manifold pressure of Bank A and Bank B is displayed on the gauges mounted on the trailer control panel (see Figure 14). To see an individual cylinder pressure, each cylinder valve can be opened and closed one at a time so as to display the cylinder's pressure on the Bank A or Bank B pressure gauge.



Figure 13: Inlet/Outlet Assembly



Figure 14: Control Panel Valves and Pressure Gauges for "A" & "B" Banks

2.4.12 PRD Line Assembly

The PRD vent lines allow escaping gas from all of the temperature activated pressure relief devices to vent to atmosphere through four stacks - two for each bank of cylinders, with one at each end of each cylinder bank (see Figure 15). All PRD vent lines on the valve side of each cylinder set are connected together using two stacks (one for each bank), and all PRD vent lines on the end plug side are connected together using another two stacks (one for each bank). The four (4) vent stacks each have their own ventilation point and vent through a dedicated outlet. The PRD outlet fitting on all stacks has a polyethylene cap to keep moisture from entering the tubing. A drain plug is installed on the bottom of each PRD vent stack for draining in the event that moisture enters the stack.



Figure 15: PRD Vent Stacks

2.4.13 Safety Relief Valve

The safety relief valve shown in Figure 16 is installed to protect the cylinders from overfilling. The valve is a re-closing type set to open at 312.5 bar (4,532 psig). The safety relief valve is connected to a separate vent stack.



Figure 16: Safety Relief Valve and Vent Stack

2.4.14 HTT-223 Filling and Discharging Hydrogen Interface Panels

As illustrated in Figure 17, filling and defueling interface panels are required to fill and defuel the HTT-223. An interface panel is required on the fueling side due to the difference in pressure offered by the fueling station (6,700 psi) to the trailer service pressure (3,234 psi). This difference in pressure also causes the trailer to be designed with alternative fittings to that used on standard 350 Bar refueling systems (SAE 2601). The reason for this is so that they cannot be mistakenly connected. The design of the fueling panel is shown below in Figure 18 and contains a pressure regulator to regulate to the aforementioned pressures, a vent valve for purging the lines (through the station vent system) and a pressure relief valve to relief the pressure if it exceeds maximum allowable pressure of trailer (4,500 psi). The pressure relief valve has a flow rate of 1,800 SCFPM, which is the maximum flow rate through the supply fueling station, and is vented through a separate NFPA 2 compliant pressure relief vent stack. A list of the parts/adaptors is shown in Figure 19. Figure 20 shows the as-built interface panel connected to the supply station, ready to complete a fill of the HTT-223.







Figure 18: P&ID Diagram of the Filling Interface Control Panel

| | | Service Pressure | | | | |
|--------|--|-------------------|----------|---------------------|------|------------------------|
| Item # | Part Description | Rating (PSI) | Material | Part Number | QTY. | Supplier |
| 1 | WEH Recepticle (Filtered - 3/8" Swage Tube End) | 9922.5 | SS | C1-31316 | 1 | WEH |
| 2 | 3/8" Tube 0.083 Wall | 7500 | SS | N/A | N/A | Swagelok |
| 3 | 3/8" Mounting Bracket | N/A | SS | 304-S1-PP-6T | 5 | Swagelok |
| 4 | Ball Valve | 15000 | SS | SS-6FKBFK6 | 2 | Swagelok |
| 5 | Tee - 3/8" Tube with 1/4 NPT | 7500 | SS | SS-600-3TTF | 2 | Swagelok |
| 6 | Pressure Indicator (0-10K PSI) | 10000 | SS | PGI-115P-PG10K-LA01 | 2 | Swagelok |
| 7 | Adaptor 3/8" Swage to 1/2" MNPT | 7500 | SS | SS-600-11-8 | 3 | Swagelok |
| 8 | Pressure Regulator (6700 - 3234 PSI) | 10000 | SS | 26-1063-28-780 | 1 | TESCOM |
| 9 | 3/8" Tube 0.049 wall | 4800 | SS | N/A | N/A | Swagelok |
| 10 | 3/8" Tee | 7500 | SS | SS-SS-600-3 | 2 | Swagelok |
| 11 | Pressure Relief Valve | 14000 | SS | 151101-2150S114 | 1 | Mechanics Fluid Valves |
| 12 | Adaptor Fitting 1/2 MNPT - 3/4 Swage Tube | 5800 | SS | SS-1210-1-12 | 1 | Swagelok |
| 13 | Vent Needle Valve | 6000 | SS | SS-6DBS6 | 1 | Swagelok |
| 14 | 3/4" Tube 0.049 Wall | 700 | SS | N/A | N/A | Swagelok |
| 15 | M UNF 9/16-18 Flare to 3/8" Swage Tube | TBD | SS | TBD | 1 | Parker |
| 16 | Flexible Hose (3 Meter Length - Female 9/16-18 UNF Ends) | 7500 | SS | Text | 1 | WEH |
| 17 | M UNF 9/16-18 Flare to 1/4" MNPT | TBD | SS | TBD | 1 | Parker |
| 18 | Walther Prazision Female Quick Connect to 1/4" FNPT | 7250 | SS | HP-004-0-NP513-01 | 1 | Powertech |
| 19 | Braided Flexible Vent Hose | 1800 (Burst 7200) | SS | SS-FM8SL8SL8-48 | 1 | Swagelok |
| 20 | 3/4" Tee | 5900 | SS | SS-1210-3 | 1 | Swagelok |
| 21 | 3/4" Mounting Bracket | N/A | SS | TBD | 1 | Swagelok |
| 22 | 3/8 to 1/2 swage tube reducing union | 7500 | SS | SS-810-6-6 | 1 | Swagelok |
| 23 | 1/2 Tube 0.035 Wall | 3600 | SS | N/A | N/A | Swagelok |
| 24 | Ball Valve | 5000 | SS | SS-AFSS6 | 1 | Swagelok |
| 25 | 3/4" Mounting Bracket | N/A | SS | 304-S3-PP-12T | 2 | Swagelok |

Figure 19. Filling Interface Panel Parts List



Figure 20: Schofield Filling Control Panel

Connecting the HTT-223 to the MCBH fueling station required the design and build of a complete permanent interface panel. This panel also required interface fittings, breakaways, vent valve with stack, and pressure relief valve with stack. It also required external grounding (lightening protection) along with system Emergency Shut Down (ESD) button and manual pull station fire alarm notification (NFPA 2 requirements). The design of the panel is shown in Figure 21. A parts/adaptor list is shown in Figure 22. The built and installed panel is shown in Figure 23.



Figure 21: P&ID Diagram of the Defueling Interface Control Panel

| | | Service | | | | |
|--------|--|----------|----------|----------------------|------|------------------------|
| | | Pressure | | | | |
| | | Rating | | | | |
| Item # | Part Description | (PSI) | Material | Part Number | QTY. | Supplier |
| 1 | 3/8 Union | 7500 | SS | SS-600-6 | 1 | Swagelok |
| 2 | 3/8" Tube 0.049 wall | 4800 | SS | N/A | N/A | Swagelok |
| 3 | 3/8" Tee | 7500 | SS | SS-SS-600-3 | 2 | Swagelok |
| 4 | Adaptor 3/8" Swage to 1/2" MNPT | 7500 | SS | SS-600-11-8 | 1 | Swagelok |
| 5 | Pressure Relief Valve | 14000 | SS | 151101-2150S114 | 1 | Mechanics Fluid Valves |
| 6 | Adaptor Fitting 1/2 MNPT - 3/4 Swage Tube | 5800 | SS | SS-1210-1-8 | 1 | Swagelok |
| 7 | 3/4 Swage Elbow | 5900 | SS | SS-1200-9 | 1 | Swagelok |
| 8 | 3/4" Tube 0.049 Wall | 700 | SS | N/A | N/A | Swagelok |
| 9 | 3/4" Тее | 5900 | SS | SS-1210-3 | 1 | Swagelok |
| 10 | Tee - 3/8" Tube with 1/4 F NPT | 7500 | SS | SS-600-3TTF | 1 | Swagelok |
| 11 | Pressure Indicator (0-5K PSI) | 5000 | SS | PGI-115P-PG5000-LA01 | 1 | Swagelok |
| 12 | Vent Needle Valve | 6000 | SS | SS-6DBS6 | 1 | Swagelok |
| 13 | Check Valve | 6000 | SS | SS-6C-10 | 1 | Swagelok |
| 14 | Ball Valve | 5000 | SS | SS-AFSS6 | 1 | Swagelok |
| 15 | 3/8" Tube 0.049 wall | 4800 | SS | N/A | N/A | Swagelok |
| 16 | F UNF 9/16-18 Flare to 3/8" Swage Tube | TBD | SS | TBD | 1 | Parker |
| 17 | Breakaway (Male 9/16-18 ends) | 6615 | SS | C1-77227 | 1 | WEH |
| 18 | Flexible Hose (3 Meter Length - Female 9/16-18 UNF Ends) | 7500 | SS | Text | 1 | WEH |
| 19 | M UNF 9/16-18 Flare to 1/4" MNPT | TBD | SS | TBD | 1 | Parker |
| 20 | Walther Prazision Female Quick Connect to 1/4" FNPT | 7250 | SS | HP-004-0-NP513-01 | 1 | Powertech |
| * | 3/8 Supports | N/A | SS | TCB6 | 15 | Swagelok |
| * | 3/4 Supports | N/A | SS | TCB12 | 5 | Swagelok |

Figure 22: Defueling Interface Panel Parts List



Figure 23: MCBH Defueling Control Panel



Trailer Under Construction



Trailer Being Towed by Pickup Truck



Trailer Parked at MCBH Hydrogen Station with Safety Barriers



Trailer Parked at MCBH Hydrogen Station with Safety Barriers

3. Commissioning

In this section, we describe our experience in commissioning the system. It is noted that the HTT-223 is the first hydrogen transport trailer to be registered in Hawaii and there were several entities and issues that needed to be addressed in getting it commissioned and licensed to operate on State roads. These mainly involved educating state officials on the design of the trailer and hydrogen safety. We found state officials to be genuinely interested in the HTT-223 and very helpful in assisting us through the process. Now that they have had this experience it will be much easier for additional trailers to be registered and licensed in the future.

3.1 Ownership, Registration & Licensing, Insurance

3.1.1 Ownership

The HTT-223 is owned by the University of Hawaii.

3.1.2 Registration & Licensing

The trailer was originally licensed in Canada and arrived with Province of British Columbia license plates and registration. The requirement for a vehicle registered out of state is to submit a Motor Vehicle Registration *"Application For Registration of Trailer*" to the state Department of Motor Vehicles (DMV). We were required to submit the previous jurisdiction's last issued certification of registration/title. It is very important to have all the necessary documentation accompany the trailer.

Because the university is a state university, all vehicles owned by the university are considered state government vehicles. Therefore the HTT-223 is registered as a state government vehicle and carries State of Hawaii government tags.

The HTT-223 was required to be weighed at a certified weigh station to certify its Gross Vehicle Weight. This required us to hire a truck and driver with a commercial drivers license (CDL) to haul the HTT-223 to and from the weigh station.

Because this was the first vehicle of this type, the DMV conducted the initial safety inspection. Normally the university's Department of Transportation is authorized to conduct safety inspections. Subsequent annual safety inspections have been performed by the university.

3.1.3 Insurance

The University of Hawaii is self-insured. A Certificate of Self Insurance was issued by the State of Hawaii Department of Commerce and Consumer Affairs Insurance Division. This is required to be carried at all times and is stored on the HTT-223.

3.2 Purging

3.2.1 Initial Nitrogen Purge

The HTT was shipped from the manufacturer with the tanks filled with nitrogen. A sample of the Nitrogen was taken and oxygen was detected indicating a leak occurred during shipment. A loose fitting was found and tightened and then the HTT-223 was purged with medical grade nitrogen. A sample was taken and the test report came back within specification.

3.2.2 Hydrogen Purge and First Fill

The HTT-223 was filled with hydrogen using hydrogen supplied by the Schofield hydrogen station. Three purges were completed in accordance with the first filling requirements in the user manual. A sample of the hydrogen was not taken to ensure that the hydrogen met the SAE J2719 specifications. After filling the MCBH hydrogen station tanks samples were taken and analyzed by Smart Chemistry. The results showed the only non-hydrogen parameter over the SAE J2719 limit was Nitrogen at 5700 ppmv. The SAE J2719 limit is 100 ppmv. The source of the Nitrogen was the HTT-223 which showed

that the initial hydrogen purge was not successful. The lesson learned is to ensure a test sample is taken after a purge or first filling of empty tanks.

While this incident was unfortunate it also serves to highlight and important observation about hydrogen storage in general. There are many components that make up a hydrogen storage system, any one of which can introduce a contaminant. Currently it is very difficult, time-consuming, and expensive to test hydrogen for impurities. There are very few laboratories that have the equipment and trained personnel. In Hawaii there are no labs in the state that can conduct this testing. Samples must be shipped to the mainland. Obtaining a result can take up to a week. While this may be acceptable for a research and demonstration project it will not be acceptable for commercial operations. How can a hydrogen distributor quickly test his hydrogen supply after a delivery to ensure contaminants are not introduced and infect the systems of his customers? One can imagine the liability issues associated with dispensing "bad" hydrogen. One answer is a system that can be installed at the dispenser that can continuously monitor hydrogen purity as it is being dispensed. The development of a quick-response hydrogen contaminant detection system should be a research priority for the US DOE.

4. State & Federal Regulations

Hydrogen is a hazardous material and is strictly regulated by the federal government. In this section, we identify the Federal and State regulations that control the operations of the HTT-223.

4.1 State of Hawaii

The Federal Hazardous Material Transportation Law preempts state and local laws and regulations. See:

http://phmsa.dot.gov/portal/site/PHMSA/menuitem.ebdc7a8a7e39f2e55cf2031050248a0c/?vgnextoid=d047b82aa7

Under the authority of Hawaii Revised Statute HRS 286-202 and per Hawaii Administrative Regulation HAR 19-145 dated December 23, 2013, the State of Hawaii complies with the federal Hazardous Materials Regulations 49 CFR Parts 107, 171-173, 177, 178, and 180. The Director of the State of Hawaii DOT is authorized by section 286-202, Hawaii Revised Statutes to adopt the federal Hazardous Materials Regulations.

4.2 Federal Hazardous Materials Regulations

US DOT Hazardous Materials Regulations means the Hazardous Materials Regulations issued by the Materials Transportation Bureau of the Department of Transportation in Title 49 of the Code of Federal Regulations, Parts 171 through 177 (49 CFR 171-177). US DOT regulations can be found at the following websites:

DOT regulations: http://www.fmcsa.dot.gov/rules-regulations/rules-regulations.htm

Approvals and Permit issuance requirements: http://phmsa.dot.gov/hazmat/regs/sp-a/special-permits

The Codes of Federal Regulations pertaining to hazardous material transportation: http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title49/49cfrv2_02.tpl

Information on how to comply with Federal Hazardous Materials regulations: http://www.fmcsa.dot.gov/safety-security/hazmat/complyhmregs.htm

Information on Federal Hazardous Materials training requirements: http://www.phmsa.dot.gov/hazmat/training/requirements

Federal Motor Carrier requirements: http://www.fmcsa.dot.gov/

Hazmat Registration requirements: http://www.fmcsa.dot.gov/registration

4.3 Drivers License Requirements

Drivers of vehicles transporting hazardous materials requiring placards under subpart "F" of 49 CFR

Part 172 require a Commercial Drivers License (CDL) with a hazardous materials endorsement ("H"). The driver must pass a HazMat knowledge test, show proof of U.S. citizenship or immigration as specified in the Federal Motor Carrier Safety Administration Regulations, 49 CFR 383.71. Finally the driver requires a Transportation Security Administration TSA HazMat Endorsement Threat Assessment.

The project attempted to have one of its O&M contractor personnel obtain the required licenses and endorsements but eventually found it easier to contract a transportation company with the qualified personnel to supply the drivers, tow truck, and insurance coverage.

4.4 Insurance Requirements

The public liability requirement for shipping compressed hydrogen is \$5,000,000.

4.5 HazMat Training

Transporting HazMat materials must be taken seriously. In preparation for HTT-223 operations an onsite HazMat training course was provided on 8 March 2014 by Transportation Training Group ("TDG") for 10 personnel who have an expectation of being involved with the transport of hydrogen with the HTT-223.

TDG highlighted the following points that are important to the transport of hydrogen using the HTT-223:

- 1. Training is required by federal law for any person meeting the definition of a "HazMat Employee". This regulation is found in 49 CFR Part 172, Subpart H. Having a commercial driver's license with a HazMat endorsement is NOT enough to meet this requirement.
- Penalties for honest mistakes have a statutory maximum of \$75,000 per violation. That maximum does not exist if the violation is intentional (i.e. someone decides to ignore a rule). This information is found in Part 107 of 49 CFR. A DOT violation may permanently bar someone from ever obtaining a HazMat endorsement on a CDL.
- 3. The DOT has priorities for various hazardous materials including those that pose a more intense safety and or security (or both) risk. Cylinders of highly flammable Hydrogen Gas would certainly be considered a "risk". So in addition to federally mandated General Awareness Training one must provide DOT Security Training (again, even if the person has a CDL with a HM endorsement) as well as DOT Safety Awareness training.
- 4. The DOT requires that each employee used to load, unload, move, or transport a shipment of hazardous materials must be certified every three years and receive function-specific training in performing their job, as it relates to hazardous materials. This training must have been completed by the 90th day of employment and during that 90-day period they must work under the direct visual supervision of a certified employee.
- 5. Violations can be reported to the DOT on a toll free tip line, so if one ever has a disgruntled employee, or competitor or whatever, they can report you anonymously to the DOT who will automatically perform an audit of your operations.

The training syllabus was as follows:

- 1. DOT General Awareness Training.
- 2. DOT Function Specific Training for Parts 171-177 of 49 CFR.
- 3. Overview and General Introduction to FMCSA regulations and instruction on where to go for more information from both the FMCSA and the State of Hawaii.
- 4. DOT Safety Training.
- 5. DOT Security Awareness Training.
- 6. Exam.

5. Operations

The following paragraphs describe the project's experience in delivering hydrogen with the HTT-223.

5.1 Transporting the HTT-223

The project originally planned to use the internal resources of its O&M contractor to provide a driver to tow the HTT-223 from Schofield or JBPH-Hickam to MCBH at KBay. After several months of trying to obtain a Commercial Drivers License with the appropriate endorsements with no success it was decided to employ a commercial trucking firm with experience in transporting HazMat fuels such as gasoline, to take on the task of handling the transport of the HTT-223. This proved to be the correct decision and worked well. The transport firm was issued a Tasking Notice 72 hours in advance. They provided the driver, truck and carried all the appropriate insurances and certification. Most importantly this is their business so they had the relevant experience.

5.2 Bill of Lading

Figure 24 is an example of the Bill of Lading required to transfer responsibility for the shipment from the supplier to the transport carrier.

| SES | | | Select Engineering Services (SES) 1544 Woodland Park Dr. Suite 310 Layton UT 84041 (801) 399-1858 | | |
|---|-----------------------------|--|--|--|--|
| Select Linguteerin | ig service | 3 (| Fax: (801) 399-1863 | | |
| | | BILL OF LADIN | NG | | |
| Ship from: HNEI Hydrogen Station 1 st Street & C Street Bldg, 6169 Morine Come Base Haumii | | | | | |
| Ship to: | TAR Scho 1976 Wahi | DEC Hydrogen Station field Barracks East Range; Build Higgins Road awa, HI. 96786 | ing 6042X | | |
| HAZARDOUS M | LATERL | <u>NL</u> | | | |
| Proper Shipping 1 | Name: | Hydrogen, Compressed | | | |
| Hazard Class: | | 2.1 | | | |
| UN Number: | | 1049 | | | |
| Packing Group: | | Not applicable (gas) | | | |
| Qty: | | 16 | | | |
| Type: | | Cylinder | | | |
| Weight: | |) kilograms | | | |
| Shipper Signature | Date: | | | | |
| This is to certify t | hat the ab | ove named materials are properly | y classified, packaged, marked, and | | |
| labeled, and are i | n proper o | condition for transportation acco | rding to the applicable regulations | | |
| of the DOT. | | | | | |
| Carrier Signature | Date: | | | | |
| Carrier acknowle response informa | dges receition was n | pt of packages and required plac ade available and/or carrier has | cards. Carrier certifies emergency the DOT emergency response | | |
| guiaebook or equ good order, excep | ot as noted | cumentation in the vehicle. Prop | erty aescribed above is received in | | |
| | | D 1 000 540 1000 | | | |
| | | | | | |

Figure 24: Example of Bill of Lading