Establishing High Certification Standards in an Innovation Industry -the Case of Korea's Hydrogen Vehicle (Fuel Cell Electric Vehicle) Certification Standards: Are They Safe Enough?

By

CHAE, Ye Na

THESIS

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF PUBLIC MANAGEMENT

2020

Establishing High Certification Standards in an Innovation Industry -the Case of Korea's Hydrogen Vehicle (Fuel Cell Electric Vehicle) Certification Standards: Are They Safe Enough?

By

CHAE, Ye Na

THESIS

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF PUBLIC MANAGEMENT

2020

Professor Kim, Byoung-Joo

Establishing High Certification Standards in an Innovation Industry -the Case of Korea's Hydrogen Vehicle (Fuel Cell Electric Vehicle) Certification Standards: Are They Safe Enough?

By

CHAE, Ye Na

THESIS

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

For the Degree of

MASTER OF PUBLIC MANAGEMENT

Committee in charge:

Professor Kim, Byoung-Joo, Supervisor

Professor Michell, Anthony

Approval as of August, 2020

Korea's Hydrogen Vehicle Certification Standards:

Are they Safe Enough?

A comparative study of Hydrogen Fuel Cell Vehicles HFCV technical regulations and corresponding standards in Korea and other countries.

Abstract

This study supports the hypothesis that Korea's Hydrogen Vehicle Certification Standards are lower than those of leading countries in Europe and North America and that there is a need for stricter certification standards. Korea's hydrogen vehicle standards follow the Ministry of Land, Infrastructure and Transport's Hydrogen Vehicle Certification Standard (HVCS), which is based on the European Parliament and Council Regulation (EC) No 79, EC79 established in 2009; therefore, one can arguably conclude that the standard is outdated. The issues raised in this research are on the basis of literature works that generally report findings implying the importance of urgency in adopting international examples of hydrogen energy management and safety policy cases to bring about hydrogen safety management (Kim & Lee, 2019). Further, the cause of our research is similarly supported by research on "The Roles and Impacts of Technical Standards on Economic Growth and Implications for Innovation Policy", where standardization is described as a catalyst for innovation (Sullivan & Dodin, 2012).

I support this argument by carrying out a comparative analysis of domestic HVCS against international Hydrogen Ground Vehicle HGV 2, Economic Commission for Europe

Regulation 134 ECE 134, and Global Technical Regulation GTR) standards by experimental test category and technical test stringency. A comparative analysis is carried out using the consequent model in this research termed “impact assessment”. The impact assessment involves scaling each technical standard covering aspects of safety disruption, impact upon failure, and catastrophic levels. The hypothesis in the research analysis is effectively proven right, showing Korea HVCS are lower. Further, whether Korea is currently equipped to carry out tests of international standards is analysed, which in this research we find to be mostly positive (more of a reason to support a raise in HVCS standards.)

To further support my argument, the implication of low certification standards, technological regulation in relation to international standards in facilitating international trade and fostering technological innovation are discussed. Implications of current HVCS are explored closely in the following context 1) double-testing by corporations to meet international standards creating economic costs, 2) low standards opening up the domestic market vulnerable to low standard imports, and posing a threat to existing high quality domestic products, 3) low technical regulations slowing technological innovation.

In contrast to the position this study establishes, one can see arguments that in terms of testing category, HVCS is not entirely exclusive of the global common tests, and technological advances have seen revisions in HVCS (exemplified by the revision in hydrogen testing container pressure from 350bar to 700bar). It may also be argued that harmonization of international standards, (such as International Laboratory Accreditation Cooperation ILAC, an international arrangement between member accreditation bodies based on peer evaluation and mutual acceptance), do not hold in real trade/practice setting.

Therefore, aspects such as double-testing by corporations to meet international standards is inevitable and therefore the implications of HVCS are unavoidable regardless of level of stringency in technical standards.

Further, another key counter-argument against raising HVCS standards is that international standards development, GTR 13 is an extension of the mandate for the Hydrogen and Fuel Cell Vehicles Sub Group Interagency Working Group (HFCV-SGS IWG) that works to tackle the development of the remaining issues of certification tests to meet improving technologies. GTR-13 is already well under development, which would establish a set of universal standards.

This study counters these competing arguments by showing that despite GTR-13, developed countries with technological competitiveness are creating stricter standards (especially for hydrogen vehicle equipment and parts-supported by "impact assessment" in this research). While GTR-13 will take time to develop, it is important that in order for South Korea to emerge with the world's top technologies in hydrogen vehicle equipment and parts, it must raise the bar in its technical standards to cater for innovation. The timing of standards in relation with the technology S-curve is followed in adopting technological standards research in order "to avoid delay in the diffusion of innovation, the timescale for standards should not be longer than for the innovation process" (Sherif, IEEE Com. Mag. 2001).

Moreover, standards may be seen as evolving documents, therefore there is a need to regularly update standards to reflect new technologies, material and methods. In the hydrogen energy area, this is complicated, since research and product development is happening simultaneous to the standards development. More the reason to revise hydrogen vehicle technical standards, which we discuss in further detail in this paper.

Through the efforts made in this research, I hope to contribute to HVCS development by finding critical areas of improvement in the current technical standards. This will be achieved through the "impact assessment" in this research. Further, by illustrating the importance of technical regulations standards in fostering innovation, I hope my research will raise awareness of the need strengthen HVCS standards. Raising HVCS in Korea will give medium sized enterprises in Korea the opportunity to grow beyond subsidiaries of conglomerates. SMEs of hydrogen vehicle equipment and parts can gain sheer size and become dominant players of the global market as they expand their capacity to meet standards of international levels.

As Korea enters the 4^{th} industrial age, more studies on technical regulations and standards influencing practices associated with research, development, manufacturing and market development will be required; consequently influencing innovation, productivity and growth (Tassey, 2017; Blind, 2009) as well as the growing hydrogen economy in the future could take the contributions made in this research further forward.

Acknowledgements

I would first like to thank my thesis advisors Professor Kim Byoung Joo and Professor Antony Michell of the KDI School of Public Policy and Management.

The doors to both Prof. Kim's office and Prof. Michell's office were always open whenever I had a question about my research or writing. Both professors have allowed this paper to be my own work, but steered me in the right the direction whenever I needed it.

I would also like to thank the experts who were involved in the "impact assessment" for this research project. Dr Dong Hoon Lee, Associate Director/ Senior Research Engineer of the Empirical Research Department at Korea Gas Safety Corporation and Dr Kim Won Jin, Deputy General Manager of Korea Gas Safety Corporation. Without their participation and input, the "impact assessment" could not have been successfully conducted.

Finally, I must express my very profound gratitude to my family for providing me with unfailing support and continuous encouragement throughout my study and through the process of researching and writing this thesis. Thank you.

Contents

Tables & Figures

Background

Hydrogen as an alternative fuel has the elements to address concerns of accelerating development for alternative fuel, independence from foreign oil, and securing renewables. In its purest form, there are zero emissions, the supply is endless, and production may use a variety of energy sources, including renewables (Michael & AnshumanKhare, 2005).

“Hydrogen could be a new energy which would fundamentally change our civilization.” (Rifkin, 2002). Following the International Energy Agency (IEA)’s recognition of the potential of hydrogen for the future in 2015, the ‘Hydrogen Economy’ has become a more popular concept. In October 2019, in a quest to improve air quality and as a potential driver of innovation, the Korean government announced the “Hydrogen Economy Roadmap Korea” with a focus on the expansion of hydrogen mobility. By the year 2025, Japan expects to commercialize passenger hydrogen vehicles in the amount of 2 million around the globe, with 800,000 vehicles in the United States, 650,000 vehicles in Germany and 100,000 vehicles in Korea. Given that these global policy trends support hydrogen mobility, the importance of hydrogen vehicle standards is increasing.

However, hydrogen’s two major disadvantages, the economics of producing sufficient quantities of hydrogen and the safety of hydrogen, have prevented any significant amount of development that has fueled hope for a hydrogen economy. The consensus is that the economics of producing sufficient quantities of hydrogen will be met with an increase in supply. Which leaves the issue of safety; to which all agree that a more significant effort on ensuring the safety of new hydrogen systems needs to be made.

The issue of safety in hydrogen in its most popular application to mobility will be addressed in this research, through hydrogen vehicle technical regulations for safety. In detail, “a hydrogen fuel-cell electric vehicle uses a fuel-cell system to convert hydrogen as its fuel to generate electricity.” (Hyundai Motors Group, 2020 a). I will assess the safety of hydrogen containers (and their materials) and equipment and parts which make up the fuel-cell system.

The importance of technical regulations and corresponding standards lies in that the development of performance-based standard methods affect the commercialization of fuel cells. Further, it allows for the evaluation of safe performance, and provides a basis for comparing similar products (Cairns, 2010, 1). Hence it is not that surprising standards that are reviewed regularly to reflect the knowledge gained during research and development (Cairns, 2010).

Korea's HVCS

Korea's current hydrogen vehicles technical regulations are based on the Ministry of Land, Infrastructure and Transport's Hydrogen Vehicle Certification Standard (HVCS).

For fuel cell and hydrogen vehicle safety, Korea established its domestic technical regulations through the then Ministry of Land, Transport and Maritime Affairs (after reorganization now known as the Ministry of Land, Infrastructure and Transport) on 20th Aug 2012. The developed standards have challenges. Developing component standards in a hydrogen environment means that there are no suitable component level standards available to be used as a pattern for the new standards. Using the existing natural gas standards for anything more than a framework is difficult as substantial differences exist in the process of storing and dispensing of hydrogen. To ensure compatibility and safety of components, new qualification test protocols are needed (Cairns, 2010). Therefore, the Ministry of Land, Infrastructure and Transport turned to adopt the European EC79 in practice at the time. Consequently, HVCS is a translation of EC79.

"EC79, Regulation EC No70 2009 of the European Parliament was promulgated on 14th January 2009 following the request of the European Parliament. Through EC79, a new regulatory approach was applied by the European Parliament and of the Council Regulation EC vehicle legislation." (Council Regulation EC79, 2009). It is important to note that the EC79 regulation only lays down fundamental provisions on requirements for the type approval of hydrogen systems and components. Thus, the European Parliament acknowledges there is more work to be done (Council Regulation EC79, 2009). The Korean HVCS regulations reflecting EC79 are only reflecting the fundamental provisions for hydrogen vehicle safety.

Existing View

Since Korea's HVCS establishment, there have been revisions in 2012, twice in 2013, 2014, twice in 2015 and in 2017. Based on this, it can be argued that Korea's current hydrogen vehicles certification standards are sufficient. There have indeed been revisions to HVCS. Further, existing HVCS does not vary extensively in technical test areas or numbers in comparison to the standards of other developed countries.

However, revisions to HVCS have been minor and have not kept up to the level of quickly evolving hydrogen technical standards of other countries. Individual technical test requirements have increased, and Korean HVCS have failed to follow through. Evidence of this will be provided in the appendix and the technical test's 'impact factor' assessment in this research.

Of the revisions made, the most notable revision has been to cater to technical regulations testing container pressure from 350bar to 700bar. This transformation of the certification standards technical regulation has primarily been due to the development of Hyundai's NEXO hydrogen vehicle. From this, one could argue either that crucial revisions are being made to Korea's HVCS appropriately to technical change or argue otherwise that HVCS is responding in a lag of technical change.

Indeed, low hydrogen vehicle technical regulations and corresponding certification standards in cases help to protect domestic corporations where the technology has not yet risen to the level of higher certification standards. However, this is an unlikely reason that standards are lower in Korea than of other countries, as taking a simple example of Hyundai Motors, it is producing hydrogen vehicles equipped with technology that is well beyond the safety standards of domestic and international technical regulations.

NEXO Fuel Cell Electric Vehicle FCEV, the first commercially produced hydrogen fuel cell vehicle, revealed in 2013 and equipped with Hyundai's latest 100KW fuel cell stack and hydrogen storage tank at 700 bar undergoes not only the Korean Ministry of Land, Infrastructure and Transport's administrative notice on the Regulation for Safety of CNG Pressure Vessels which sets forth 14 items to be tested for safety, but also other safety tests such as extreme cold and weather condition tests. Extreme cold and weather conditions tests are included in both the European ECE and North American HGV standards. Safety tests for NEXO's hydrogen fuel tanks have nearly doubled since early development, and safety standards were raised for mass production beyond international levels (Hyundai Motors Group, 2020 a).

Methodology of research

Given the background in the previous section, this research seeks to test and analyze how Korea's hydrogen vehicle (Fuel Cell Electric Vehicle) certification standards fare against those of other countries.

The hypothesis is that Korea's hydrogen vehicle (Fuel Cell Electric Vehicle) certification standards are lower than that of other countries. This paper aims to discover specific technical standards that need improvement under HVCS. Further, research is performed to examine whether Korea is currently equipped to carry out testing according to international standards.

Deciding what variables to compare within the hydrogen vehicle and determining adequate standards for comparison is essential. Consequently, in this research, we make comparisons of Korea's hydrogen car technical standards in three parts: hydrogen fuel vehicle container, container materials, and equipment & parts. Further certification standards are divided into categories by experimental testing types. Details of the comparison standards variables are outlined in the research subject / variables section.

The procedure of the comparative analysis will follow efforts to measure impact, from now on referred to as the "impact assessment" for standards. The impact assessment will be carried out measuring the 'effect' the container or equipment and parts can have upon failure, primarily judged based upon safety disruptions and accidents and tested for 'frequency' to measure how frequently the particular standard is tested for under both domestic and international mandatory standards. These two components will be assessed to form a matrix deducing individual safety standard's impact factor.

For hydrogen containers:

To be more specific, the standard test will be assessed for “effect” to measure impact. Effect correlated with the breakage or failure of the hydrogen carrying container (leakage and / or bursting of the container) will be assessed on a scale of 2, having a direct ability to affect, 1 having an indirect ability to affect, and 0 having no ability to affect.

< Table 1-1. Hydrogen Container Assessment score chart for 'effect' >

Failure effect	Direct effect	Indirect effect
Leakage	2 points	1 point
Burst	2 points	1 point
Total	4 points	2 points

For hydrogen vehicle equipment and parts:

The impact will be assessed based on the leakage and breakage of equipment concerning the vehicle breaking down. The table below shows the assessment mechanism this research will use to evaluate the hydrogen vehicle equipment and parts for effect.

< Table 1-2. Hydrogen vehicle equipment and parts score chart for 'effect' >

Failure effect	Direct effect	Indirect effect
Leakage	2 points	1 point
Breakage	2 points	1 point
Total	4 points	2 points

'Frequency' of the test will be based on whether the standard is covered under the domestic standards (Ministry of Land, Infrastructure & Transport notification), Europe (EU 406, R 134) and North America (HGV 3.1). If the technical test is included in all these standards, it receives 4 points, if included in one, it gets 1 point, and so on. As GTR and ECE R134 overlap in the technical standards, this research will assess both standards as the being the same, assigning a single point for inclusion in both GTR and ECE R134.

< Table 1-3. Hydrogen vehicle container, equipment & parts score chart for 'frequency' >

Technical standard	Included	Not included
Domestic standard	1 point	0 point
EU 406	1 point	0 point
HGV 3.1	1 point	0 point
R 134	1 point	0 point
Total	4 points	0 point

With the ‘Effect’ factor and the ‘Frequency’ factor, we produced a matrix. The matrix depicts our measurement of impact through a scale of points from 1 to 16 for each technical standard.

< Table 1-4. “Impact” assessment score >

Effect / Frequency	Very high (4)	High (3)	Average (2)	Low (1)
Very high 4)	16	12	8	4
High (3)	12	9	6	3
Average (2)	8	6	4	2
Low (1)	4	3	2	1

: Importance high

: Importance middle

: Importance low

Scores between 12-16 are rated high, between 6-9 are rated middle, and between 1-4 are rated low for hydrogen containers. For equipment and parts, a score between 12-16 are rated high, between 4-9 are rated middle and between 1-3 are rated low.

A detailed impact assessment of the standards and corresponding results will highlight specific technical standards that need improvement. The analysis and summary of the results can be found in the latter part of the research paper.

Implications (arguments and counter-arguments)

Strict technical regulations serve as a safety baseline accepted and trusted by industry and code officials (Cairns, 2010). This critical role of technical regulations and standards certifications point to a need to for Korean technical regulations to be revised upward to reflect stringent standards of peer countries to avoid implications as discussed below.

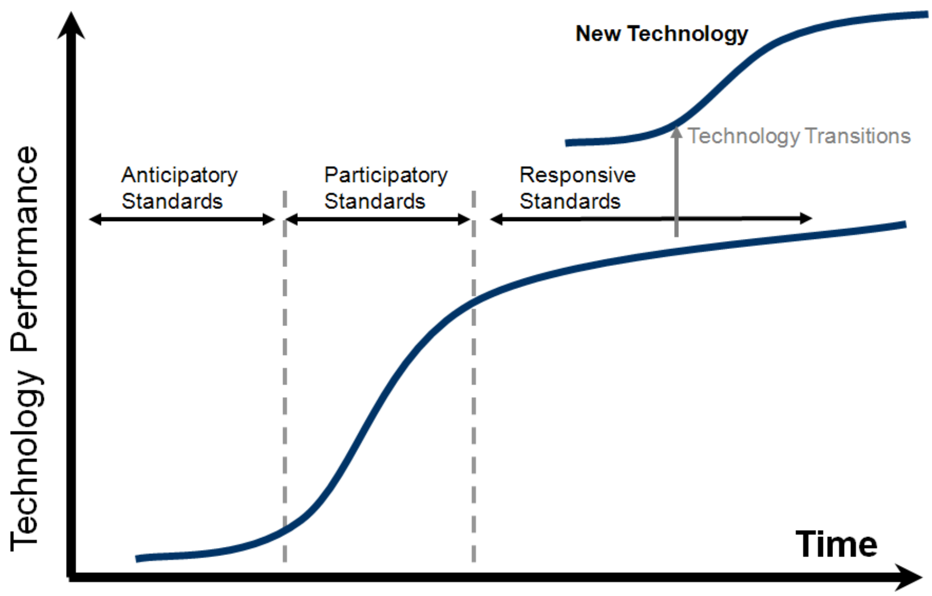
A vital issue of the current domestic certification standards of hydrogen vehicles (testing of its parts) means that in order to export, South Korean domestic firms have to undergo double testing to comply with both domestic and overseas standards. Coordination of standards development activities, both national and international, is necessary to prevent duplication of effort and development of conflicting requirements (Cairns, 2010).

Currently, Hyundai Group Motors is meeting safety regulations in exports through the use of overseas testing. Hyundai doubled the number of test criteria for a hydrogen tank to not only comply with domestic standards but also meet well above international safety standards to ensure absolute safety. In order to achieve this Hyundai sets 200 different tests internally to ensure that hydrogen tanks meet the most strict safety and durability standards which has seen the results of NEXO receiving top safety rating in The European New Car Assessment Programme, EURO NCAP European new car assessment program Hyundai Motors Group, 2020 b). Hyundai's case of double testing to satisfy international standards to export is a clear illustration of the extra cost that current hydrogen vehicle technical regulations would bear on domestic corporations.

Regulation standard setting is lagging behind technology for HVCS; therefore, it can be argued the government is not playing the role of protecting domestic corporations' interests. There seems to be weak logic in keeping the HVCS low considering, for instance, that Hyundai boosts top technology that surpasses international standards.

Following the timing of standards in relation with the technology S-curve adopted in technological standards research, it is easy to see that if "the timescale for standardization is longer than for the innovation process, there is a concern that the introduction and diffusion of innovations may be delayed or stifled." (Sherif, IEEE Com. Mag. 2001).

<Fig.1: Timing of standards in relation with the technology S-curve>



(Source: Sherif, A Framework for Standardization in Telecommunications and Information Technology, IEEE Com. Mag. 2001)

In a related way, the product life cycle also offers an interesting perspective to explore the ways in which standards can facilitate product innovation. In the early stages, standardization may be used to apply and try new technologies as well as encourage adoption.

It is widely accepted that once a roadmap or a draft of revision in technical tests are established it is important to get feedback from the industry and reflect the revisions accordingly. The reason for this is clear, as technical regulations play a key role in facilitating trade. Similarly, international requirements facilitate international trade and eventual international-to-regional harmonization of standards. (Michael & AnshumanKhare, 2005). Standardization provides product information in this case, safety insurance and facilitates buyer-seller relationships, promotes market information and confidence by signaling product quality (Azim, 2005), collectively promoting international trade.

It is true that standards are evolving documents, regularly updated to reflect new technologies, material and methods. In the hydrogen energy area, this is complicated further since research and product development is happening simultaneously to the standards development. As noted above, this creates a set of unique challenges to manage.

Some current challenges include revising technical standards for material compatibility and temperature. Therefore it is not surprising current research is ongoing to identify the range of temperatures that various components may be exposed to in both ambient and process temperatures (Michael & Anshuman Khare, 2005).

Considering the above, in the case of the United States, it has formed a DOE Hydrogen Codes and Standards Coordinating Committee (HC & SCC) to make sure that the technical gaps and related issues are considered expeditiously and the timely flow of information exists between all interested parties.” (Wilson & Otsuki, 2004). This is an illustration of how seriously developed countries are facing the challenge of applying hydrogen standards.

Similarly, the EU understands the critical role of standards in technology. This is illustrated in Part 11 of Official Journal of the European Union, as manufacturers might follow different approaches to the development of hydrogen-powered vehicles, specification of common requirements concerning the safety of hydrogen powered vehicles is necessary and it is important to establish safety requirements in a technology-neutral manner. This is increasingly becoming more important as hydrogen-powered vehicles in the total fleet increase over time.

Likewise, Korea needs to up its game by taking into consideration how to adopt technical-neutral standards where technological change is rapid. Fortunately, Korean corporations are investing heavily with the knowledge that actively participating in setting standards will help protect and elevate their competitive advantage. The reason is because different standards testing and certification measures for products and services are among the most important technical barriers to trade (Tassey, 2017). Following Korean corporations, the Korean government needs to take a more significant role in building the existing frame of technical standards for hydrogen vehicles, like the United States has done.

Continuing the discussion above that technical measures can support market development and promote trade (Azim, 2005), applying it to the case of South Korea: strengthening technical regulations and corresponding standards will allow medium-sized enterprises to grow beyond subsidiaries of conglomerates. By meeting the higher safety regulation standards of export countries, businesses will be equipped to produce products for both the domestic market and the international market, thus being able to expand beyond domestic sales to cover international sales theoretically. Hydrogen vehicle equipment and parts manufacturing medium-sized enterprises will naturally gain opportunities to increase in size, and potentially become dominant players of the global market. The source of new growth that the hydrogen economy can bring about is large. It is not just limited to a specific car manufacturer, but extends to related businesses. For Hyundai Motors, about 300 domestic parts makers are already involved in the development and production of hydrogen cars (Hyundai Motors Group, 2020 c). All the more reason to raise hydrogen vehicle technical standards to foster these businesses.

Domestic standards should be raised so that it can stimulate change. In line with the government's conferred privilege on hydrogen policies, upgrading standards will be necessary to boost technological innovation which is key to building a Hydrogen Economy. Contrary to this, as discussed in the standards of the previous section, currently, regulation is lagging behind technology. New technology in the current market, such as Hyundai's "smart hydrogen tanks with real-time status monitoring systems" is far advanced beyond technical regulations (Hyundai Motors Group, 2020 b). FCEV certification standards will need to be quickly developed to meet Korea's fast-advancing hydrogen technologies. In addition, welldesigned, properly implemented technical measures can improve welfare in the sense that they can mitigate production and consumption externalities.

Above all, the key importance of keeping regulations in line with technological development is that the current FCEV certification standards allow overseas hydrogen vehicles parts ease of entry into Korea. This opens up the domestic market to being vulnerable to low standard imports. This exposure poses a threat to existing high-quality domestic products that would naturally lose price competitiveness against these lower standard products.

This argument is supported by the Grossman and Helpman (1994) model which suggests that "Industries with lower import penetration and lower import demand elasticities have a greater incidence of technical measures enjoy greater protection". Following Grossman and Helpman, technical regulations act as protection for imports (Azim, 2005). Like other forms of trade protection, many technical regulations and standards favor domestic producers over foreign competitors.

Eliminating safety risk is also imperative with these standards, given hydrogen's volatility range and its hazardous nature. After the release of the Hydrogen Roadmap by the Korean government in 2019, there were two major Hydrogen Refueling Station (HRS) explosion accidents. One in Gangneung, which resulted in 2 fatalities and 6 injured, and another in Oslo, Norway, which resulted in 2 injured.

Even with the recent accidents and heightened anxiety about the safety of hydrogen, there are disadvantages to strict levels of standardization. Standardization can reduce product variety, however in the case of hydrogen cars the industry is still at an early stage for this disadvantage to be significant (Azim, 2005).

Similarly, the costs of compliance through product re-design is another disadvantage inapplicable in the case of Korea because Korean corporations are already producing products beyond international standards. Importantly it may be argued that double testing is unavoidable in real practice. This is an invisible barrier that exists despite global standard agreements and unilateral standards.

In the case of FCEV certification standards, ILAC (an international arrangement between member accreditation bodies based on peer evaluation and mutual acceptance) should hold in real trade / practice settings. However, even stronger than ILAC is the enforcement of domestic law on technical standards, which means that although, in theory, cross-recognition of international standards should hold, this may not hold in practice. Testing bodies may hold a sample to be re-tested even if it has passed the international standards. Therefore, for the international standard to have significant effect in practice, it needs to be outlined in the domestic standards, mandatory by law.

When it comes to HVCS standard certification in Korea, the Ministry of Lands, being the competent authority on such regulations recognizes the following testing authorities and technical regulations: U.S ANSI American National Standards Institute's technical regulations and Independent Inspection Agency as U.S's technical regulation testing body, Europe's ECE Economic Commission of Europe's technical regulations and E-marking test notified body as Europe's technical regulation testing body, Japan's High Pressure Gas Law's technical regulations and KHK (High Pressure Gas Safety Institute of Japan) as the technical regulation testing body. HVCS is translatable to the Ministry of Land, Infrastructure and Transport's Minister approved technical regulations and the Ministry of Land, Infrastructure and Transport's Minister approved technical regulation testing body.

Korea is a part of GTR-13, which is the new global FCEV certification standards. As governments and industries generally expect the GTR-13, one could argue that upgrading HVCS is as waste of resources. Phase 2 of GTR No. 13, submitted by the representatives of the European Union, Japan and Republic of Korea is well underway for which Korea has authorization to develop. This will eventually become the international safety standard for hydrogen vehicles and therefore, arguably, there is no need to revise the current HVCS.

GTR 13 is "an extension of the mandate for the HFCV-SGS IWG that tackles the development of the remaining issues of certification tests to meet improving technologies and adherence to stricter safety standards. The scope of work in Phase 2 covers the original items derived in ECE / TRANS WP.29/AC3./17, the potential scope of revisions to address additional vehicle classes, requirements for material compatibility and hydrogen embrittlement, requirements for fueling receptacles, evaluation of performance-based tests for long-term stress ruptures proposed in Phase 1, consideration of research results reported after the completion of Phase 1, specifically research related to electrical safety, hydrogen storage systems, and post-crash safety; consideration of 200 per cent NWP or lower as the minimum burst requirement and consideration of a safety guard system for the case of isolation resistance breakdown. Already Phase 2 activities have started as of March 2018. (United Nations Global Registry, 2013).

“However, since hydrogen fueled vehicles and fuel cell technologies are in early stages of development of commercial deployment, it is expected that revisions to these requirements may be suggested by an extended time of on-road experience or additional time for fuller technical consideration.” (United Nations Global Registry, 2013). Therefore, to achieve GTR-13 will take time and a lot of collaborative work. GTR-13 may take too long in the making as technologies and the hydrogen vehicle industry develops. Some critics argue however that “harmonization should not go too far, particularly when harmonization challenges national regulatory standards” (Egan, 2002), citing the difficulty of achieving a single global regulatory standard.

Essentially GTR-13 is an upgrade from the existing standards and in order to ease the transition Korea needs to start changing the standards now to prepare for the new global standardization, GTR-13. For South Korea, partaking in international standards development GTR-13, a well-established domestic standards development needs to be in place to cater to change in early stages of product development. Similarly, the EU is advancing its standards to greet the new GTR-13 (Part 7 of Official Journal of the European Union) “Commission should continue to support the development of internationally harmonized requirement for motor vehicles under the auspices of UNECE. In particular, if a Global Technical Regulation GTR on hydrogen and fuel cell vehicles is adopted, the Commission should consider the possibility of adapting the requirements laid down in this Regulation to those established in the GTR.” (United Nations Global Registry, 2013) In the case of U.S and Europe, in fact, the information used to develop national standards is channeled to international standards development committees (Cairns, 2010).

Research subject and variables

To compare Korea’s HVCS against other countries, the following international technical standards were used for comparison:

- <u>Technical standards for different regions</u>

Hydrogen fuel vehicle container and parts technical standards were first established in the year 2009 with EC 79, and Korea adopted it in 2013. Korean HVCS has recently been revised in 2018 and has been in operation. Below are the technical standards that are in use in different countries.

< Table 2. Technical standards for hydrogen fuel vehicle container and components for countries >

<table>
<tr><th>Country</th><th>Type</th><th>Regulation</th></tr>
<tr><td rowspan="2">South Korea</td><td>Container (for hydrogen storage)</td><td>. Ministry of Land, Infrastructure & Transport notification Article2013-Issue562 “Vehicle Pressure resistant container safety regulations.”
. Ministry of Land, Infrastructure & Transport notification Article2018-Issue176 “Vehicle Pressure resistant container safety regulations.”
-Appendix 4 “Compressed hydrogen gas pressure-resistant container manufacturing specifications, testing methods and procedures.”</td></tr>
<tr><td>Equipment and parts/ components</td><td>. Ministry of Land, Infrastructure & Transport notification Article2013-Issue562 “Vehicle Pressure resistant container safety regulations.”
. Ministry of Land, Infrastructure & Transport notification Article2018-Issue176 “Vehicle Pressure resistant container safety regulations.”
-Appendix 7 “Compressed hydrogen gas container valve and container manufacturing specifications, testing methods and procedures.”</td></tr>
</table>

		-Appendix 11 "Hydrogen vehicle fuel supply equipment and parts certification standards."
North America	Container (for hydrogen storage)	. ANSI HGV2 "Compressed hydrogen gas vehicle fuel containers"-2014
	Equipment and parts/ components	. HGV3.1, Fuel system components for compressed hydrogen gas-powered vehicles-2015 . ANSI HPRD1, Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers-2013
Europe	Container and equipment and parts/ components	. Regulation (EC) No 79/2009, on type-approval of hydrogen-powered motor vehicles . Commission Regulation (EU) No 406/2010, implementing Regulation (EC) No 79/2009 . UN ECE Regulation No.134, Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety-related performance of hydrogen fueled vehicles (HFCV)
Japan	Container (for hydrogen storage)	. Japan High-pressure gas safety management laws (KHK S 0128)
	Equipment and parts/ components	
China	Container (for hydrogen storage)	. GB/T 35544-2017 Fully-wrapped carbon fiber reinforced cylinders with an aluminum liner for the on-board storage of compressed hydrogen as a fuel for land vehicles
	Equipment and parts/ components	
Other	Container and equipment and parts/ components	. Global technical regulation No.13, Global technical regulation on hydrogen and fuel cell vehicles . SAE J2600 NOV 2012, Compressed hydrogen surface vehicle fueling connection devices . ISO 12619 Part 1 ~ Part 16, Road vehicles – Compressed gaseous hydrogen(CGH2) and hydrogen/natural gas blends fuel system components

Further, there is an HFCV-SGS; IWG informal working group on hydrogen and fuel cell vehicles -sub safety that was set up in 2007. Since its establishment, in June 2013, the Global Registry as GTR No.13 provisions, were transposed into UN Regulation No 134 annexed to the 1958 Agreement. So effectively the GTR we mention in the below comparisons were provisions set in 2013. ECE 134 established in June 2015. HGV 3.1 established in March 2013.

Of the international standards, GTR standards are the most strict regulations of the current technical regulations and corresponding standards around the globe because it requires testing of all standards in series.

Korea’s hydrogen car technical standards will be compared in three parts: hydrogen fuel vehicle containers, container materials, and equipment and parts. Further certification standards will be divided into categories by experimental testing types.

Research Comparison

Research comparison is made for different categories as outlined in research subject and variables. The reason for this is, as there is significant amount of data, to write the data is words would be too verbose and distract from clearly presenting the data.

- Hydrogen vehicle container technical regulation

In Korea, hydrogen vehicle container technical regulation is regulated by the Ministry of Land, Infrastructure & Transport through compressed hydrogen gas pressure-resistant container, manufacturing specifications, testing methods, and procedures. In North America, it is regulated by HGV 2, in Europe by EC 79 and ECE R 134 combined. For international standards, GTR-13 is the regulation standard.

A. Hydrogen containers' material testing standards

In Korea hydrogen vehicle container material standards are regulated by 10 test criteria of HVCS, in North America, it is regulated by 9 test criteria of HGV-2, in Europe, by 9 test criterions from EC 79 and ECE R 134 combined.

< Table 3-1 Technical testing standards for hydrogen vehicle container materials >

Technical tests		Ministry of Land, Infrastructure & Transport Legislation	HGV2-2014	EC79 &ECER134
Liner	Liner tensile test	○	○	○
	Liner softening temperature, melting point test	○	○	○
Epoxy resin	Resin sheer strength test (ILSS)	○	○	○
	Resin sheer strength test	X	X	X
	Resin glass transition temperature test	○	X	○
Fiber material	Tensile test for fiber material	○	X	X
Aluminum	Tensile test for aluminum	○	○	○
	Aluminum bending test	X	○	○
	Aluminum material test	○	○	X
	Sustained load cracking test (SLC)	○	○	○
	Corrosion test	○	○	○
Other	Coating test	○	○	○

B. Hydrogen container testing standards

The hydrogen carrying container technical tests follow Ministry of Land, Infrastructure & Transport notification Appendix 4 “Compressed hydrogen gas pressure resistant container manufacturing specifications, testing methods and procedures”, which is comprised of 14 tests of which 12 are taken from ECE R 134.

See Appendix A for the comparison between Korean hydrogen container standards against global peers of Europe and North America.

■ Hydrogen vehicle equipment and parts technical regulation

A. Domestic technical regulation

1) Hydrogen container valve and valve safety devices

Container valves and safety devices must comply with 8 technical standards from the Ministry of Land, Infrastructure & Transport notification Appendix 7 “Compressed hydrogen gas container valve and container manufacturing specifications, testing methods and procedures.”

< Table 3-2. Technical tests for hydrogen container components >

Categories of design stages of testing	Technical test
2.1.3.1	Exterior test
2.1.3.2	Material test
2.1.3.3	Corrosion resistance test
2.1.3.4	Endurance test
2.1.3.5	Pressure cycle test
2.1.3.6	Internal leakage test
2.1.3.7	External leakage test
2.1.3.8	Pressure proof test

2) Hydrogen fuel cell car equipment and parts

The following technical standards under “hydrogen car fuel supplying equipment and parts certification standards” from the Ministry of Land, Infrastructure & Transport, notification Appendix 11 “Hydrogen vehicle fuel supply equipment and parts certification standards” are required to be followed. Appendix 11 regulates that 9 Hydrogen fuel cell car equipment be tested.

< Table 3-3. Technical test for hydrogen car fuel supply equipment and parts >

Equipment and parts	Technical tests					
	Material test	Corrosion resistance device	Endurance test	Pressure cycle test	Internal leakage test	External leakage test
Fittings	√	√	√	√		√
Flexible fuel lines	√	√	√	√		√
Hydrogen filters	√	√		√		√
Automatic valves	√	√	√	√	√	√
Manual valves	√	√	√	√	√	√
Pressure regulators	√	√	√	√	√	√
(PRV) Pressure relief devices	√	√	√	√	√	√
Receptacles	√	√	√	√	√	√
Sensors for hydrogen systems	√	√	√	√		√

B. International technical regulation

1) Regulation (EC) No 79/2009

< Table 3-4. Equipment and parts that require testing under EC79 >

Equipment and parts that require testing	1. Container 2. Automatic shut-off valve 3. Container assembly 4. Fittings 5. Flexible fuel line 6. Heat exchanger 7. Hydrogen filter 8. Manual or automatic valve 9. Non-return valve 10. Pressure regulator 11. Pressure relief device 12. Pressure relief valve;(PRV) 13. Refueling connection or receptacle 14. Removable storage system connector 15. Pressure, temperature, hydrogen and flow sensors (if used as a safety device) 16. Hydrogen leakage detection sensors.

Technical tests that must be carried out for these parts include 6 tests for material tests, corrosion resistance test, endurance test, pressure cycle test, internal leakage test, and external leakage test. While the testing classification is different, the Korean technical standards are comprised of the same tests.

There are 16 hydrogen vehicle container and equipment parts (including container valves) that require testing based on European standards.

< Table 3-5. Hydrogen container technical testing list >

Hydrogen component	Type of test					
	Material test	Corrosion resistance device	Endurance test	Pressure cycle test	Internal leakage test	External leakage test
Pressure relief devices	√	√	√	√	√	√
Automatic valves	√	√	√	√	√	√
Manual valves	√	√	√	√	√	√
Non-return valves	√	√	√	√	√	√
Pressure relief valves	√	√	√	√	√	√
Heat exchangers	√	√		√		√
Refueling connections or receptacles	√	√	√	√	√	√
Pressure regulators	√	√	√	√	√	√
Sensors for hydrogen systems	√	√	√	√		√
Flexible fuel lines	√	√	√	√		√
Fittings	√	√	√	√		√
Hydrogen filters	√	√		√		√
Removable storage system connectors	√	√	√	√		√

2) HGV 3.1/2015

There are 17 hydrogen vehicle container and equipment parts (including container valves) that are require to be tested based on North American technical standards, regulations under HGV 3.1.

15 technical tests are conducted including, atmospheric exposure and salt spray exposure tests. Compared to the technical standards in Korea, the following tests are additional: excess torque resistance, ultraviolet resistance for external surfaces, automotive fluid exposure, abnormal electrical voltage, vibration resistance, insulation resistance, and pre-cooled hydrogen exposure tests.

< Table 3-6. Equipment and parts that require testing and corresponding tests under North America HGV 3.1 >

<table>
<tr><th>Equipment and parts</th><th>Technical test</th></tr>
<tr><td rowspan="15">• Check valve
• Manual valve
• Manual container valve
• Automatic valve and automatic container valve
• Gas injector
• Pressure sensors and pressure gauges
• Pressure regulator
• Pressure relief valve
• Pressure relief device
• Excess flow valve
• Gas-tight housing and leakage capture lines and passages
• Stainless steel rigid fuel line
• Flexible fuel line
• Filter housing
• Fitting
• Non-metallic low pressure rigid fuel line
• Discharge line closures</td><td>Leakage venting</td></tr>
<tr><td>Leakage</td></tr>
<tr><td>Hydrostatic strength</td></tr>
<tr><td>Excess torque resistance</td></tr>
<tr><td>Bending moment</td></tr>
<tr><td>Continuous operation</td></tr>
<tr><td>Corrosion resistance</td></tr>
<tr><td>Ultraviolet resistance of external surfaces</td></tr>
<tr><td>Automotive fluid exposure</td></tr>
<tr><td>Atmospheric exposure</td></tr>
<tr><td>Abnormal electrical voltages</td></tr>
<tr><td>Stress corrosion cracking resistance</td></tr>
<tr><td>Insulation resistance</td></tr>
<tr><td>Pre-cooled hydrogen exposure</td></tr>
<tr><td>Water jet protection</td></tr>
</table>

3) UN ECE R134

Equipment and parts that need to be tested under UN ECE R134 for Pressure Relief Device include check valve and automatic shut off valve’s two equipment parts. 13 technical tests are performed, including the atmospheric exposure test and the salt corrosion resistance test. Vehicle environment test, electrical tests, drop & vibration test, pre-cooled hydrogen exposure test, benchtop activation test, flow rate test, and so on are additional testing standards in comparison to Korean testing standards.

< Table 3-7. Equipment and parts that require testing and corresponding tests under European ECE R 134 >

Equipment and parts	Technical test
TPRD	Pressure cycling test
	Accelerated life test
	Temperature cycling test
	Salt corrosion resistance test
	Vehicle environment test
	Stress corrosion cracking test
	Drop and vibration test
	Leakage test
	Bench top activation test
	Flow rate test
Check valve and automatic shut-off valve	Hydrostatic strength test
	Leakage test
	Extreme temperature pressure cycling test
	Salt corrosion resistance test
	Vehicle environment test

	Atmospheric exposure test
	Electrical tests
	Vibration test
	Stress corrosion cracking test
	Pre-cooled hydrogen exposure test

Please find a comprehensive comparison of hydrogen vehicle equipment and parts in Appendix B.

Impact Assessment and results

Following the comparative analysis methodology introduced previously, the following results of “impact assessment” were obtained from the analysis.

A. *Hydrogen container “impact” assessment*

The “impact” assessment of container technical testing standards was carried out for 23 testing standards taken from both domestic and international standards.

< Table 4-1. Analysis of hydrogen container technical tests >

Classification	Test type	Effect	Frequency	Impact/risk factor
1	Liner tensile test	2	3	6
2	Corrosion resistance test	1	3	3
3	SLC sustained load cracking test	1	3	3
4	Softening temperature test	1	2	2
5	Glass transition temperature test	1	2	2
6	Resin (interlaminar) sheer strength test	2	3	6
7	Protective coating test	2	3	6
8	Hydrostatic burst test	4	4	16
9	Ambient temperature pressure cycle test	4	4	16
10	Drop test	2	4	8
11	Composite flaw tolerance test	2	4	8
12	Environment test	2	4	8

13	Accelerated stress rupture test	2	4	8
14	Extreme temperature cycling test	4	4	16
15	Airtight test/ leak test	2	4	8
16	Boss torque test	2	4	8
17	Permeation test	2	3	6
18	High strain rate impact test	2	3	6
19	Gas repeat test	4	4	16
20	(Bon)Fire test	2	4	8
21	LBB Leak before break test	4	4	16
22	Hydraulic pressure repeat process	4	1	4
23	Gas sequential tests/ gas pressure cycling test	4	1	4

Scores between 12-16 are rated high, between 6-9 middle and between 1-4 low for containers. From the assessment, 5 scored high including the ambient temperature pressure cycle test, 12 including the environment test scored middle and 6 including the corrosion resistance test scored low.

< Table 4-2. Hydrogen container technical tests “impact assessment” results >

	Low	Medium	High
Technical test	-Hydrostatic burst test -Ambient temperature pressure cycle test -Gas (cycling) repeat test -Extreme temperature cycling test -LBB leak before break test	-Environment test -Accelerated stress rupture test -Airtight test/leak test -Boss torque test -Drop test -Composite flaw tolerance test -Liner tensile test -Resin sheer strength test -Protective coating test -Fire test -Permeation test -High strain rate impact test	-Corrosion resistance test -Softening temperature test -Glass transition temperature test -Hydraulic pressure repeat process -Gas sequential tests/ gas pressure cycling test -SLC sustained load cracking test

Technical tests that fall in the category of high “impact factor” should be considered for adoption with urgency. Technical tests that fall in the middle and low “impact factor” should be viewed with careful consideration in being adopted in the current technical standards.

B. Equipment and parts technical tests “impact” assessment

Equipment and parts "impact" assessments were carried out for 18 equipment and parts technical tests (including tests for PRD) from domestic, European and North American standards.

< Table 4-3: Analysis of hydrogen vehicle equipment and parts technical tests >

No	Technical test	Test Importance	Test Frequency	Impact/risk factor
1	Hydrostatic strength	2	2	4
2	Aging test	4	4	16
3	Ozone compatibility test	2	4	8
4	Corrosion resistance test	2	4	8
5	Endurance Test	4	4	16
6	Hydraulic pressure cycle test	4	4	16
7	Internal leakage test	2	4	8
8	Eternal leakage test	2	4	8
9	Excess torque test	2	1	2
10	Bending test	2	1	2
11	Ultraviolet resistance for external surfaces test	2	1	2
12	Automotive fluid exposure test	2	2	4
13	Excess current test	2	2	4
14	Internal vibration test	2	2	4
15	Insulation resistance test	2	1	2
16	Cold hydrogen gas test	4	2	8
17	Bench top activation test (PRD)	4	1	4
18	Flow rate test (PRD)	2	1	2

< Table 4-4: Hydrogen vehicle equipment & parts technical tests "impact assessment" results>

	High	Medium	Low
Technical tests	-Aging test -Endurance Test -Hydraulic pressure cycle test	-Corrosion resistance test -Internal·external leakage test -Cold hydrogen gas test -Hydrostatic strength test -Automotive fluid exposure test -Excess current test -Internal vibration test -Bench top activation test (PRD) -Ozone compatibility test	-Excess torque test -Bending test -Ultraviolet resistance for external surfaces test -Insulation resistance test -Flow rate test

For equipment and parts, a score between 12-16 is rated high, between 4-9 middle and between 1-3 is low. 3 tests, including the ageing test, fall under the high "impact" category. 7 tests, including internal leakage test fall under the medium "impact" category, and 6 tests including the excess torque test fall under the low "impact" category.

Discussion

From the above impact analysis, the technical standards that are recommended to be adopted for both hydrogen vehicle containers and hydrogen vehicle equipment and parts were deduced. A summary of the findings of this research report can be found in the following table.

< Table 5-1. Technical standards classification based on the “Impact Assessment” >

Impact assessment		High	Medium	Low
Being applied in the standards already	Container	-Hydrostatic burst test -Ambient temperature pressure cycle test -Gas repeat test	-Environment test -Accelerated stress rupture test -Airtight test -Boss torque test	-Corrosion resistance test -Softening temperature test -Glass transition temperature test
	Equipment and parts	-Ageing test	-Ozone compatibility test	
Needs assessment	Container	-Extreme temperature cycling test -LBB leak before break test	-Drop test -Composite flaw tolerance test -Liner tensile test -Resin sheer strength test -Protective coating test	-Hydraulic pressure repeat process -Gas sequential tests -SLC sustained load cracking test

Continued:

< Table 5-1. Technical standards classification based on the “Impact Assessment” >

Impact assessment		High	Medium	Low
Needs assessment	Equipment and parts	-Endurance test -Hydraulic pressure cycle test	-Internal · external leakage test -Cold hydrogen gas test -Excess current test -Internal vibration test -Automotive fluid exposure test -Corrosion resistance test -Hydrostatic strength test -Automotive fluid exposure test -Bench top activation test (PRD)	-Excess torque test -Bending test -Insulation resistance test -Ultraviolet insulation resistance test -Flow rate test

The question that follows is whether, in adopting hydrogen container standards, Korea is currently equipped to carry out these standards tests with the existing testing infrastructure.

This is illustrated through the use of a table.

Re-grouping the low to high impact technical standards in terms of the current capacity to presently adopt testing of these standards is as follows under Table 5-2.

< Table 5-2. Technical & infrastructural capacity to carry out technical tests for hydrogen containers >

Importance	High	Medium	Low
Sustain current technical standards	-Hydrostatic burst test -Ambient temperature pressure cycle test -Gas repeat test	-Environment test -Accelerated stress rupture test -Airtight test -Boss torque test	-Corrosion resistance test -Softening temperature test -Glass transition temperature test
Equipped to carry out these tests	-Extreme temperature cycling test -LBB leak before break test	-Drop test -Composite flaw tolerance test -Liner tensile test -Resin sheer strength test -Protective coating test	
Not Equipped to carry out these tests		-Fire test -Permeation test -High strain rate impact test	-Hydraulic pressure repeat process -Gas sequential tests/gas pressure cycling test -SLC sustained load cracking test

The title 'Sustain current technical standards', above, is where the standard is being carried out with the current testing capacities. This is where we are doing well. There are 10 standards under this category. 'Equipped to carry out these tests' are technical standards included in international standards but excluded from the domestic standards that we can carry out. There are 7 standards under this category. 'Not Equipped to carry out these tests' are technical tests that are not included in the domestic standard but are included in the international standard and also standards where we cannot carry out tests. There are also 7 standards under this category. Overall, it is clear that Korea is currently equipped to carry out 50% of technical tests to the level of international standards.

Similarly, for hydrogen vehicle equipment and parts, whether Korea is currently equipped to carry out these standards tests with the existing testing infrastructure is illustrated in the below table. Re-grouping the low to high impact technical standards in terms of current capacity to currently adopt testing of these standards is as follows:

< Table 5-3. Technical & infrastructural capacity to carry out technical tests for hydrogen vehicle equipment and parts>

Importance	High	Medium	Low
Sustain current technical standards	-Ageing test	-Ozone compatibility test	
Equipped to carry out these tests	-Endurance Test	-Internal · external leakage test -Cold hydrogen gas test -Hydrostatic strength test - Excess current test -Internal vibration test -Automotive fluid exposure test	-Excess torque test -Bending test -Insulation resistance test
Not equipped to carry out these tests	-Hydraulic pressure cycle test	-Corrosion resistance test -Hydrostatic strength automotive fluid exposure -Bench top activation test (PRD)	-Ultraviolet insulation resistance test -Flow rate test

As above, the title ‘Sustain current technical standards’ is where the standard is being carried out with the current testing capacities. This is where we are doing well. There are 2 standards under this category, which is rather low. ‘Equipped to carry out these tests’ are technical standards included in international standards but excluded from the domestic standards, that we can carry out. There are 9 standards under this category. ‘Not equipped to carry out these tests’ are technical tests that are not included in the domestic standards but are included in the international standard and also standards we cannot carry out tests for. There are also 7 standards under this category.

In the table below, we note that Korea as of the year 2018 is equipped with infrastructure to carry out almost all technical tests included in the international standards. However, considering the quantity of tests, repeat tests and testing methods, there is room for further infrastructural development to support further development in standards.

< Table 5-4. A summary of hydrogen container technical testing capacity >

Technical test	Type of container				Domestically able to carry out test	Note
	I	II	III	IV		
Ambient temperature pressure cycling	√	√	√	√	√	Equipped to carry out test from 2018
Chemical exposure	-	√	√	√	√	Equipped to carry out test from 2018 Need additional small parts
Extreme temperature pressure cycling	-	√	√	√	√	Equipped to carry out test from 2018
Hydrostatic pressure burst	√	√	√	√	√	Equipped to carry out test from 2018

Composite flaw tolerance test	–	√	√	√	√	Equipped to carry out test from 2018 Flaw process can be conditionalized from outside sources
Impact damage test	–	–	√	√	√	Equipped to carry out test from 2018
Bonfire test	√	√	√	√	√	Equipped to carry out test from 2018
Accelerated stress rupture test	–	√	√	√	√	Equipped to carry out test from 2018
Penetration test	√	√	√	√	X	Not equipped to test Licence to use guns under approval
Permeation test	–	–	–	√	√	Equipped to carry out test from 2018
Hydrogen gas cycling test	–	–	–	√	√	Equipped to carry out test from 2018
LBB (Leak Before Brake) test	√	√	√	√	√	Equipped to carry out test from 2018
Boss torque test	–	–	–	√	√	Equipped to carry out test from 2018
Sequential hydraulic test	√	√	√	√	√	Equipped to carry out test from 2018 Need additional small parts
Sequential pneumatic test	√	√	√	√	▲	Equipped to carry out test from 2018 (Up to 124L, for additional need to be further equipped)

Conclusion

Hydrogen is one of the most common substances available, and the combustion process creates virtually no emissions. As such, hydrogen fuel cell vehicles are set to be the driving force of a new hydrogen-based society as well as being a pillar in the future of mobility (Hyundai Motors Group, 2020 a).

Hydrogen safety, technical regulations and standards are becoming ever more important as standards are becoming “the new guns in global competition” (Cargill, former Standards Director of Netscape). Hydrogen specific codes and standards are an enabler for the growth of emerging hydrogen fuel cell markets by providing a sound basis for certification and permitting activities (Burgess, McDougall, Newhouse, Rivkin, Buttner & Post, 2011).

In this research, we have found from the “Impact assessment” carried out, there are ten technical tests under the category of hydrogen containers and two technical tests under the category of hydrogen vehicle equipment and parts under the current technical standards in place that meet the standards of other developed countries.

There are thirteen technical tests for hydrogen containers and ten for hydrogen vehicle equipment and parts that need to undergo revision from the “impact assessment”. Of the technical tests that require review, most of these tests are included in Korea HVCS under a lower requirement. For instance, for the gas repeat test, under Korea HVCS, compressed air or nitrogen is adequate for testing, while under ECE R 134, the test is required to be carried out with hydrogen gas. There are also a few technical tests that are entirely excluded in the domestic standards (summary of results are summarized in Table 4-1).

On the whole, “Impact Assessment” proves Korean technical regulations need to be revised upward to reflect stringent standards of peer countries where technological change is rapid.

The issue of whether South Korea is equipped to carry out additional testing for more stringent standards is analysed with the “Impact Assessment” results, to show Korea is currently equipped to test for most of the upgrades in the standards. In fact, Korea is equipped to carry out tests for not only domestic technical standards but also for European certification such as the Technical Inspection Association (TUV SUD), the Technical Service Provider TUV Nord, the Institute for Applied Automotive Research (IDIADA), and the Vehicle Certification Agency (VCA). These findings are significant as they provide solutions to policy makers to reflect such areas of stringent technical standards with the existing testing infrastructures.

The reason why these finding are important was also discussed in the section on implications of standards on technical innovation in this research. Regulation standard setting is lagging behind technology for HVCS in Korea (discussed under implications), therefore it can be argued the government is not playing the role of protecting domestic corporations’ interests. Current FCEV certification standards allow overseas hydrogen vehicles parts ease of entry into Korea. This opens up the domestic market to being vulnerable to low standard imports. This exposure poses a threat to existing high-quality domestic products that would naturally lose price competitiveness against these lower standard products. Further, the current domestic certification standards of hydrogen vehicles (testing of its parts) means that in order to export, South Korean domestic firms have to undergo double testing to comply with both domestic and overseas standards. Coordination of standards development activities, both national and international, is necessary to prevent duplication of effort and development of conflicting requirements (Cairns, 2010).

Fortunately, Korean corporations are investing heavily with the knowledge that actively participating in setting standards will help protect and elevate their competitive advantage. The reason is because different standards testing and certification measures for products and services are among the most important technical barriers to trade (Tassey, 2017). Following Korean corporations, the Korean Government needs to take a more significant role in building the existing frame of technical standards for hydrogen vehicles, like the United States has done.

UN GTR international standards or the latest ECE regulations that parallel GTR standards are becoming recognized as the benchmark in hydrogen vehicle technical regulations. It may be difficult to implement all GTR/ECE technical regulations at once. Therefore, it is favorable to adopt the standards in the section of this paper entitled “impact assessment” from high to low (deduced from the analysis in this research).

Technical standards facilitate trade, protect domestic corporations, support technological growth, and overall effective and efficient regulatory approval procedures that accommodate the interests of the general public. HVCS needs improvement as Korea works towards GRT-13, aligning national standards with international requirements will facilitate international trade, and provide the basis for international-to-regional harmonization of standards (Burgess, McDougall, Newhouse, Rivkin, Buttner & Post, 2011).

Appendix A.

< Hydrogen container testing standards>

Technical tests			Ministry of Land, Infrastructure & Transport Legislation	EC79	HGV2	GTR
Material testing	Liner	Tensile yield strength	3.1.3.4.1 Liner tensile test	4.1.1 Tensile test	6.7 Non-metal liner	
		Softening temperature	3.1.3.4.5 Softening temperature test	4.1.2 Softening temperature test	6.7 Non-metal liner	
		Fault test	2.6.2.1.2			
	Epoxy resin	Sheer strength (ILSS)	3.1.3.4.7 Resin shear strength test	4.1.4 Resin shear strength test	6.6 Resin	
		Glass transition temperature test	3.1.3.4.6 Glass transition temperature test	4.1.3 Glass transition temperature test		
	Fiber material	Tensile strength	2.2.3.1 Tensile strength		6.3.3 Tensile tests for metals	

	Aluminum	Sustained load cracking rest (SLC)	3.1.3.4.4 Internal Stress Crack test (Sustained Load Cracking, SLC)	4.1 Material test	6.3.4 Sustained load cracking test for aluminum	
		Corrosion test	3.1.3.4.3 Corrosion resistance test	4.1 Material test	6.3.5 Corrosion test for aluminum	
	Others	Coating test	2.7 Protective coating 3.1.3.4.8 Protective coating test	4.1.5 Coating test 4.1.6 Coating batch test	6.4 Ultraviolet resistance of external coating test	
Container test	Verification tests for baseline metrics	Burst test	3.1.3.5 Burst test	4.2.1 Burst test	18.3.5 Burst test	5.1.1.1 Burst test
		Ambient temperature cycling	3.1.3.6 Ambient temperature pressure cycle test	4.2.2 Ambient temperature pressure cycle test	18.3.2 Ambient temperature pressure cycle test	5.1.1.2 Ambient temperature pressure cycle test
		Leak before break (LBB) test	3.1.3.7 Leak before break (LBB) test	4.2.3 Leak before break (LBB) test	18.3.14 Leak before break (LBB) test	
		Drop test	3.1.3.14 Drop test	4.2.10 Drop test	18.3.7 Drop test	
		Flaw test	3.1.3.11 Composite flaw tolerance test	4.2.7 Composite flaw tolerance test	18.3.6 Composite flaw tolerance test	
		Environment test	3.1.3.10 Environment test	4.2.6 Environment test	18.3.3 Environment test	
		Accelerated stress rupture test	3.1.3.12 Accelerated stress rupture test	4.2.8 Accelerated stress rupture test	18.3.9 Accelerated stress rupture test	

		Extreme temperature cycling test	3.1.3.13 Extreme temperature cycling test	4.2.9 Extreme temperature cycling test	18.3.4 Extreme temperature cycling test	
		Hydraulic sequential tests				5.1.2.1 Proof pressure test 5.1.2.2 Drop(impact) test 5.1.2.3 Surface damage test 5.1.2.4 Chemical exposure test 5.1.2.5 High temperature test 5.1.2.6 Extreme temperature pressure cycling test 5.1.2.7 Excess current test 5.1.2.8 Burst test
	Gas testing	High strain rate impact test	3.1.3.9 High strain rate impact test	4.2.5 High strain rate impact test	18.3.10 High strain rate impact test	
		Airtight test	3.1.3.15 Airtight test	4.2.11 Airtight test		
		Boss torque test	3.1.3.17 Boss torque test	4.2.13 Boss torque test	18.3. Boss torque test	
		Gas permeation test	3.1.3.16 Permeation test	4.2.12 Permeation test	18.3.11 Permeation test	
		Hydrogen gas cycling test	3.1.3.18 Hydrogen gas cycling test	4.2.14 Hydrogen gas cycling test	18.3.13 Hydrogen gas cycling test	

		(Bon)fire test	3.1.3.8 (Bon)fire test	4.2.4 (Bon)fire test	18.3.8 (Bon)fire test	5.1.4 Verification test for service terminating performance in fire
		Pneumatic sequential tests (Verification tests for expected on-road performance)				5.1.3.1 Proof pressure test 5.1.3.2 Ambient and extreme temperature gas pressure cycling test(pneumatic) 5.1.3.3 Extreme temperature static gas pressure leak/permeation test (pneumatic) 5.1.3.4 Residual proof pressure test 5.1.3.5 Residual strength burst test
		Hydraulic pressure repeat process				
		Gas repeat test process				

Appendix B

< Technical standard comparison for hydrogen vehicle equipment and parts >

No.	Domestic classification (Appendix 7)	Domestic classification (Appendix 11))	EC 79/EU 406	HGV 3.1	ECE R 134
	9 tests	9 tests	9 tests	15 tests	13 tests
1	Hydrogen compatibility test (metal)	Hydrogen compatibility test (metal)	Compatibility test		
2	Hydrogen compatibility test (non-metal)	Hydrogen compatibility test (non-metal)			
3	Ageing test	Ageing test	Ageing test	Atmospheric exposure test	Atmospheric exposure test (shut-off valve)
4	Ozone compatibility test	Ozone compatibility test	Ozone compatibility test		
5	Corrosion resistance test	Corrosion resistance test	Corrosion resistance test	Salt spray exposure test	Salt corrosion resistance test
6				Accelerated cyclic corrosion test	Stress corrosion cracking test
7	Endurance Test	Endurance Test	Endurance test	Continuous operation test	Pressure cycling test (TPRD)

8					Temperature cycling test
9	Hydraulic pressure cycle test	Hydraulic pressure cycle test	Hydraulic pressure cycle test	Hydrostatic strength	Hydrostatic strength test (Shut-off valve)
10	Internal leakage test	Internal leakage test	Internal leakage test	Internal leakage test	Leak test
11	External leakage test	External leakage test	External leakage test	External leakage test	
12				Excess torque resistance test	
13				Bending moment test	
14				Ultraviolet resistance of external surfaces test	
15				Automotive fluid exposure test	Vehicle environment test
16				Abnormal electrical voltages test	Electrical tests (Shut-off valve
17				Vibration resistance	Drop and vibration test
18				Insulation resistance test	
19				Pre-cooled hydrogen exposure test	Pre-cooled hydrogen exposure test
20					Bench top activation test (PRD)
21					Flow rate test (PRD)

References

Adler, A. (2019). *Toyota, Nikola and Shell seek fuel cell truck-fueling standards*. Retrieved from Trucks.com: https://www.trucks.com/2019/02/21/toyota-nikola-hydrogen-truck-fueling/

Azim, E. (2005). The political economy of technical regulations. Available from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.491.1450&rep=rep1&type=pdf

Blind, K. (2009). Standardization as a catalyst for innovation, ERIM Report Series References, EIA-2009-LIS. Technische Universität Berlin.

Burgess, R.M., McDougall, M., Newhouse, N.L., Rivkin, C., Buttner, W.J., & Post, M.B. (2011). Validation testing in support of hydrogen codes and standards development USA: International conference on hydrogen safety presentation material.

Cairns, J. (2010). North American and international hydrogen/fuel cell standard. *International Journal of Hydrogen Energy*, *35*(7), 2767-2771.

Carcassi, M., Tchouvelev, A., Jordan, T., & Hawksworth, S. (2019). Preface to the special issue on the 7th International Conference on Hydrogen Safety (ICHS 2017). *International Journal of Hydrogen Energy*, *44*(7), 8681.

Council Regulation (EC) 13/2009 of 14 January 2009 on type-approval of hydrogen-powered motor vehicles, and amending Directive 2007/46/EC (2009) *Official Journal* L35/32.

CSA Group. (2013). *Fuel system components for compressed hydrogen gas powered vehicles.* Misssissauga: CSA Group.

CSA Group. (2014). Compressed hydrogen gas vehicle fuel containers (ANSI HGV 2-2014).

DOE OFFICE of ENERGY EFFICIENCY & RENEWABLE ENERGY, Fuel Cell Technologies Office, Fuel cell system.

Egan, M. (2002), Setting standards: Strategic advantages in international trade. *Business Strategy Review*, *13*(1), 51–64.

Grossman. G. M-. & Helpman.E. (1994). Endogenous innovation in the theory of growth, *Journal of Economic Perspectives*, *8*(1), 23-44.

Hydrogenics. (n.d.). *Hydrogen technology*. Available from https://www.hydrogenics.com/technology-resources/hydrogen-technology

Hyundai Motors Group. (2020). *All about FCEVs: How safe are fuel cell electric vehicles.* Available from Hyundai Motors Group Newsroom: https://news.hyundaimotorgroup.com/Article/How-safe-are-Fuel-Cell-Electric-Vehicles (a)

Hyundai Motors Group. (2020). *Hydrogen tank: Safety proven.* Available from Hyundai Motors Group Newsroom: https://news.hyundaimotorgroup.com/Article/Hydrogen-Tank-Safety-Proven (b)

Hyundai Motors Group. (2020). *What makes fuel cell electric vehicles safe?* Available from Hyundai Motors Group: https://tech.hyundaimotorgroup.com/article/what-makes-the-fuel-cell-electric-vehicle-safe/ (c)

International Energy Agency. (2017). *Global outlook and trends for hydrogen*. Available from http://ieahydrogen.org/pdfs/Global-Outlook-and-Trends-for-Hydrogen_Dec2017_WEB.aspx

International Renewable Energy Agency. (2019). *Hydrogen: A renewable energy perspective*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Hydrogen_2019.pdf

Kim, J. H., & Lee, C. C. (2019). *Mobility policy proposal for safe hydrogen economy*. Policy brief No.731. Korea Research Institute for Human Settlements.

Kim. J. W. & Lee, J. C. (2019). *Mobility policy proposal for a safe hydrogen society*. Presentation, Korea Research Institute for Human Settlements.

Lee, D. H., Kim, W. J., Kim, B. G., Baek, D. H., & Kim. H. C. (2019). The Approach Method of *improvement* of certification criteria for fuel cell electric vehicle. *Korea Society for Energy*, *2019*(5), 150-150.

Michael, B. J., Anshuman, K., & Mayo, M. C. (2005). Hydrogen: The energy source for the 21st century. *Technovation*, *25*(6), 569-585.

Ministry of Land, Infrastructure and Transport. (2013, September). *Vehicle pressure resistant container safety regulations*. (Amended by Issuance No. 562, 2013).

Mo, K. F. (2019). *CEV technological development*. Presentation, The Korea Society of Automotive Engineers.

Nole, S. (1998). Avoiding confusion: A case for establishing standards for measures of effectiveness. ITEA Journal for Test and Evaluation, *19*(3), 26-30.

O'Sullivan, E., & Brévignon-Dodin, L. (2012). Role of standardisation in support of emerging technologies: A study for the Department of Business. Innovation & Skills (BIS) and the British Standards Institution (BSI). Cambridge: Institute for Manufacturing.

Rifkin, J. (2001). *The hydrogen economy: The creation of the worldwide energy web and the redistribution of power on Earth.* Oxford: Polity Press.

Sherif, M. H. (2001). A framework for standardization in telecommunications and information technology. *IEEE Communications Magazine, 39*(4), 94-100.

Tassey, G. (2017). The roles and impacts of technical standards on economic growth and implications for innovation policy. *Annals of Science and Technology Policy*, *1*(3), 215-316.

U.S. Department of Energy. (2002*). National hydrogen roadmap*. Washington, DC: The U.S. Department of Energy.

U.S. Department of Energy. (2015). Fuel cell technologies office multi-year research, development, and demonstration plan. Available from https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22.

United Nations Global Registry, *Global technical regulation on hydrogen and fuel cell vehicles*, Global technical regulation No.13, ECE/TRANS/180/Add.13 (27 June 2013).

United Nations Economic Commission for Europe, Agreement Addendum 133-Regulation No.134.

Wilson, J. S., & Otsuki, T. (2004). Standards and technical regulation and firms in developing countries: New evidence from a world bank technical barriers to trade survey. World Bank.s

Yeom, J. W., Cho, S. M., Moon, J. S. & Lee, S. K. (2018). Analysis of international standard for evaluation of durability of container in hydrogen electric vehicle.

Yong, G. J., & Lee. K.B. (2014). Development of safety assessment for hydrogen fuel cell vehicle. *The Korean Hydrogen and New Energy Society*, *25*(5), 500-508.