REGULATIONS, CODES AND STANDARDS (RCS) FOR HYDROGEN TECHNOLOGIES
A US HISTORICAL OVERVIEW

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ABSTRACT

RCS for hydrogen technologies were first developed approximately sixty years ago when hydrogen was being sold as an industrial commodity. The advent of new hydrogen technologies, such as Fuel Cell Electric Vehicles (FCEVs) created a need for new RCS. These RCS have been developed with extensive support from the US DOE. These new hydrogen technologies are approaching commercial deployment and this process will produce information on RCS field performance that will create more robust RCS.

1.0 INTRODUCTION

RCS are required for the safe deployment of hydrogen technologies. Without RCS public safety may not be protected sufficiently and Code Officials will have difficulties permitting projects. This paper will give an historical overview of the development of the RCS required to deploy hydrogen technologies. The primary focus of the paper will be on hydrogen fuel cell applications as opposed to more established chemical production processes that utilize the majority of hydrogen [1]. Hydrogen technologies include:

- Fuel Cell Electric Vehicles (FCEVs)
- Stationary fuel cells for power generation
- Fuel Cell Electric Vehicle repair facilities
- Hydrogen generation equipment (such as electrolyzers)
- Hydrogen production equipment (such as Steam Methane Reformers (SMRs))
- Hydrogen cooling systems
- Chemical production processes utilizing hydrogen such as;
    - Ammonia production
    - Petroleum refining
    - Float glass production
    - Electronic component manufacturing

The definitions of RCS taken from the International Building Code 2012 (NFPA 1 or 5000) edition that reflects the most widespread usage are as follows [2]:

Regulation- a legal requirement promulgated by the executive branch of government under the authority of a law promulgated under the legislative branch of government.

Code – a high level document written in legally enforceable language that can be adopted and made law by a jurisdiction

Standard - a document with a relatively narrow scope that provides detailed requirements to implement the more general requirements dictated in a code.

2.0 RCS HISTORY

The development of RCS in the United States for hydrogen technologies tracks the development of hydrogen technologies with varying lag times. RCS have become much more comprehensive and detailed since the initial development of US RCS in the late 19th century (sprinkler standards)[1]. The expansion of hydrogen in the industrial gas industry in the 1950s led to the promulgation of Compressed Gas Association (CGA) component and system standards and the development of National Fire Protection Association (NFPA) 50A[3] and NFPA 50B[4], the first widely used hydrogen specific standards. The advent of new applications for hydrogen in the last twenty years has spurred the need for and development of more comprehensive and detailed hydrogen RCS.

The US DOE has supported the development of hydrogen specific RCS and this effort has culminated in a baseline set of hydrogen RCS that allows for both stationary and vehicular hydrogen fuel cell project deployment. The DOE effort has focused on research to address code issues, outreach to provide information on RCS, and geographically targeted training to support infrastructure projects. These RCS will need to be modified as more information is produced from deployment projects and technology develops. This process of modifying RCS to incorporate lessons learned from deployment and new technology is called by NREL Continuous Codes and Standards Improvement (CCSI). This CCSI process is very similar to the American National Standards Institute (ANSI) process for creating and revising codes and standards that all ANSI compliant Standard Development Organizations (SDOs) follow. The difference is in the CCSI process the action of reviewing field data is specifically identified and the information from these data are incorporated into the RCS revision process. In the ANSI process field data might be reviewed but it is not a required part of the ANSI process.

Table 1.Timeline for the development of Hydrogen RCS

Date	Document
1965-1970	NFPA 50A Standard for Gaseous Hydrogen. Systems at Consumer (NFPA 50A) NFPA 50B Standard for Liquefied Hydrogen. Systems at Consumer Sites (NFPA 50B)
1965-1970	Development of first hydrogen specific CGA Standards
1970s	OSHA 29 CFR 1910 Subpart H Hydrogen Regulations
1970s	DOT Hazardous materials regulations
1970s	Development of DOT regulations for the transport of hydrogen in commerce
1998-2000	Development of NFPA 853 Standard for the Installation of Stationary Fuel Cell Power

	Systems (NFPA 853)- 1998-2000
1998-Ongoing	Development of SAE fuel cell vehicle standards
1998-Ongoing	Development of CSA H series of hydrogen component standards
2004-2013	Development of Global Technical Regulations for fuel cell vehicles
2000-2003	Development of hydrogen specific requirements in the International Fire Code and other International codes 2000-2003
2002-2005	Development of NFPA 52 Vehicular Alternative Fuels Code (NFPA 52) for fueling hydrogen fuel cell vehicles
2005-2010	Development of NFPA 2 Hydrogen Technologies Code
2000-2014	International hydrogen safety standards – ISO activities 2000-Ongoing

2.1 Regulatory Structure for Hydrogen Technologies

The regulatory structure in the US follows the hierarchy of Federal Regulation, State Regulation, and Local ordinances

Federal regulations apply to the entire US. States and other jurisdictions can adopt laws and regulations based on their specific needs. A law is promulgated by the legislative branch of government and a regulation, typically more detailed than a law and containing the required enforcement content, is promulgated by the executive branch of government. For example the US Congress passed the OSHA act of 1970 which led to the promulgation of 29 CHR 1910 Subpart H regulations which addresses the bulk storage of gaseous and liquefied hydrogen.

State and local ordinances can be more stringent than Federal regulations but cannot relax requirements in Federal regulations. The specific and detailed requirements found in Codes and Standards that address hydrogen technologies typically derive their legal authority through adoption by a jurisdiction of a building and fire code. A jurisdiction is a legal entity that has the authority to enforce laws and regulations. Examples of jurisdictions are States, Cities, and Counties. Figure 1. Codes & Standards Hierarchy shows the legal path of requirements from the adoption by a jurisdiction of a Building and Fire Code. The Building and Fire Codes reference technology or application specific codes and standards. This reference makes them legally enforceable documents. These technology or application specific standards reference component standards which makes these standards legally enforceable documents.

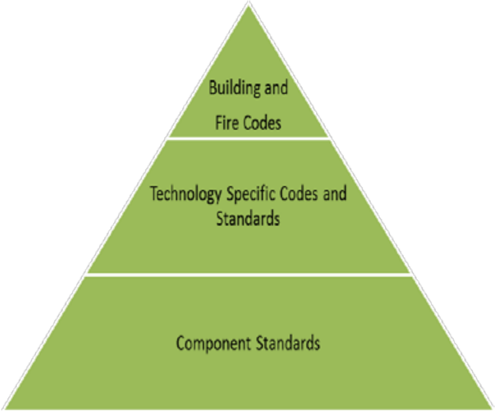

Figure1. Codes & Standards Hierarchy

2.2 The Early Years of Hydrogen RCS: 1960-1995 Regulations Codes and Standards for Industrial Hydrogen Applications

Chemical processes for both the production of hydrogen and the utilization of hydrogen were developed in the early twentieth century [5]. The development of the Haber-Bosch process for commercial scale production of ammonia was one of the first processes to utilize hydrogen. The Haber – Bosch process for producing ammonia developed in 1913 created large demand for hydrogen. The basic equation for the Haber Bosch process is shown in Equation 1. Haber - Bosch process.

$$(1)\ N_2 + 3\ H_2 \rightarrow 2\ NH_3 \quad (\Delta H = -92.4\ kJ \cdot \underline{mol}^{-1})[5]$$

There were no Federal Regulations that specifically addressed chemical or hydrogen production or utilization worker safety until the creation of the DOT Hazardous Material Regulations in 1970 and the Occupational and Health Safety Administration (OSHA) in 1970.There were state safety programs to protect workers but these programs were inherently inconsistent across states [6]. Plant workers followed company safety guidelines that were typically company enforced. In 1907, 362 coal miners were killed at Monongah, W. Va., in the worst U.S. mine disaster measured by number of fatalities. This incident led to the creation in 1910 of the U.S. Bureau of Mines to promote mine safety. The chemical process and petroleum refining industries were unsafe compared to current industry safety performance. [7] They were regulated primarily at a State level with large variations from state-to-state.

The 1970 OSHA act led to the promulgation of regulations that addressed hydrogen safety, 29 CFR1910 Subpart H. These regulations were copies of the 1968 edition of NFPA 50A and 1969 edition of NFPA 50B [8]. These regulations addressed bulk storage systems. The originated out of the concern that consumers of hydrogen might not be familiar with hydrogen safety, hence the term consumer in the title. The supplier would typically be an industrial gas company and the standards applied to consumer sites were the industrial gas company supplied hydrogen. The standard did not apply to hydrogen stored at hydrogen production facilities.

Figure 2. East 20th Street between 2nd Avenue and 1st Avenue, looking east towards 1st Avenue, in Manhattan, New York City in 1938.[9]

The gas storage tank shown in Figure 2 at the eastern end of 20th street probably contains Town gas which is manufactured gas often made from coal. Assuming that this tank contains a flammable gas, if sited according to current RCS would be subject to the setback distances in NFPA 55. Although, it is not clear where the lot line is relative to the tank in the photograph, it appears that it would not meet the lot line setback distance. The current requirements for safe siting of bulk gases are an example of a gap that RCS now address.

2.3 Codes and Standards for Emerging Hydrogen Technologies 1995-2012

In the 1990s, a developing interest in hydrogen as a fuel for fuel cells brought on a new round of RCS work focused on developing requirements for stationary fuel cells, FCEVs, fuel cell powered industrial trucks, and infrastructure to support FCEVs. The interest in fuel cells was driven by several factors including their higher efficiency compared to internal combustion engines and the absence of carbon emissions from the operation of the fuel cell.

This interest in these new applications for fuel cells in the 1990s translated into RCS project work in the early 2000s. One of the major issues that RCS needed to address was bringing hydrogen out of the industrial environment and into the retail environment. Hydrogen fueling stations for FCEVs would in most cased be publicly accessible. The general public would be conducting vehicle fueling operations. The new hydrogen technology applications required RCS development. Table 2. Regulations, Codes and Standards for Hydrogen Technologies illustrates the different application areas and the RCS developed to address these new applications.

Table 2. Regulations, Codes and Standards for Hydrogen Technologies

Requirements for the design, installation, and operation of stationary fuel cells	
Documents	Subject Matter
NFPA 853 Standard for the Installation of Stationary Fuel Cell Power Systems	Addresses installation requirements for stationary fuel cell systems including hydrogen powered systems

NFPA 55 Compressed Gas and Cryogenic Fluids Code	Addresses requirements for storage of hydrogen in bulk and non-bulk configurations
CSA Fuel Cell (FC)1	Addresses requirements for the design and operation of fuel cells
Requirements for FCEVs	
Documents	Subject Matter
SAE J2578 Recommended Practice for General Fuel Cell Vehicle Safety	Addresses general safety issues
SAE J2579 Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles	Addresses fuel system integrity and performance
SAE J2719 Hydrogen Fuel Quality for Fuel Cell Vehicle	Addresses allowable contaminant levels for select materials
SAE J2601 Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles	Addresses fueling protocols setting allowable temperature and pressure parameters to achieve desired fill time
SAE J2600 Compressed Hydrogen Surface Vehicle Fueling Connection Devices	Addresses requirements for the fueling nozzle
GTR Global technical regulation (GTR) on hydrogen and fuel cell vehicles-Established in the Global Registry on 27 June 2013	Addresses requirements for vehicle fuel system
SAE J2601/2 Fueling Protocol for Gaseous Hydrogen Powered Heavy Duty Vehicles	Addresses fueling protocols setting allowable temperature and pressure parameters to achieve desired fill time
SAE J2601/3 Fueling Protocol for Gaseous Hydrogen Powered Industrial Trucks	Addresses fueling protocols setting allowable temperature and pressure parameters to achieve desired fill time
Requirements for Infrastructure	
Documents	Subject Matter
International Fire Code (IFC)	Addresses basic hydrogen fueling system safety and flammable gas and cryogenic fluid storage
NFPA 55 Compressed Gases and Cryogenic Fluids Code	Addresses the safe storage, handling, and use of flammable gases including hydrogen
NFPA 2 Hydrogen Technologies Code	Addresses all aspects of the safe, design, use, and storage of hydrogen
ASME Boiler and Pressure Vessel Code , Section	Addresses safe design of pressure vessels

XIII	for hydrogen storage
ASME B31.12 Hydrogen Pipelines and Piping	Addresses the design, installation, and testing of hydrogen piping and pipelines
CGA standards for pressure relief and venting and CGA H documents	Addresses safe design and use of hydrogen storage system components
CSA Standards for fueling system components	Addresses safe performance of hydrogen fueling system components
ISO Hydrogen component standards	Addresses safe performance of hydrogen fueling system components

The development of these RCS created the basic requirements for the deployment of hydrogen technologies and is a major accomplishment in addressing safety concerns for the emerging technologies that employ hydrogen. These RCS are now in position to be tested by the deployment of hydrogen technology projects.

As hydrogen technology projects are deployed it is likely that issues with the RCS will surface. Examples of these issues are conflicting requirements, poorly worded requirements that can be clarified, technology developments that are not addressed in current RCS, and field data that indicates required RCS revisions [10].

During the effort to develop RCS to address emerging hydrogen technologies, many resources have developed that should be effective in addressing the revisions to RCS that will be required as deployment proceeds. Many of these resources are either DOE national laboratory capabilities or technical code development groups that DOE has supported. These resources will likely prove to be very helpful in addressing the future RCS revision needs. These resources include the National Hydrogen and Fuel Cell Coordinating Committee, H2First, and H2USA.

The National Hydrogen and Fuel Cell Coordinating Committee is a DOE supported group that meets on a monthly basis to share information on RCS activities. Many of the SDOs are represented on this committee and provide updates on their projects.

2.4 Codes and Standards for Deployment of Emerging Hydrogen Technologies 2012-beyond

Current hydrogen fueling stations are low volume fueling operations fueling substantially fewer vehicles than a conventional gasoline station. As the fueling volume increases, there will be more wear on components. This increased wear may translate into failure modes that were not anticipated in the system design. This new failure information could require that component test standards or system installation codes be modified to prevent these failures. These modifications could address a wide range of issues including material selection, system integration to increase efficiency and reduce system wear, control software for dispensing systems, modified maintenance schedules or procedures, and improved ergonomics.

Hydrogen has been used in industrial processes for over one hundred years [6]. Hydrogen has not been placed in a retail environment where the general public would handle hydrogen dispensing equipment. This exposure means that hydrogen dispensing equipment must be very reliable and simple to operate. As the level of deployment increases, there will likely be issues that surface regarding fueling operations and ways to make these operations less vulnerable to system malfunction or operator error.

As FCEV deployment proceeds, vehicles will move through the phases of their life cycle. This movement through the life cycle will produce issues that include repair work at facilities other than dealerships where personnel may be less familiar with FCEV and their energy storage and transfer systems, work by private individuals on high pressure storage systems, performance of after-market parts, disposal of hazardous materials, and depressurization of high-pressure hydrogen gas storage systems [10].

All of these issues are the manifestation of a technology proceeding through the deployment process. They present safety challenges that can be solved and these solutions will have a place in the RCS.

The RCS that have been developed form a good basis for addressing the safety issues that will appear with widespread deployment. In addition to having fairly comprehensive requirements for a developing technology, the structure also exists with RCS to identify and address required changes. The American National Standards Institute (ANSI) process that most Codes and Standards development organizations follow requires periodic review and updating of documents. This ANSI process combined with the active participation of the hydrogen technologies user community will ensure that documents reflect the development in technology as well as the lessons learned in deployment. NREL has developed a process that compliments the ANSI process called Continuous Codes and Standards Improvement (CCSI) that uses information from deployment activities to improve code and standards [12].

2.5 US Department of Energy Contributions to Codes and Standards Development

The US Department of Energy, Fuel Cell Technologies Office (FCTO) has supported the development of RCS through several activities including:

- Coordination of Codes and Standards development
- National Laboratory technology contributions to codes and standards development
- Data collection and analysis of deployment projects
- Risk informed safety requirements for bulk hydrogen storage
- Materials research to support development of codes and standards
- Sensor evaluation to support UL2075
- Contaminant evaluation to support SAE J2719 Fuel Quality Standard
- Tank integrity testing to support the development of SAE J2579 and the Global technical Regulations for fuel cell vehicles [13].

Sections 2.5.1 and 2.5.2 provide a more in-depth picture of some of these project areas.

2.5.1 Sandia National Laboratories Projects

Risk-informed separation distances in the fire code

Experts at Sandia National Laboratories have worked closely with the NFPA 2 and 55 code committees to develop a risk-informed framework to revise separation distances in the fire code. This methodology combines the physical characteristics of high-pressure hydrogen releases and consensus-based harm criteria from quantitative risk assessment to determine safe distances for the deployment of hydrogen infrastructure with respect to the surroundings. Analysis of the risk-informed safety distances in NFPA 2 (2008 revision), for example, were found to enable the deployment of hydrogen refueling infrastructure at an estimated 20% of the existing gasoline stations in California, while previous versions of the code would prevent these deployments [14]. Additionally, NFPA 2 allows a performance-based design (PBD) strategy to approve the permitting of hydrogen infrastructure; PBD requires quantitative risk assessment to show that the a given design has the same risk profile as a generic station design that meets the prescriptive safety distance requirements in the code. Sandia is currently developing a scenario-based methodology to meet the PBD requirements of the code as well as comprehensive risk-modeling software called Hydrogen Risk Assessment Models (HyRAM). These tools will aid safety review, design optimization and PBD risk assessments of hydrogen infrastructure as well as supporting the permitting process and qualification of code requirements. These innovations in the code were enabled by unique experimental capabilities for characterizing hydrogen jets in the Turbulent Combustion Laboratory at Sandia National Laboratories (Combustion Research Facility, Livermore CA), innovative combination of combustion physics and quantitative risk assessment, as well as state-of-the-art computational fluid dynamics (CFD) tools.

Methods for qualification of materials for hydrogen service

There are several standards for qualification of materials for hydrogen service [15, 16], depending on the application. However, there are relatively few laboratories in the world with experimental equipment for measuring the properties of materials with concurrent exposure to gaseous hydrogen environments. The Hydrogen Effects on Materials Laboratory (HEML) at Sandia National Laboratories (Livermore CA) maintains such equipment and expertise, co-funded by DOE's Safety Codes and Standards program and other DOE customers. The development of testing methodologies for qualifying materials for high-pressure hydrogen service [17] is one of the core missions of the HEML. Article KD-10 in the ASME BPVC VIII.3 [18] provides rules for qualifying pressure vessels for service in gaseous hydrogen at pressures greater than 700 bar. These rules include materials evaluation in gaseous hydrogen, which were developed in coordination with testing in the HEML. Recently an additional test methodology was developed in the HEML to improve evaluation of hydrogen-assisted fracture [19, 20] and has been adopted in the CHMC1 standard from CSA Group [21]. The CHMC1 standard was developed with leadership from the HEML and also proposes a new method for fatigue assessment of material. Current laboratory work in the HEML seeks to inform the existing document and future revisions to the test methodology proposed in CHMC1 as well as SAE J2579 [22].

While materials evaluation in gaseous hydrogen is the core expertise of HEML, full-scale component evaluation can also be performed at HEML. High-pressure cycling of pressure vessels with gaseous hydrogen was funded by DOE's Fuel-Cell Technologies Office (FCTO) and performed at HEML [23, 24]. The testing protocol and qualification strategy developed in the course of this testing informed the development of the performance-based rules for pneumatic testing (i.e., with gaseous hydrogen) in SAE J2579 [22] and the draft standard from CSA Group HPIT1 [25], as well as provided the safety basis for the widespread deployment of hydrogen-powered materials handling equipment (e.g., the replacement of batteries on forklifts with hydrogen fuel-cell power units).

2.5.2 Los Alamos National Laboratories Fuel Quality Project/Hydrogen fuel quality and its effect on PEM fuel cell performance

2.5.2.1 Introduction

The durability and cost of polymer electrolyte membrane (PEM) fuel cells have been identified as the key technical barriers to the commercialization of this promising technology. As such, durability issues in PEM fuel cells have garnered increasing attention over the past decade and various degradation mechanisms affecting membrane and catalyst durability have been identified and mitigation strategies developed. [26,27] Operating conditions such as voltage cycles and high RH-operation have been identified as detrimental to the electro-catalyst durability, while low RH operation around OCV is detrimental to membrane durability. Moreover, high voltages encountered during startup/shutdown can result in support corrosion and associated fuel cell performance loss. In addition to these, impurities in the air and hydrogen streams can also result in additional degradation mechanisms in PEM fuel cells. Therefore it is critical to understand and mitigate the effects of these contaminants on fuel cell performance. [28, 29]

The hydrogen fuel can be obtained from various sources including steam reforming or partial oxidation of fossil fuels (mainly natural gas), gasification of coal or biomass, electrolysis of water, photo-electrochemical water splitting etc. Today, 95% of the hydrogen produced is obtained from fossil fuels with steam reforming of natural playing a major role. The main impurities present in H_2 obtained from fossil fuel sources are CO, CO_2, H_2S, NH_3, CH_4 and other hydrocarbons.[30] Contaminants such as H_2S, CO, and NH_3, even at the part per billion (ppb) levels, in the fuel stream have been shown to affect the PEMFC's overall performance and durability. [28, 29] Research suggests that there are 2 primary degradation mechanisms by which the impurities affect the performance of fuel cell membrane electrode assemblies (MEAs). First, the contaminant may lower the ionic conductivity in the catalyst layer and/or in the bulk membrane. This particular phenomenon has been observed and attributed to cationic substitution of the impurity ion with proton in the ionomer phase. Secondly the contaminants can lower the performance of the electrodes due to adsorption on the electro-catalyst surface. [28,29] The effect of these contaminants can become even more pronounced as the DOE technical targets for platinum loadings are continuously being reduced and fuel cell systems are expected to maintain high performance at electro-catalyst loadings as low as 0.1 mg.Pt/cm^2 at the cathode and 0.025 mg.Pt/cm^2 at the anode.[31]

Recently published hydrogen fuel standards (ISO 14687-2 and SAE J2719) set the limits of the critical contaminants at levels up to 4 ppb H_2S, 200 ppm CO, and 100 ppb NH_3.[32,33] The DOE safety codes and standards program has evaluated the impact of these impurities in the hydrogen fuel on PEMFC performance. Initial evaluation was performed on membrane electrode assemblies (MEAs) with 0.2 mg.Pt/cm^2 loading operating at constant current. However more recent studies have started examining the effect of impurity concentration, potential cycling, and ultra-low Pt-loading on PEMFC performance. [34] A summary of the technical work performed in the DOE safety codes and standards program in support of the fuel quality standards is presented in the next section.

Open discussions and/or meetings have been held with original equipment manufacturers (OEMs), hydrogen suppliers, other test facilities from the North America team, and International collaborators regarding experimental results, fuel clean-up cost, modeling, and analytical techniques to help determine levels of constituents for the development of an international standard for hydrogen fuel quality (ISO TC197 WG-12). The group's focus has been to help determine the acceptable level of non-hydrogen constituents that would not cause any degradation in PEMFCs. Our approach was to ensure the validity and reproducibility of the data being produced, perform experiments to measure the effect of impurities on fuel cell performance and disseminate the data. Therefore, a DOE round robin test, with participation from four universities and two national laboratories, was initiated to increase confidence in the fuel impurities data to be generated by testing laboratories in support of the hydrogen fuel quality effort in order to gauge different test facilities. The round robin results would re-enforce the need for timely equipment calibrations and software upgrades, and proper adherence to test protocols to ensure data quality. In addition, WG12 members were to perform fuel cell testing at the agreed upon contaminant levels using a 'Common MEA' loaded at 0.1 and 0.4 mg Pt/cm^2 under various operating conditions.

The Pt loading on the 'common MEA' are higher than the DOE 2015 targets, since securing low loaded MEAs with good quality control was an issue at that time. Previous test results with contaminant mixtures showed that the fuel cell performance losses were due to hydrogen sulfide (H_2S), ammonia (NH_3), and carbon monoxide (CO).[35,36] These impurities are referred to as 'critical constituents'. Our fuel cell test results include investigating the critical constituents both isolated and combined.

2.5.2.2 Round Robin Testing

A fuel cell test article with a LANL in-house produced MEA was assembled and initially tested at LANL according to the USFCC/LANL protocol. The 50 cm^2 active area MEA was prepared using a ≈ 50 μm thick Nafion® membrane and 0.2 $mg.Pt/cm^2$ at each electrode. The fuel cell hardware was sent to the test labs along with detailed testing instructions. The tests performed included 'gross leak' test, hydrogen crossover measurements, cyclic voltammetry, and polarization curves. In each case, multiple Current-Voltage (IV) curves were obtained until the voltage deviations between the last three curves was less than 5mV. The article was then shipped to subsequent testers. After all of the test facilities completed their tests, the test article was returned to LANL for a re-test. Figure 3 shows IV curves with excellent reproducibility for the test article operated at 80°C with 25 psig back pressure and 100% relative humidity. The stoichiometric gas flows were 83% utilization for hydrogen and 50% for the air. Tests were conducted in constant current mode while the voltage at each current set point was recorded. The results indicated less than 6mV of deviation along the entire polarization curve, excluding the 11mV in the high current region (possibly due to liquid water). These results allowed us to determine if any degradation was observed in the test article during the round robin. Since there was no degradation, we were able to assimilate all of participants' results for a direct comparison.

2.5.2.3 Round Robin Testing Conclusion

The fuel cell studies conducted in support of the hydrogen codes and standards program reveal that the effect of impurities on fuel cell performance is influenced by the cell operating conditions. While impurity levels of CO and H_2S specified in the fuel quality standards will have an impact on the fuel cell performance at low Pt loadings, these effects can be significantly mitigated when operating at high temperatures and high RHs and during start/stop operations.

3.0 CONCLUSION

In the last twenty years the RCS for hydrogen technologies have developed from support of industrial use of hydrogen to a broad set of RCS that support retail deployment of hydrogen technologies for both stationary and vehicular applications. This expansion of RCS scope has been strongly supported by the US DOE and incorporated analytical tools such as CFD modeling and risk informed code development. At the present, commercial deployment of FCEVS and the infrastructure required to support these vehicles has begun.

As the deployment of hydrogen technologies proceeds, particularly the infrastructure to support FCEVs, RCS issues will surface. These issues will likely include

- System performance issues as hydrogen fueling stations move from very low volume fueling to commercial scale fueling.
- Unforeseen safety issues with hydrogen technologies usage among the general public
- Hydrogen technologies end of life RCS issues

The RCS will adjust to meet the demands of commercial deployment of hydrogen technologies. Thus use of feedback from field deployment through the CCSI will ensure the RCS address the critical issues using the tools developed to form the baseline RCS.

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