Hydrogen Systems Component Safety

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Abstract

The deployment of hydrogen technologies, particularly the deployment of hydrogen dispensing systems for passenger vehicles requires that hydrogen components perform reliably in environments where they have to meet the following performance parameters:

1. Perform safely where the consumer will be operating the dispensing equipment
2. Dispense hydrogen at volumes comparable to gasoline dispensing stations in timeframes comparable to gasoline stations
3. Deliver a fueling performance that is within the boundaries of consumer tolerance
4. Perform with maintenance/incident frequencies comparable to gasoline dispensing systems

This paper will describe the typical components of a hydrogen dispensing and storage system, describe the hazards associated with these systems and components, describe safety measures currently in place in codes and standards, identify outstanding areas of safety concern, and measures to address the outstanding areas of concern.

The paper will use incident frequency data from NREL's Technology Validation project to more quantitatively identify safety concerns in hydrogen dispensing and storage systems.

1.0 Introduction

This paper describes the analysis of a representative hydrogen fueling system to determine which components present the greatest risk. The system selected would employ both cryogenic storage and a gaseous cascade storage system. This system would provide for the larger hydrogen volume required to support a commercial station operating at comparable vehicle fueling levels to a commercial gasoline station.

Figure 1. Representative Hydrogen Fueling System depicts that type of system that might be deployed at hydrogen fueling stations to supply hydrogen to the hydrogen fuel cell vehicles currently produced.

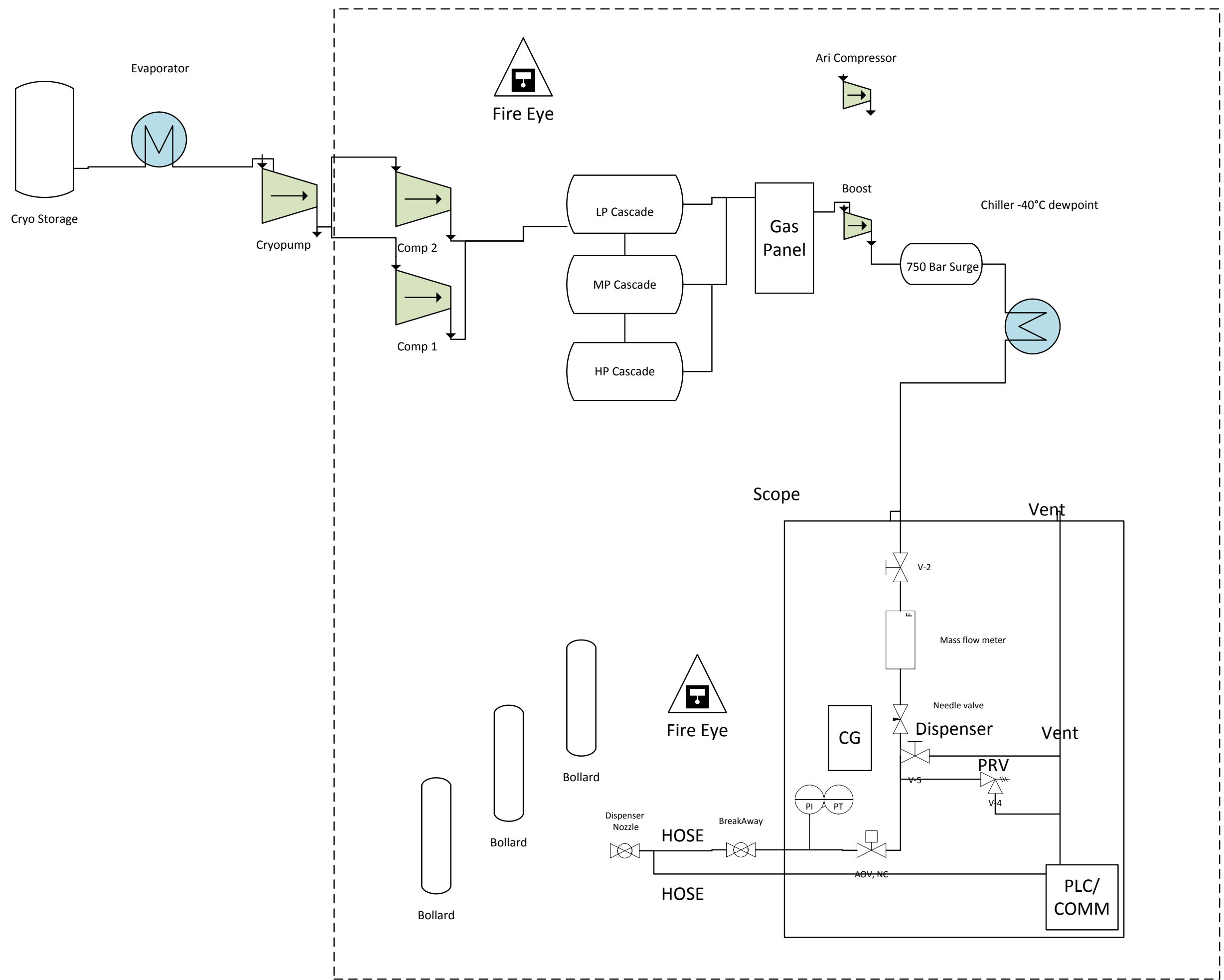

Figure 1. Representative Hydrogen Fueling System

A Process Hazard Analysis (PHA) was conducted on this representative station. The analysis was performed by NREL staff familiar with operating hydrogen fueling stations and component safety and performance issues. In addition to the authors, Dr. Kevin Harrison and Chris Ainscough, P.E. of NREL participated in this analysis. NREL employed PHAWorks®5, a spreadsheet software package designed to perform risk analyses.[1]

The analysis was based on the assumption that the system complied with the requirements of codes and standards typically used in the US. These documents include:

- NFPA 2 Hydrogen Technologies Code
- International Fire Code (IFC) – addresses hydrogen applications
- International Building Code (IBC) – general construction requirements
- ASME B31.12 Hydrogen Pipelines and Piping Code – hydrogen piping design
- ASME Boiler and Pressure Vessel Code (BPV) Section XIII and X Pressure Vessels
- CGA S-1.1-3 Pressure Relief for hydrogen storage systems
- NFPA 70 National Electric Code® (NEC) for classified electrical areas

2.0 Analysis

NREL conducted a PHA on the system shown in Figure 1. Table 1. Risk Value Frequencies shows the preliminary results of the PHA. Figure 2. NREL Risk Matrix and Table 2. NREL Event Probability Classification show the hazard assessment and frequency categories used in the PHA. The system was broken down into the eight nodes shown in Table 1. Undesirable outcomes were identified based on defining variations at nodes. Safety measures were identified for these undesired outcomes. The residual risk was then defined for each undesirable outcome. The residual risk is based on assigning a consequence and probability using the rating system shown in Table 2. The combination of consequence and probability produces a risk rating as determined by the risk matrix.

Node/Parameter	HR	MR	LR	RR	Sum
Node 1 Dispensing Nozzle	0	0	5	1	6
Flow	0	0	5	1	6
Temperature	0	0	0	0	0
Node 2	0	2	3	0	5

Dispensing Hose					
Flow	0	2	3	0	5
Node 3 Dispenser Cabinet	0	0	0	0	0
Flow	0	0	0	0	0
Node 4 Cascade tanks to Dispenser	0	0	2	5	7
Flow	0	0	0	1	1
Temperature	0	0	2	4	6
Node 5 Compression to Cascade Tanks	0	0	7	9	16
Pressure	0	0	7	9	16
Node 6 Cryogenic Storage to Compressors	0	0	0	1	1
Temperature	0	0	0	1	1
Node 7 Air System	0	0	0	5	5
Flow	0	0	0	5	5
Node 8 Control Electronics	0	0	2	4	6
Level	0	0	2	4	6
PROJECT TOTAL	0	2	19	25	46

Table1. Risk Value Frequencies

The PHA used the risk evaluation system shown in Figure 2. NREL Risk Matrix. This matrix integrates event severity and event frequency to produce four categories of risk. These categories are High Risk (HR), Medium Risk (MR), Low Risk (LR), and Routine Risk (RR).

Probability

Consequences	Category	Descriptive Word	A Frequent	B Reasonably Probable	C Occasional	D Remote	E Extremely Remote	F Impossible
	I	Catastrophic						Hose rupture
	II	Critical					Nozzle Leak	
	III	Marginal					Compressor failure	
	IV	Negligible						

High Risk Moderate Risk Low Risk Routine Risk

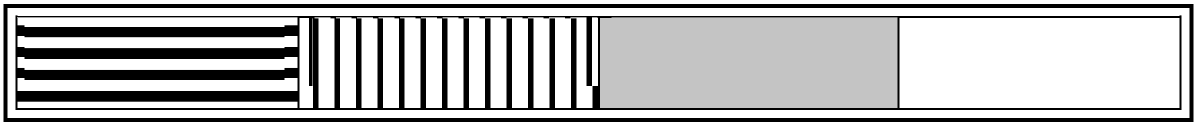

Figure 2. NREL Risk Matrix

Probability (Probability that the potential consequence occurs)		
Level	**Annual Probability**	**Potential Consequences**
A	Frequent > 1.0	Likely to occur many times during the life cycle of the system (test/activity/operation)
B	Reasonably Probable 1.0 to 0.1	Likely to occur several times during the life cycle of the system
C	Occasional 0.01 to 0.1	Likely to occur sometime during the life cycle of the system
D	Remote 0.0001 to 0.01	Not likely to occur in the life cycle of the system, but possible
E	Extremely Remote 0.000001 to 0.0001	Probability of occurrence cannot be distinguished from zero
F	Impossible < 0.000001	Physically impossible to occur

Consequence		
Category	Description (Est. $ Lost)	Potential Consequences
I	Catastrophic (equipment loss > $1,000,000)	May cause death or system loss.
II	Critical ($100,000 to $1,000,000)	May cause severe injury or occupational illness, or minor system damage.
III	Marginal ($10,000 to $100,000)	May cause minor injury or occupational illness, or minor system damage.
IV	Negligible (< $10,000)	Will not result in injury, occupational

		illness, or system damage.

Table 2. NREL Event Probability Classification Table

3.0 Results

The preliminary results shown in Table 1 were weighted on a 1 to 4 system with a High Risk (HR) =4 and Routine Risk (RR) =1 to develop a total relative risk at each node. The results of this process are shown in Table 3. Total Risk at Node

Node	Node Description	HR	MR	LR	RR	Node Total Risk
5	Compressor to Cascade Tank	0	0	7	9	23
2	Hose	0	2	3	0	12
1	Nozzle	0	0	5	1	11
4	Cascade Tanks to Dispenser	0	0	2	5	9
8	Control Electronics	0	0	2	4	8
7	Air System	0	0	0	5	5
6	Cryo Storage to Compressor	0	0	0	1	1
3	Dispenser Cabinet (evaluated under control electronics)	0	0	0	0	0

HR - High Risk
MR - Medium Risk
LR - Low Risk
RR - Routine Risk

Table 3. Total Risk at Node

The results of this analysis shows that three nodes that present the greatest risk are:

1. Compressors

2. Fueling hoses

3. Fueling nozzles

Only fueling hoses had any failure scenarios that, after safety measures were considered, had risks above the low risk level. This result is significant because individuals are directly exposed to fueling hoses during fueling operations.

There are a variety of problems with the fueling system component. These problems generally fall under the heading of unintended releases brought on by both the high pressure and temperature variations that these systems must accommodate. The NREL technology validation data were used to develop frequency ratings for the incidents associated with systems components. [2] The relative ranking shown in Table 3 demonstrates the importance of compressor performance. The NREL data show a relatively high number of leaks in compressors. These leaks often have a significant impact on fueling system performance because they require shutting systems down to repair the compressor.

4.0 Conclusions

The analysis provided a ranking of hydrogen fueling system component risks. This ranking is important in prioritizing safety and performance issues and research required to resolve these issues.

The high level of public exposure for hoses and nozzles makes them of particular concern. The general public will conduct vehicle fueling and handle the fueling nozzle and hose. A failure of either of these components could have severe short and long term impacts.

NREL has developed a component safety analysis plan to determine the causes of the components failures that appear at the top of the priority list and how they might be prevented. The work defined under this plan will commence in 2013 and continue over the next few years. Potential topical areas where action may be taken to reduce risk include:

-Material selection

-Maintenance

-Detection of incipient failures

-System demand

Data collected under NREL's Technology Validation project will continue to be analyzed to determine whether the test plans require modification and to add testing elements as deployment of hydrogen fueling stations progresses. NREL will also evaluate the technology validation data to determine whether component safety performance improves as a result of safety and performance data distributed to industry and other interested parties.

5.0 References

1. PHAWorks®5 software web site http://www.primatech.com/software/phaworks-5

2. NREL Technology Validation Data. http://www.nrel.gov/hydrogen/cdp_topic.html