

Design of Hydrogen Drop-In Fueling Station

Mohammed fawzi^{1*}, Tarek A. Hamad², AL-Hassan M. Azouz³

¹ mohammed.fawzi@omu.edu.ly, ² Tah5xd@mst.edu, ³ alhassan.mohammed@omu.edu.ly

^{1,2} Sustainable and Renewable Energy Engineering Department, Faculty Engineering, Omar Al-Mukhtar University, El-Beida, Libya

³ Mechanical Engineering Department, Faculty Engineering, Omar Al-Mukhtar University, El-Beida, Libya
*Corresponding author email: mohammed.fawzi@omu.edu.ly

ABSTRACT

Many developed countries around the world are currently competing to find low-cost, sustainable and clean energy sources. To replace conventional energy sources such as (oil, coal, etc.) for several reasons. mainly, because of the negative environmental impact of the Greenhouse Gas (GHG) emission problem. Also, these resources will deplete in the near future. As a result, seeking for a better replacement of fossil fuels either by converting to electric vehicles or by using other possible renewable energy sources with low (GHG) emissions is essential. Hydrogen is one of the primary potential future alternatives of current automotive petroleum-related due to its high mass-energy ratio and abundance since it can be obtained from a broad spectrum of sources and by various techniques, such as anaerobic digestion from organic materials, rendering it a prospective target for safe and renewable energy. Hydrogen fuel stations are predicted to have a significant impact on the implementation of hydrogen as a fuel substitution on the worldwide fuel market, especially for heavy transportation. The primary objective of this innovative station branch is not only to promote the idea of hydrogen as fuel on the vehicle fuelling industry, but also to enhance the advancement of hydrogen fuel facilities while minimizing the danger to the investor. There are, though, some areas that need to be investigated with such drop-in facilities as storage and delivery mechanisms which this study covers. The key idea of such a system is to provide a safe, affordable and accessible car fuel source equivalent to conventional vehicle fuel on the industry, whether it is renewable. The primary goal of this research is to develop a secure, flexible and environmentally friendly hydrogen fueling facility.

Keywords: Renewable energy, drop-in hydrogen, fueling station, design

1. Introduction

Hydrogen is widely considered as a clean substitution of energy from a carbon dioxide emission decreasing outlook. If renewable energy can obtain hydrogen, it can create a significant impact on developing a sustainable society. The revolutionary endeavor was to actively implement fuel cell vehicles (FCVs) and hydrogen fuel stations. Hydrogen fueling facilities are essential for the proper functioning of an FCV. Several hydrogen fueling stations have been constructed and running around the world since December 2014 [1]. Sakamoto et al. [2] investigated accidents at hydrogen fuel facilities in Japan and the United States to identify safety risks. Most accidents and events involve leakage of small quantities of hydrogen, but some have had severe implications like explosions. Most of the leakage was related to insufficient momentum and improper sealing of safety in the joint parts. Other factors include an error in the key unit design and human error. Risks involved with two classifications of hydrogen fueling equipment have been identified using study threat identification (HAZID) [3, 4]. The risk assessment was conducted on the assumptions of the

maximum amount of hydrogen released[5]In addition, the rate of hydrogen released from each facility is required for the frequency-based risk assessment [6] Experiments were conducted on the frequency of release of hydrogen and the results were reported[7]. While risk assessments have been conducted for each component, such as pipes and fuel cells, the existing hydrogen fueling station lacks quantitative risk assessments. For example, if at a hydrogen fueling station numerous safety measures simultaneously fail, major accidents could occur. Only a few papers on the linking between functional and/or inoperative hydrogen release procedure. Perhaps one of the earliest articles discussing the hydrogen fueling station concept was Automotive hydrogen fueling systems: an international survey by Jasem Alazemi John Andrews [1] in 2015 discussing the probability and execution of a worldwide drop-in fueling station in each continent and the potential evaluation of difficulties and benefits.

However, the previously mentioned paper laid the foundation for other studies in this category one of the early examples is Low-cost, a transportable hydrogen fueling station for early market adoption of fuel cell electric vehicles by Ian A. Richardson, Jacob T. Fisher, and Patrick E. Frome ... etc.[2] This was the first paper to take into consideration the design of the fueling station.

A paper entitled Development of a drop-in hydrogen fueling station to support the early market construction of hydrogen infrastructure was published in 2016 by [8] exploring the practicality and physicality of the hydrogen fueling station by actually choosing a real site and choosing the necessary equipment from the cascade storage cylinders, valves, fuel cells to t.

One of the latest articles that cross-lines with this study is Evaluation of Safety Measures of a Hydrogen Fueling Station Using Physical Modeling by Junji Sakamoto, Hitoshi Misono and Jo Nakayama... etc[9], which relies more on the safety aspect of developing its new strategy by creating a physical modeling for the fueling station and the security system as well as what is also relevant in it .

The Main objective of this research is to give this relatively new technology a new understanding as well as to design an adaptable and practical hydrogen drop-in fueling station and to assess it from a safety level of perspective that will help this technology feasible for the global market. This research focuses on the use of hydrogen drop-off fueling facility layout with A profound cooling scheme to the primary storage tank with liquid hydrogen. This research will comprise the layout of the facility and the following description will be made of safety evaluation of the layout specifically for the memory segment.

2. Methodology

The methodology of this study is to collect data on the design of such a hydrogen station, after enough information, an enhanced design will be conducted based on these previous data, these main sectors will be included in the new design:

- The first is the storage sector.
- The delivery sector.
- The board of command.

Subsequently, each component will be defined in the design resulting in a better comprehension of the general scheme, providing a helpful insight into the design assessment using Failure Modes and

Effects Analysis (FMEA) method.

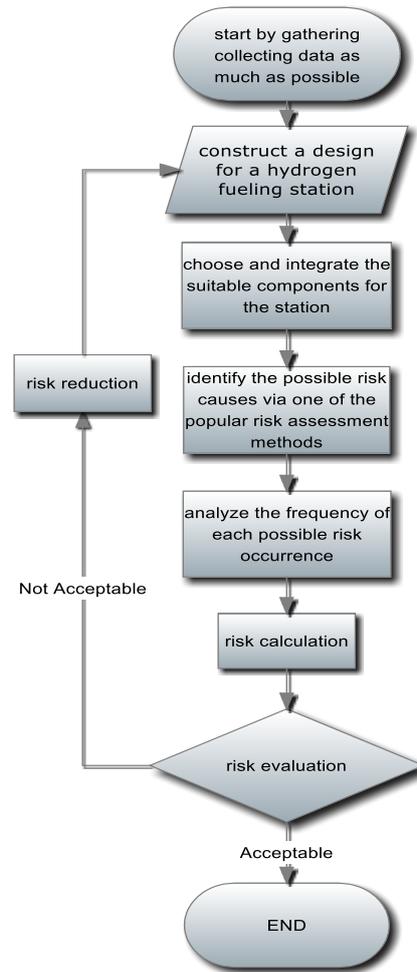


Figure 1. Hydrogen fueling station hazard evaluation scheme.

3. The design

The schematic suggested is grouped into three categories:

- Storage system composed of primary tank liquid hydrogen, 70 mpa high-pressure cascade cylinders, 35 mpa medium-pressure cascade cylinders, and cryogenic cooling unit.
- A delivery sector consisting of a dispenser.
- The monitoring system consists of MCFC, control panel, thermal and pressure sensors, a detector of hydrogen and smoke, ventilation system, CO2 fire extinguisher.

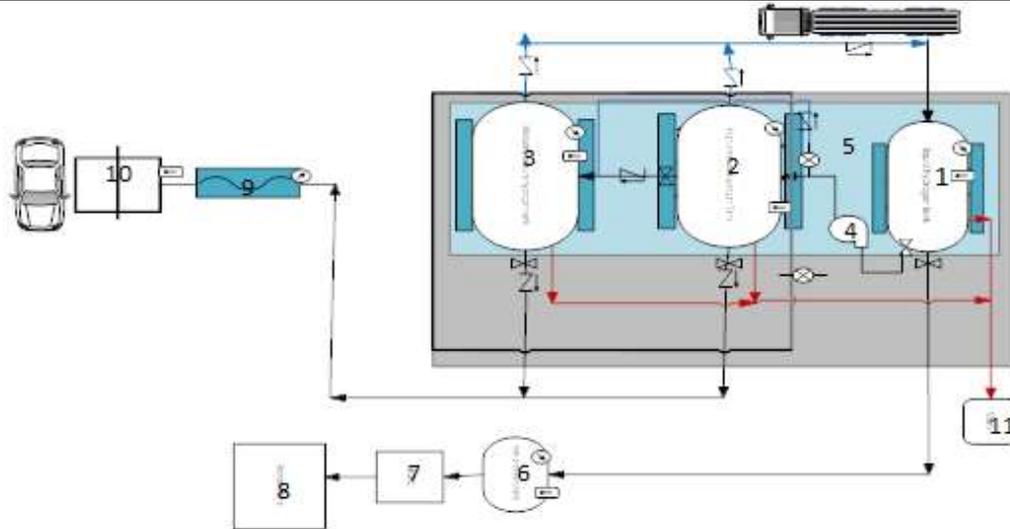


Figure 2.Demonstrates the hydrogen fueling station schematics.

where:

- 1- The main Liquid hydrogen tank storage.
- 2-70 mpa hydrogen cascade storage.
- 3-35 mpa hydrogen cascade storage.
- 4-Cryogenic pump.
- 5-The refrigeration system.
- 6-low pressure hydrogen vessel
- 7-Molten carbonate fuel cell.
- 8-monitoring panel.
- 9-chiller.
- 10-fuel dispenser.
- 11-ventilation.

4. Components used for this design

In this section will describe the Main components for the design:

Table 1: Shows the key parts for the design

Components name	No.pices	Dimensions (L x W x H)	Power input	Temperature working Rang	Maximum allowable working pressure	standard
cryo pump	1	6.1 m x 3.4 m x 4.0 m	45 Kw	-40 °C to +50 °C	100 MPa	SAE
Cryogenic Liquid Hydrogen Storage	1	3m ³ -20000m ³	-	-40 °C to +30 °C	-	ISO
Refrigeration system	1	-	25 Kw	-96 °C to 200 °C	-	ISO
MCFC	1	-	1000 kw	600 c	-	NFPA
Hydrogen Dispenser	1	-	120/240 VAC, 50/60Hz	-40°C to +50°C	75 Mpa	SAE
Detectors (hydrogen and smoke)	4	-	DC 9V	-	-	ISA

5. Cost analysis

The estimated cost is presented in Table 1 that shows in details the main parts and their costs:

Table 1. The estimated cost of the design

The components	Cost in US dollars
Liquid hydrogen tank	20000
<i>cryogenic pump</i>	<i>1000</i>
<i>Cascade storage system</i>	<i>130000</i>
dispenser	90000
MCFC fuell cell	510000

Hydrogen sensors	1520
Smoke detector	100
Thermal sensor	1196
High-pressure sensor	4240
Refrigeration system	16000
total	774,056

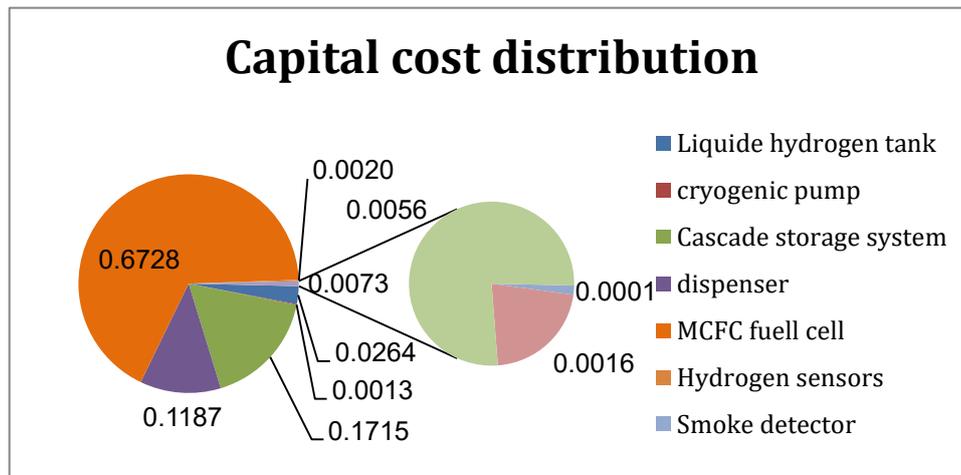


Figure 3. The percentage of the capital cost

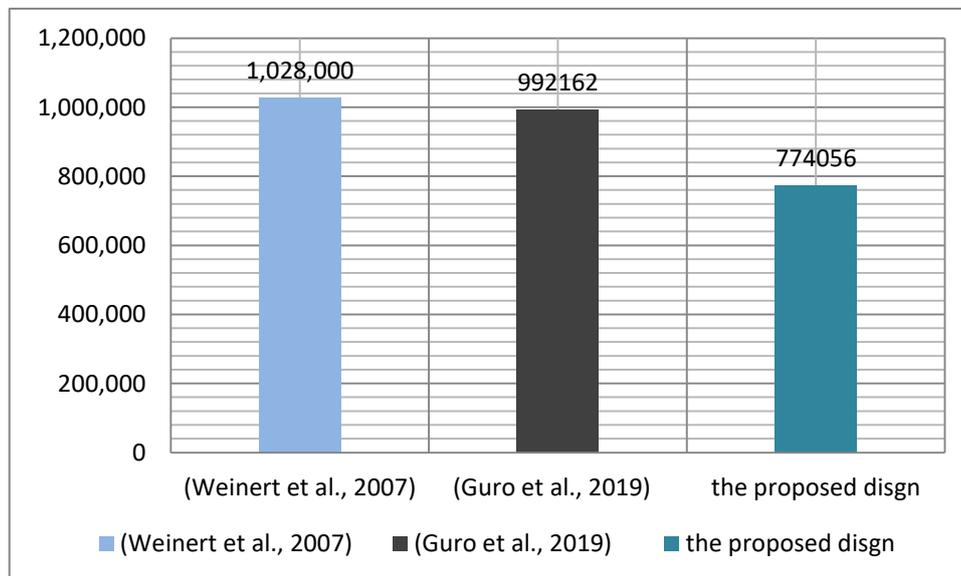


Figure 4. Economical comparison between various designs

Comparing this design with [10] showed a reduction in cost by 24.7% and by comparing it with [11] This design is cost-efficient by 21.9%.

6. The safety assessment

A safety layout needs different code and customary compliance, local regulation and global standards. First of all, constructing the plant must comply with British Standard BS EN 1990:2002. These rules provide the foundation and overall guidelines for organizational layout and inspection, including geotechnical elements, of structures and civil construction operates. ANSI / CSA America FC 1-2004 indicated that the integrated static petrol cell energy scheme had a secure procedure, significant and robust design and satisfactory results (CSA America Inc. 2011). SAE J2600-2002 must comply with the hydrogen refueling station. This norm extended to 35MPa operating stress instruments that are appropriate for our pumping scheme and stop vehicles from being fuelled by inappropriate stress (Automotive Engineers Society 2012). The layout of the pressure vessel complies with the ASME Boiler and Pressure Code (2007). Based on the calculation guideline in the ASME system, the density, manufacturing equipment, form, scope and unite form. In addition, each pressure vessel, compressor and the dispensing pump is placed at the pressure relief valve. Design of flanges and fittings in accordance with ASME B16.1 Cast Iron Pipe Flanges and Flanged Fittings (1998) covering pressure temperature, sizes, manufacturing, minimum material specifications, dimensions, and tolerances. ASME B31.3 Process Piping is used for piping in the factory. This software prescribes content and component requirements, layout, manufacture piping installation, erection, inspection, and testing. ASME B31.12 Hydrogen Piping and Pipelines protocol should be used for hydrogen piping. Specifications such as equipment, welding, brazing, heat treatment, forming, testing, inspection, testing, procedure, and servicing are based on the design rules. The pipeline is buried with steel support 1.5 m from the floor to avoid car rollover from breaking. Stainless steel was chosen as the pipeline building material. The plant also complies with NFPA 70/NEC / CEC to avoid flame accidents, which cover the assembly of electrical drivers, machinery and raceways; signals and information drivers, appliances and raceways; and optical fiber cables and raceways in business, domestic and manufacturing occupations. In addition, NFPA 50 A: Gaseous Hydrogen covers the installation requirements for gaseous hydrogen systems in consumer premises where the supply of hydrogen to consumer premises originates outside the consumer premises and is delivered by mobile equipment. Under the International Fuel Gas Code (International Code Council 2009), the hydrogen dispensing station had designed such as gaseous top storage canopy, underground tanks, liquid hydrogen tanks, separation distances, and barrier walls. Providing adequate data, instruction, and coaching to guarantee employees ' security and health. Equipment such as mask, fire-resistant cloth, a fire extinguisher is supplied in the plant's dangerous region.

Basically, FMEA is conducted to define any feasible mechanical and electrical error depending on the element, failure mode impacts, and finally to suggest safeguards and working provisions that would eliminate the likelihood of incidence. The probability and intensity ranking of HIRARC (DOSH 2008) depending on the risk matrix of the Guideline for Hazard Identification, Risk Assessment and Risk Control, with a minimum rank scale of 1 and a highest rank of 5 as shown in Table 2. The FMEA-based critical security hazard performed in Table 2 a 10-risk Hydrogen dispenser and piping and pump. This is because subterranean hose leakage and control valve inability are prevalent, but the danger is deemed to be average. The other parts are in the low-risk group in the rating spectrum from 1 to 4. Although all probabilities of incidence of error are quite small, the

seriousness of the event is usually assessed at 5. This implies that the occurrence frequency of the 19 incident is very small, but the result may trigger significant industrial accidents and fatalities. Most of the failure's impact will result in inflammable gas leakage that can trigger ball fire and explosion.

Table 2. Failure Mode and Effect Analysis (FMEA)

Component	Failure Mode	Failure Effect	Likelihood	Severity	Rating	Action
Hydrogen Tank storage	Tank rupture, leakage or overfill	Leakage of hydrogen as and may cause explosion and fire	1	5	5	Installation of a pressure safety valve.
Cryogenic Pump	Overpressure	explosion or unit failure	2	2	4	periodic maintenance for the pump and valves
Hydrogen Dispenser	Hose leakage and rupture of the pipe	Leakage of hydrogen gas and may cause explosion and fire	2	5	10	Scheduled inspection and maintenance required
Piping and Valve	Leakage of pipe and failure of valve opening	Leakage of flammable gas and may cause explosion or fire	2	5	10	Scheduled inspection and maintenance required - Installation of gas detection system required
Refrigeration	Rupture, leak or temperature drop	when hydrogen temperature may cause an explosion.	1	5	5	Scheduled inspection and maintenance

7. Conclusions

This study offered a comprehensive overview of the possibility of constructing a hydrogen fueling station as well as a thorough assessment for the possible hazards that might occur and for the economic perspective this design is considered to be cost-efficient compared to other designs by at least 21.9%. also, this design showed promising signs concerning safety procedures and hazard assessment where is scored 6.8 on average out of 25 in the FEMA analysis meaning its fairly safe.

References

- [1] J. Alazemi and J. Andrews, "Automotive hydrogen fuelling stations: An international review," *Renewable and sustainable energy reviews*, vol. 48, pp. 483-499, 2015.
- [2] J. Sakamoto, R. Sato, J. Nakayama, N. Kasai, T. Shibutani, and A. Miyake, "Leakage-type-based analysis of accidents involving hydrogen fueling stations in Japan and USA," *International journal of hydrogen energy*, vol. 41, pp. 21564-21570, 2016.
- [3] J. Mousavi and M. Parvini, "Analyzing effective factors on leakage-induced hydrogen fires," *Journal of Loss Prevention in the Process Industries*, vol. 40, pp. 29-42, 2016.
- [4] J. Nakayama, J. Sakamoto, N. Kasai, T. Shibutani, and A. Miyake, "Risk assessment for a gas and liquid hydrogen fueling station," in *Proceedings of the 49th Annual Loss Prevention Symposium*, 2015.
- [5] K. Sun, X. Pan, Z. Li, and J. Ma, "Risk analysis on mobile hydrogen refueling stations in Shanghai," *International Journal of Hydrogen Energy*, vol. 39, pp. 20411-20419, 2014.
- [6] K. M. Groth and E. S. Hecht, "HyRAM: A methodology and toolkit for quantitative risk assessment of hydrogen systems," *International Journal of Hydrogen Energy*, vol. 42, pp. 7485-7493, 2017.
- [7] T. Tanaka, T. Azuma, J. Evans, P. Cronin, D. Johnson, and R. Cleaver, "Experimental study on hydrogen explosions in a full-scale hydrogen filling station model," *International Journal of Hydrogen Energy*, vol. 32, pp. 2162-2170, 2007.
- [8] A. A. Agil, T. A. Hamad, Y. M. Hamad, S. G. Bapat, and J. W. Sheffield, "Development of design a drop-in hydrogen fueling station to support the early market buildout of hydrogen infrastructure," *international journal of hydrogen energy*, vol. 41, pp. 5284-5295, 2016.
- [9] Y.-L. Liu, J.-Y. Zheng, P. Xu, Y.-Z. Zhao, H.-Y. Bie, H.-G. Chen, *et al.*, "Numerical simulation on the diffusion of hydrogen due to high pressured storage tanks failure," *Journal of Loss Prevention in the Process Industries*, vol. 22, pp. 265-270, 2009.
- [10] J. X. Weinert, L. Shaojun, J. M. Ogden, and M. Jianxin, "Hydrogen refueling station costs in Shanghai," *International Journal of Hydrogen Energy*, vol. 32, pp. 4089-4100, 2007.
- [11] D. Guro, A. Anderson, and W. Swift, "I.I.E.1 Development of a Turnkey Commercial Hydrogen Fueling Station," 08/03 2019.