Best Safety Practices in LH2 Infrastructure and Fueling

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Abstract

Multiple LH2 Infrastructure sites are currently used in the H2 zero emission vehicles (ZEV) fueling including fork-lift trucks, buses, cars and trucks. Best safety practices were developed in order to ensure safe system commissioning and operation. These practices include among others, cryogenic subsystem purging and pressure testing, high pressure gaseous H2 subsystem purging and pressure testing, dispenser pressure testing, and defueling high pressure gaseous tanks with a faulty valve. Advanced monitoring methods are currently being developed which can be used to detect unsafe operation.

1. Introduction

A LH2 infrastructure site's main function is to process low pressure LH2, convert it to high pressure gaseous H2, store it in pressure vessels and distribute it to multiple dispensers which refuel the onboard H2 tanks of the H2 vehicles (cars, buses, trucks). Most of the sites currently in use are operated and monitored remotely. ISO 19880 defines the process and equipment for the H2 supply, H2 storage and H2 processing which include LH2 storage, cryogenic manifolds, cryogenic pump, compressor, high and low pressure vaporizers, high pressure manifold, high pressure gaseous storage and dispenser. Governing standards such as the hydrogen Technologies code (NFPA 2)[1], the flammable and combustible liquids code (NFPA 30)[2] and the International Fire code (IFC)[3] provide requirements for the safe commissioning and operation of such systems. A more comprehensive list of the applied codes and standards were presented in Table 1. Furthermore, best safety practices were developed in order to ensure safe system commissioning and operation. These practices include among others, cryogenic subsystem purging and pressure testing, high pressure gaseous H2 subsystem purging and pressure testing, dispenser pressure testing, and defueling high pressure gaseous tanks with a faulty valve. Advanced monitoring methods are currently being developed which can be used to detect unsafe operation, improve safety and reduce H2 losses across the H2 industry.

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Table 1: List of Codes Standards applied to LH2 Infrastructure Site

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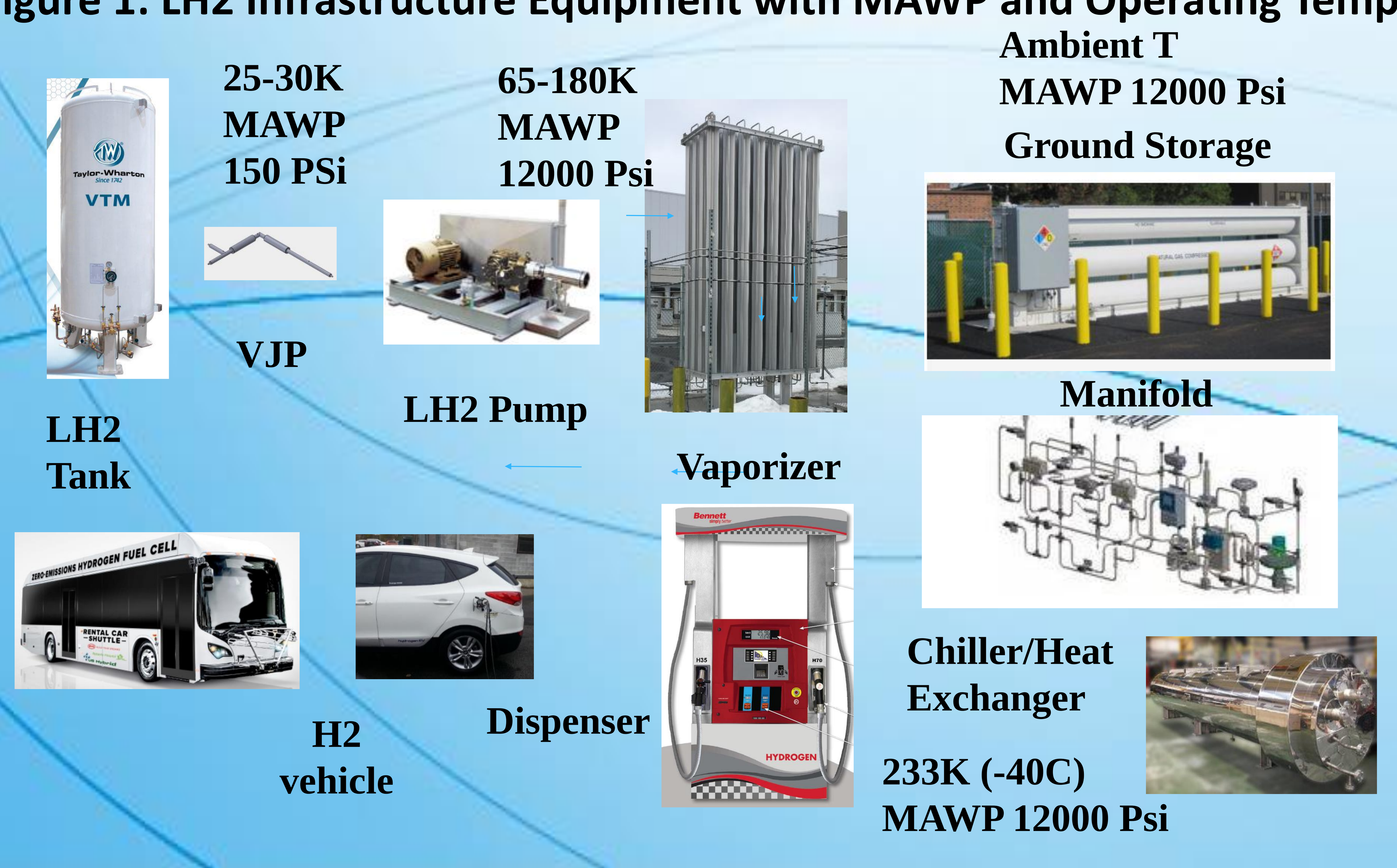
	Standard	Application
1	NFPA 2 Hydrogen Technologies Code	Entire System
2	NFPA 30 Flammable & Combustible Liquids	LH2 Tank
3	CGA H-5 Standard for Bulk H2 Supply Systems	LH2 Tank
4	CGA G-5.5 Vent Systems	Vent Stack
5	ASME B31.3/12	Pressure piping
6	ASME Boiler & Pressure Vessel Code	Ground Storage
7	SAE J2601-1 Fueling Protocol for Light Vehicles	Dispenser
8	SAE J2601-2 Fueling Protocol for Heavy Duty	Dispenser
9	SAE J2600 Compressed H2 Vehicle Refueling	Nozzle
10	NFPA70 Electrical Safety Code	Dispenser
11	IFC International Fire Code	System Siting

Figure 1: LH2 Infrastructure Equipment with MAWP and Operating Temp



2. Best Practices

2.1 Cryogenic Subsystem Purging

The entire subsystem must be purged before the LH2 tank valve is open. If air or N2 is left in the system, solid N2,O2 and ice will form causing blockage resulting in unsafe operating conditions.

When purging, always flow forward and vent downstream. Be aware of check valves and valve positioning. Ensure that the entire subsystem is purged. Purging can be done with either He or H2.

2.2 Cryogenic Subsystem Pressure Test

Testing this subsystem at MAWP and Ambient Temperature is not sufficient.
Most leaks occurred when the system is cold (65-180K).
To ensure the system is leak-free, it must be tested with H2, at MAWP & lowest design temperature

2.3 High Pressure Subsystem Purging

When purging, always flow forward and vent downstream. Be aware of check valves and valve positioning. Ensure that the entire subsystem is purged. Purging can be done with H2.

2.4 High Pressure Subsystem Pressure Test

Be aware of valve positioning and check valves during pressure test.
Most leaks occurred when the ambient temperature drops to its minimum (-40C, depending on location) caused by embrittlement of elastomeric seals of valves, sensors.
To ensure the system is leak-free, it must be tested at MAWP & lowest design temperature

2.5 Dispenser Pressure Test

The H2 delivered to the dispenser is precooled to -40C by the chiller/heat exchanger
Most leaks occurred when the nozzle and elastomeric seals get cold after several fills.
To ensure the system is leak-free, the dispenser must be tested after it reaches thermal steady state by performing multiple sequential fills.

2.6 Defueling a horizontally mounted tank with faulty valve

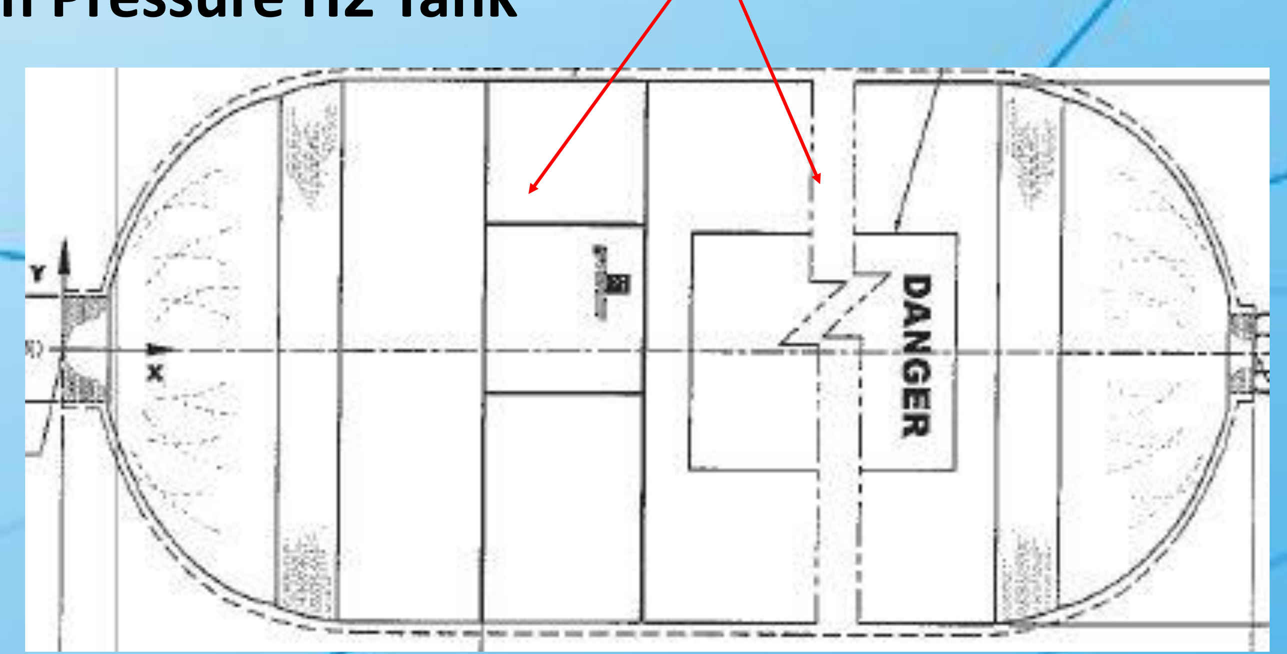
In the case of the tank valve which is stuck closed, the tank needs to be defueled for valve replacement.

Procedure

1. The tank is moved away from ignition source, outdoors if not already
2. The valve is loosened until it starts leaking
3. After an hour the valve and end plug can be removed

1st Lesson learned
Do not conclude that all the H2 is vented.
H2 is still trapped in the space above tank openings
2nd Lesson learned
Avoid ignition sources.
Do not use any source of heating in a tank which may have any amount of H2.
A halogen light bulb will cause detonation of any H2 left in the tank.
If any light is needed to inspect the tank interior surface, select one with LED bulbs.

Figure 2: Dual Port high Pressure H2 Tank



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3. Advanced Monitoring Methods

3.1 Continuous Monitoring of Fueling (CMF)

The digital Twin Model (DTM) uses the LH2 Infrastructure site data and vehicle data to predict the expected fueling histories. These Pressure and mass histories (among other data) are sent to the fueling control system which compares the expected and actual time histories and makes the appropriate decision for safe fueling. If the two graphs deviate, the fueling is paused for troubleshooting. The advantage of this advanced monitoring method is the fact that any leak is detected immediately, and unsafe fueling conditions can be avoided. If the two graphs are is close agreement, as an additional benefit of the CFM is the fact that the required pressure tests per standard can be waived for a faster fill.

Example: Fueling a Toyota Mirai at 875 Bar max pressure

Modeling Results based on several critical LH2 infrastructure site input parameters, i.e. Amount of storage, Storage pressure, ambient temp, etc

Exact Pressure time plot is known from digital twin fluid flow model. Two examples shown, first one with acceptable deviation, second one with a H2 leak at 500 Bar.

3.2 H2 Loss Quantification of LH2 Infrastructure

GE Research is currently developing a H2 Loss Quantification System for H2 Infrastructure sites. Data from an array of H2 detection sensors are used to determine unsafe operation, leak location and H2 loss Quantification.

H2 loss quantification technology uses data from an array of H2 sensors, along with historical 2-species fluid flow modeling results, to specify H2 leak mass flow rates and identify leak locations. Multiple H2 sensors are placed in the hydrogen handling facility at strategic locations. H2 concentration data from these sensors, coupled with ambient condition measurements including temperature, humidity, and wind speed and wind direction from an anemometer, are compared against different modeled scenarios in the database, in order to predict the location and magnitude of the H2 leak.

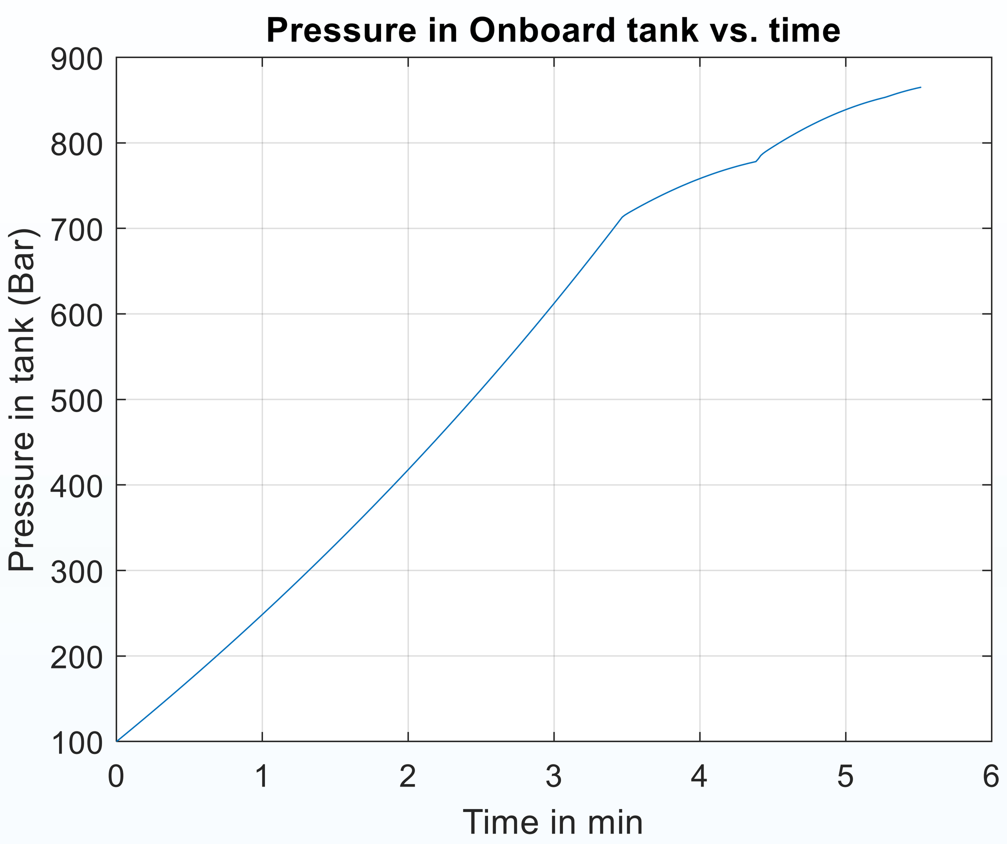

Figure 3: Pressure vs. time (DTM prediction

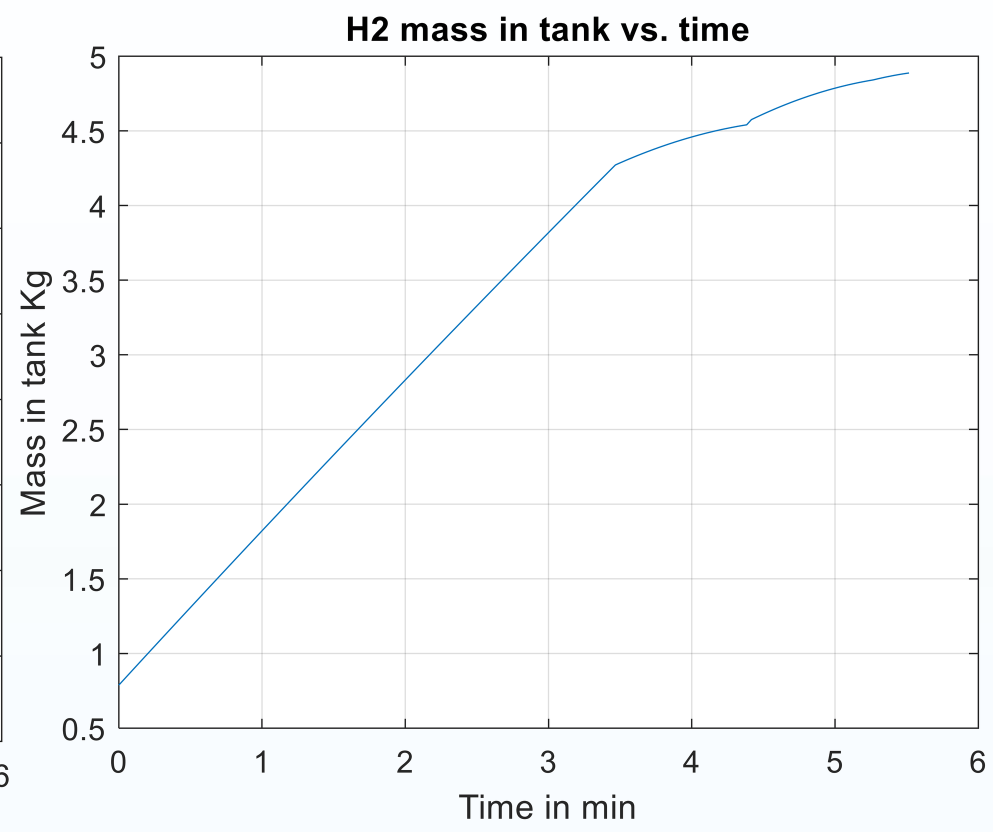

Figure 4: H2 Mass in vehicle tank vs. time (DTM prediction

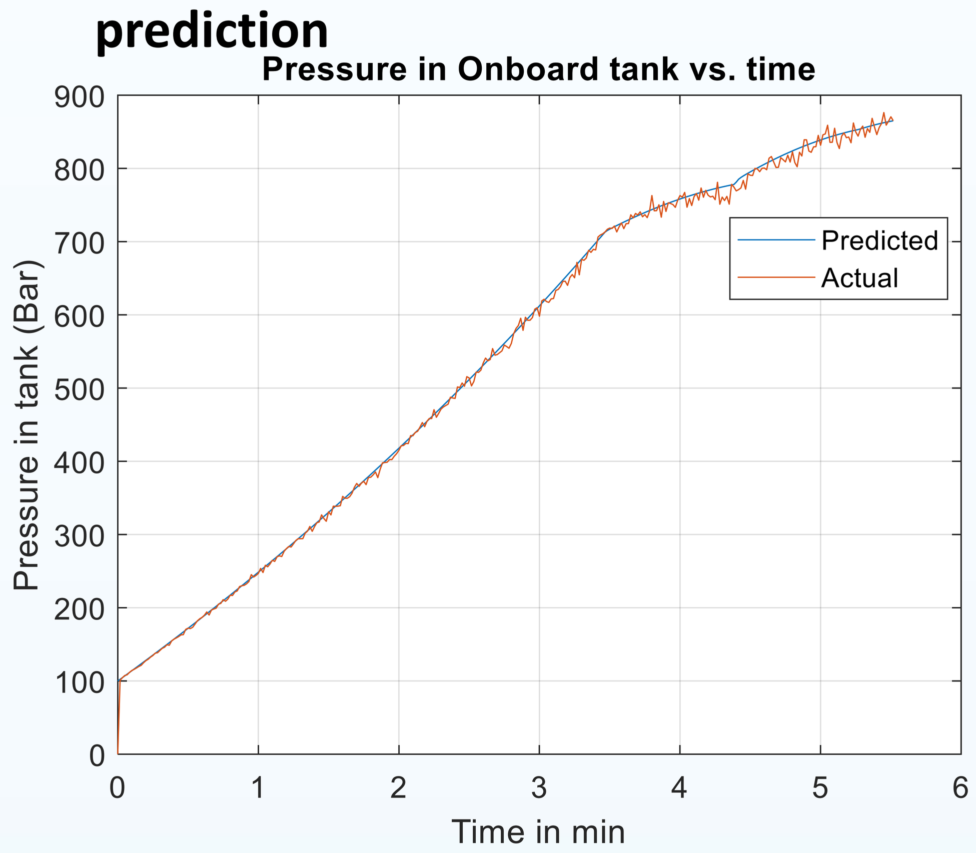

Figure 5: Pressure vs. time (DTM prediction vs. actual) –Acceptable Deviation

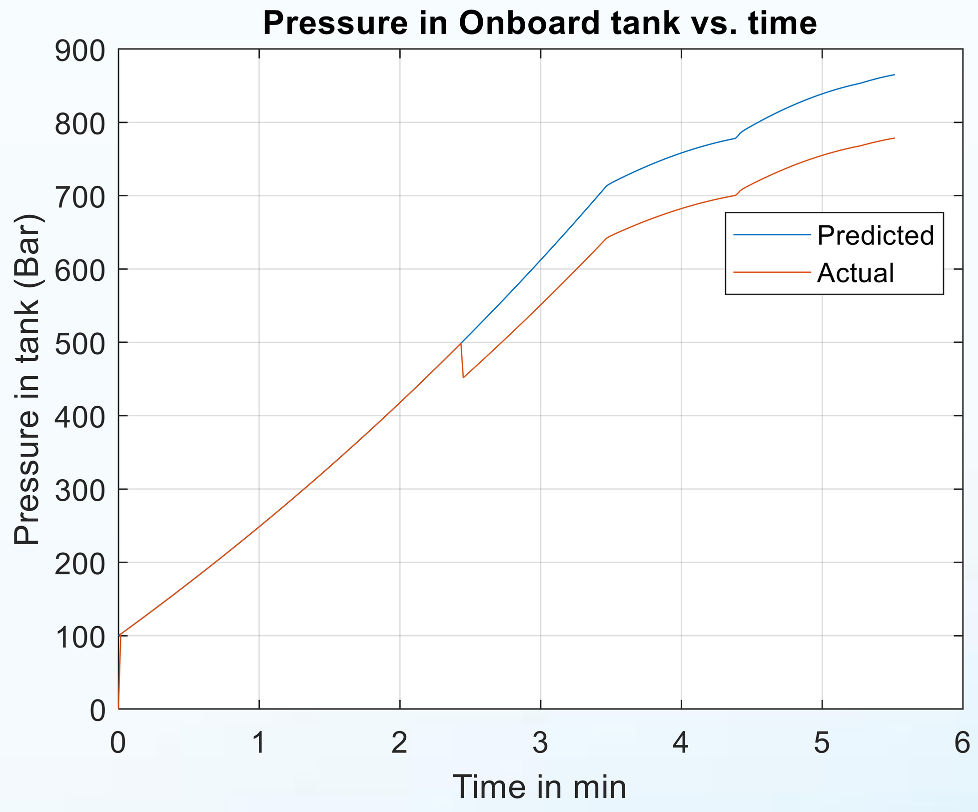

Figure 6: Pressure vs. time (DTM prediction vs. actual) –Leak occurring at 500 Bar

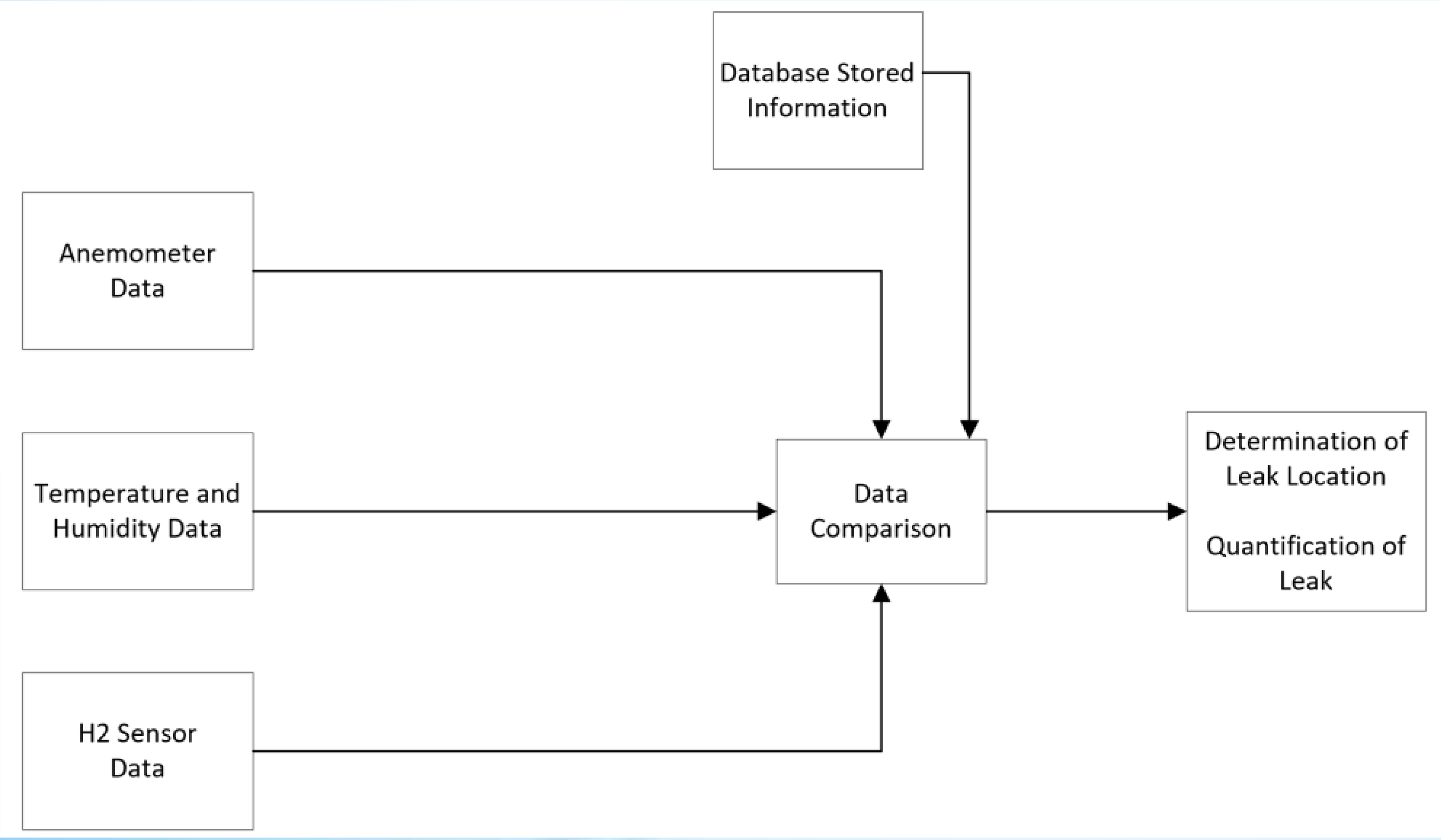

Figure 8: GE Research H2 Loss Quantification Method

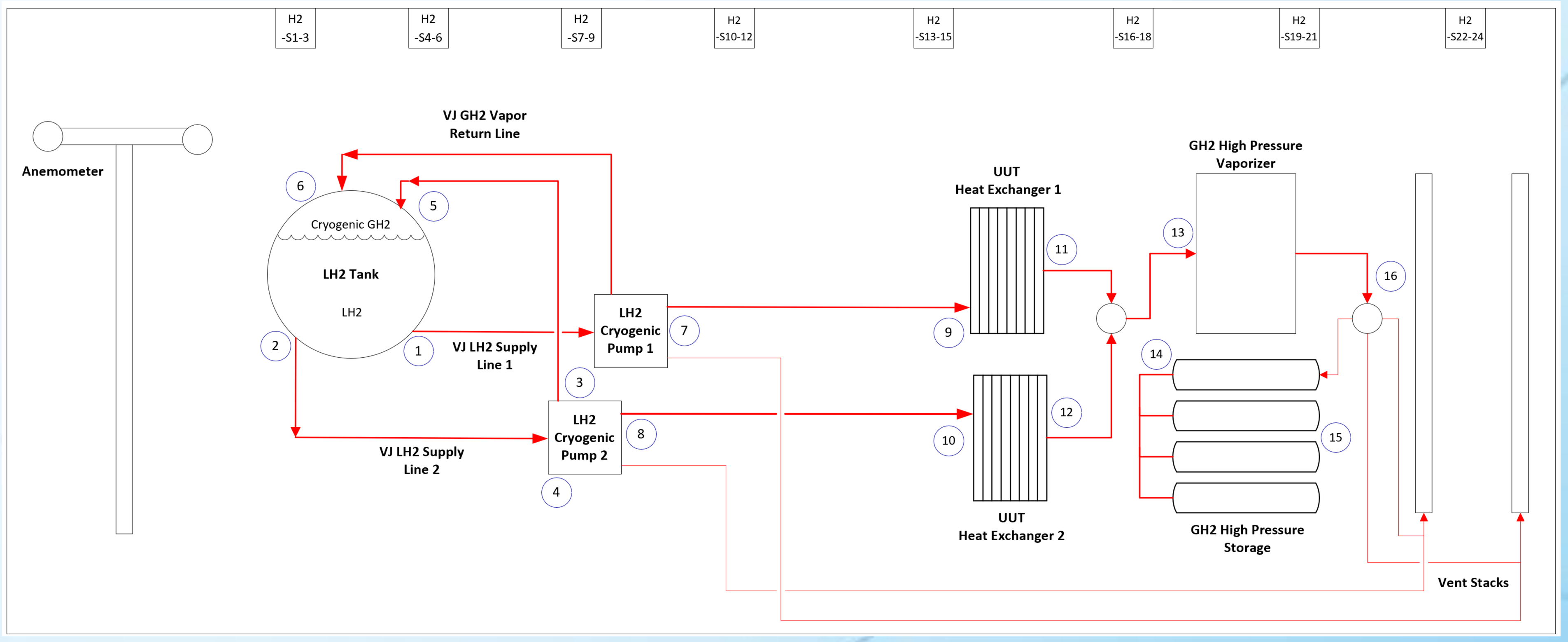

Figure 7:LH2 Testing Facility – Potential Leak locations and Sensor Array location

Summary

Lessons Learned

Cryogenic Subsystem Purging with He, or H2, is critical to avoid contamination and blockage resulting in unsafe operating conditions.

Cryogenic Subsystem Pressure Test must be carried out at cryogenic temperature.

High Pressure Subsystem & Pressure Test must be carried out at -40C, when the seals are cold.

When Defueling a tank be aware of trapped H2. Avoid ignition sources like halogen light.

Advanced Monitoring Methods

Continuous Monitoring of Fueling can detect problems as they occur and interrupt the process.

H2 Sensor network can be used to determine unsafe operation, leak location and H2 loss Quantification