

Hazard and Economical Evaluation for a Hydrogen Fuel Station

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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 soon. 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 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, this design is regarded to be cost-efficient compared to other designs by at least 48 percent. Furthermore, this design showed encouraging signs concerning safety procedures and hazard evaluation where is ranked 6.8 on average out of 25 in the FMEA review assuring it's safe further.

تقييم المخاطر والتقييم الاقتصادي لمحطة تزويد بغاز الهيدروجين

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ملخص: تتنافس العديد من البلدان المتقدمة حول العالم حالياً على إيجاد مصادر طاقة منخفضة التكلفة ومستدامة ونظيفة لاستبدال مصادر الطاقة التقليدية مثل (النفط، الفحم، إلخ) لعدة أسباب. ويشكل رئيسي، بسبب الأثر البيئي السلبي لمشكلة انبعاث غازات الدفيئة. و أيضاً، بسبب أن هذه الموارد سوف تستنفد في المستقبل القريب. ونتيجة لذلك، من الضروري البحث عن بديل أفضل للوقود الأحفوري إما عن طريق التحويل إلى مركبات كهربائية أو باستخدام مصادر طاقة متجددة أخرى محتملة ذات انبعاثات منخفضة (غازات الدفيئة). الهيدروجين هو أحد البدائل الأساسية المحتملة المستقبلية بسبب نسبة الطاقة العالية والوفرة لأنه يمكن الحصول عليه من عدة مصادر ومن خلال تقنيات مختلفة، مثل الهضم اللاهوائي من المواد العضوية، مما يجعله هدف مستقبلي للطاقة الآمنة والمتجددة. و من المتوقع أن يكون لمحطات وقود الهيدروجين تأثير كبير على تنفيذ الهيدروجين كبديل للوقود في سوق الوقود في جميع أنحاء العالم، وخاصة بالنسبة للنقل الثقيل. الهدف الأساسي لفرع المحطة المبتكر هذا ليس فقط للترويج لفكرة الهيدروجين كوقود في صناعة وقود السيارات، ولكن أيضاً لتعزيز تطوير مرافق وقود الهيدروجين مع تقليل الخطر على المستثمر. على الرغم من ذلك، هناك بعض المجالات التي تحتاج إلى التحقيق فيها مع مرافق التسرب مثل آليات التخزين والتسليم التي تغطيها هذه الدراسة. تتمثل الفكرة الرئيسية لمثل هذا النظام في توفير مصدر وقود سيارات آمن ومنخفض التكلفة ويمكن الوصول إليه و يعادل وقود المركبات التقليدية في الصناعة، سواء كان متجدداً. الهدف الأساسي من هذا البحث هو تطوير منشأة لتزويد وقود الهيدروجين آمنة ومتكيفة مع الظروف وصديقة للبيئة. ويعتبر هذا التصميم فعلاً من حيث التكلفة مقارنةً بالتصميمات الأخرى بنسبة 48 في المائة على الأقل. علاوة على ذلك، أظهر هذا التصميم علامات مشجعة تتعلق بإجراءات السلامة وتقييم المخاطر حيث تم تصنيفها 6.8 في المتوسط من أصل 25 في مراجعة FMEA مما يضمن أنها أكثر أماناً

Keywords: Hydrogen Fuel, Renewable energy, design.

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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 in (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 experiments were conducted on the frequency of release of hydrogen and the results were reported by [6-10]. 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 in [11-13].

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 by Jasem Alazemi John Andrews 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[1].

However, the previously mentioned study laid the foundation for other studies in this category one of the early examples is by Ian A. Richardson, Jacob T. Fisher, and Patrick E. Frome ... etc. This was the first paper to take into consideration the design of the fueling station[2].

A paper was published in 2016 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 ... etc [14].

One of the latest articles that cross-lines with this study was by Junji Sakamoto, Hitoshi Misono and Jo Nakayama ... etc., which relies more on the safety aspect of developing its new strategy by creating physical modeling for the fueling station and the security system as well as what is also relevant in it [15].

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. THE PROPOSED METHOD

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.

2.1. The working principle

The cycle begins after the main storage tank is delivered with hydrogen by the supplying trailer. Afterward, a compressor is distributing the hydrogen to the cascade system in (-40C°) to be ready for dispensing. If something wrong was detected by the monitoring system in the dispensing or the cascade system the hydrogen will be directed back to the main tank. On the other hand, if the main tank was the problem the hydrogen will be vented out to avoid the risk of fire or explosion. However, a small portion of the hydrogen is directed to a small storage tank of 4 m3, for using it as fuel for the PEM fuel cell, to power up the station in case of blackout happened in the main grid to make the station operate suitably. Figure 1 demonstrates the block diagram for the whole system.

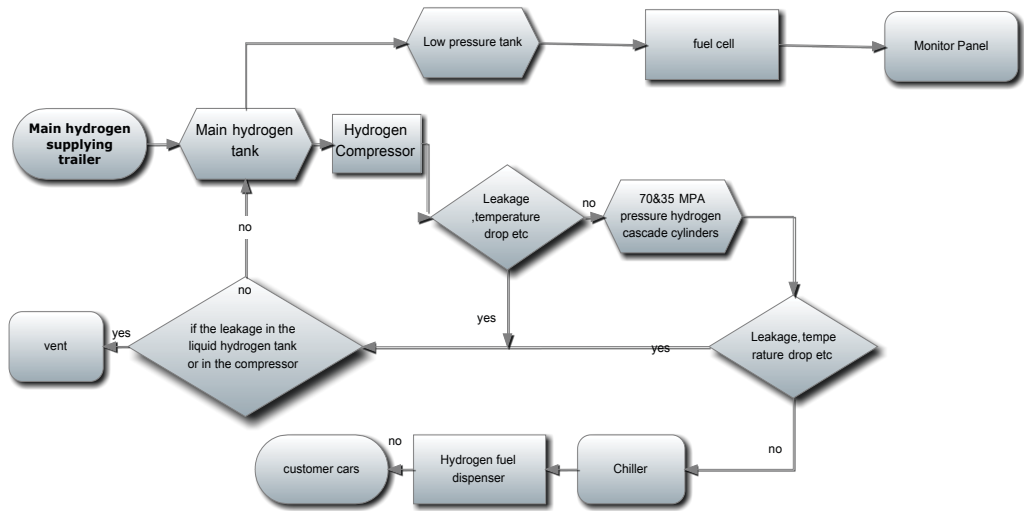


Figure (1). Block diagram shows the hydrogen fueling station.

2.2. The design

The schematic suggested is grouped into three categories:

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

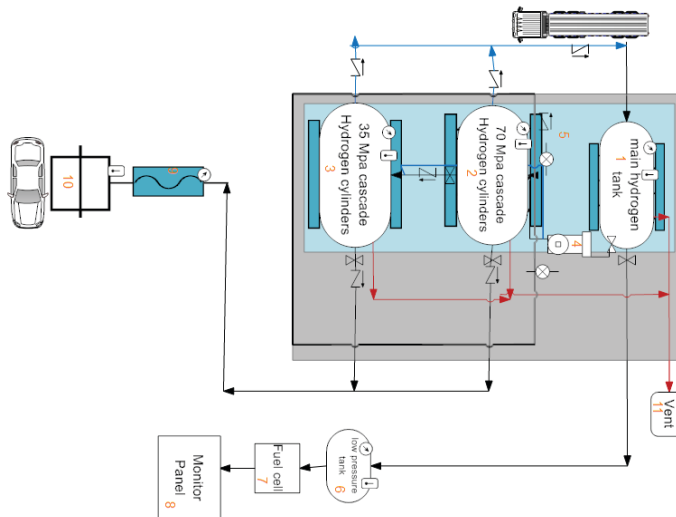


Figure (2). Schematic of the hydrogen fueling station.

Where:

1. The main Liquid hydrogen tank storage.
2. 70 MPa hydrogen cascade storage.
3. 35 MPa hydrogen cascade storage.
4. Hydrogen compressor .
5. The refrigeration system.
6. low-pressure hydrogen vessel
7. Molten carbonate fuel cell.
8. Monitoring panel.
9. Chiller.
10. Fuel dispenser.
11. Ventilation.

2.3. Cost analysis

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

Table (1).The estimated cost of the design

The components	Cost in US dollars
Hydrogen tank	25000[16]
Compressor	35569[17]
Cascade storage system	3600[18]
dispenser	90000[19]
MCFC fuell cell	300000[20]
Hydrogen sensors	270 [21]
Smoke detector	154.6 [22]
Thermal sensor	1196[23]
High-pressure sensor	4240[24]
Refrigeration system	30000[25]
Total	515,029.6

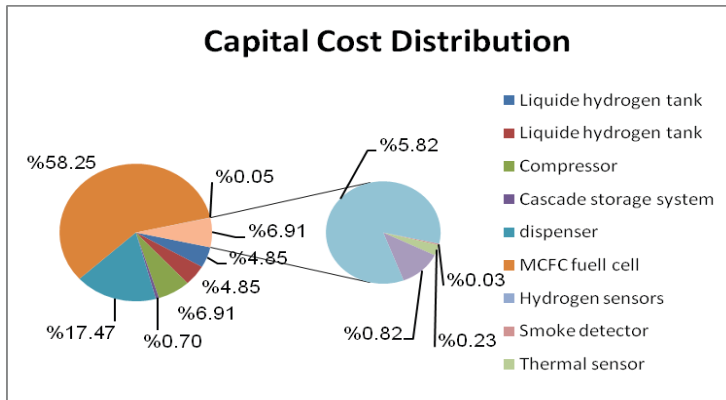


Figure (3). The percentage of capital cost.

The majority of the capital cost was consumed by the fuel cell about 67.2% to be exactly as shown in Figure 3.

2.4. The component used for this design.

In this section the main components of the design will describe in Table 2:

Table (2). 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
Hydrogen compressor [17]	1	1.1 m x1.1 m x 1 m	11 kw	-40°C to 100 °C	100 MPa	SAE
Cryogenic liquid hydrogen Storage [16]	1	3 m 3 - 20000m3	-	-40 °C to +30 °C	-	ISO
Refrigeration system [25]	1	-	25 Kw	-96 °C to 200 °C	-	ISO
MCFC [20]	1	-	1000 kw	600 °C	-	NFPA
Hydrogen dispenser [19]	1	-	120/240 VAC, 50/60Hz	-40°C to +5o°C	75 MPa	SAE
Detectors (hydrogen and smoke) [22] [21]	4	-	DC 9V	-	-	ISA

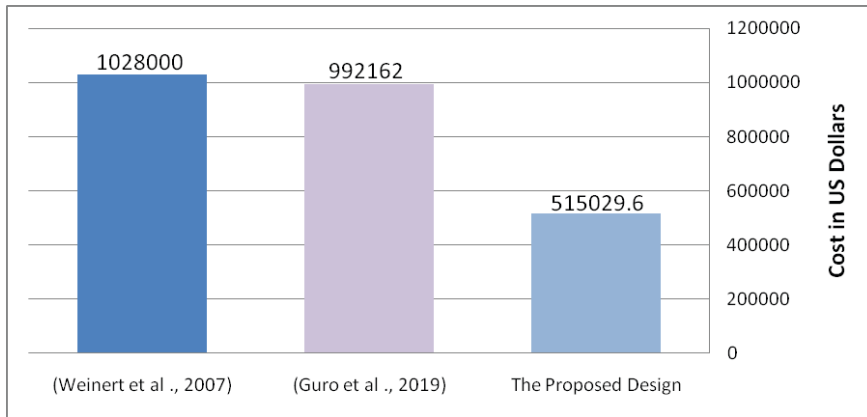


Figure (4). Economical comparison between various designs.

Comparing this design in figure 4 with [26] showed a reduction in cost by 49.8% and by comparing it with [27] This design is cost-efficient by 48 %.

2.5. 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, and 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 following 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.

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 the highest rank of 5 as shown in The FMEA-based critical security hazard performed in Table 3 a 10-risk Hydrogen dispenser and piping and pump [28]. 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[29].

Table (3). Failure Mode and Effect Analysis (FMEA).

Component	Failure mode	Failure effect	Likelihood	Severity	Rating	Action
Hydrogen Tank storage	Tank rupture, leakage or overflow	Leakage of hydrogen and may cause explosion and fire	1	5	5	Installation of a pressure safety valve.
Compressor	Overpressure	explosion or unit failure	2	2	4	periodic maintenance for the compressor 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

3. CONCLUSIONS

This study offered a comprehensive overview of the possibility of constructing 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 48 %. Also, this design showed promising signs concerning safety procedures and hazard assessment where is scored 6.8 on average out of 25 in the FMEA analysis meaning it's fairly safe.

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