Section VI. Safety and Codes & Standards

VI.A Safety

VI.A.1 Gallium Nitride Integrated Gas/Temperature Sensors for Fuel Cell System Monitoring for Hydrogen and Carbon Monoxide

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Objectives

- Adapt catalytic gate field effect transistor (FET) sensors to resolve and detect carbon monoxide (CO) contamination levels from 1-100 ppm in reformer produced hydrogen (H_2) fuel for (proton exchange membrane (PEM) fuel cells
- Use FET sensors on gallium nitride (GaN) for increased sensitivity and faster response in high temperature
- Compare performance against industry requirements to assess outcome and opportunity
- Improve measurement precision and accuracy
- Field test for reliability and lifetime

Approach

- Design catalytic gate FET sensor for high temperature applications
- Build 1st generation FETs with platinium (Pt), rhodium (Rh) and palladium silver (PdAg) gates for evaluation
- Determine the performance requirements against which to measure performance
- Test and determine the population statistics for sensitivity, interferent resolution and temperature coefficients (electrical and chemical) for 1st generation devices
- Redesign for improved performance and build and evaluate 2nd generation test articles

Accomplishments

- Built GaN MODFET sensors with Pt, Rh and PdAg gate metallization
- Demonstrated CO sensitivity enhancement at $T \geq 150^oC$ for Pt and Rh GaN FET sensorss
- Demonstrated Pt sensitivity to CO from 0-100 ppm at 150, 250, 350 and 450^oC in 10%, 35 and 50% H_2 in diatomic nitrogen (N_2)
- Demonstrated Pt sensitivity to H_2 from 0-100% at 450^oC in N_2 background

Future Directions

- Fabricate 2nd generation sensors with high surface area gate metal films and architectures for greater sensitivity, adhesion layers under the gate metal for a higher yield of working devices, insulating nitride layers between the catalytic metal and the GaN substrate for reduced gate-drain leakage current and device protection, chromium/gold (Cr/Au) cap layers for protecting source and drain ohmic contacts and Ir and other new gate metals for greater resolution and interference rejection

- Design and build five low-cost prototypes including digital sensor control electronics for improved precision (ca. 1 millivolt)
- Adapt high temperature ceramic "spark plug" packaging for field testing
- Field test prototypes at Idatech, H_2Gen, Teledyne Energy Systems and National Renewable Energy Laboratory

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Introduction

The need addressed by this project is for a sensor to detect the presence of CO in the H_2 produced from hydrocarbon feedstocks in reformers and used to power PEM fuel cells. Low-cost sensors are not available for measuring CO at 1-100 ppm levels in a fuel cell environment. The primary goal of this project is to develop a low-cost microelectronic gas sensor for detecting CO (1-100 ppm) in the fuel stream. The sensors must operate in hydrogen (30-75%), with carbon dioxide (CO_2) (15%), CO (0-10,000 ppm), H_2O (30%), percent levels hydrocarbons, and N_2 (balance), from 1-3 atm total pressure and temperatures as high as 800^oC (Glass et. al. 2000). There is also a need for hydrogen sensors that can also be addressed by this technology and must be part of the CO measurement in order to remove the confounding effect of H_2.

Approach

The technical approach is a catalytic-gate (Pt, Rh and PdAg) GaN FET sensor for operating in high H_2 and at high temperature. The detection of hydrogen was reported first by Lundstrom (Lundstrom 1975) on a palladium gate FET sensor on silicon, but high temperature operation of silicon-based FETs is limited to <150^oC. A higher bandgap semiconductor FET specifically, GaN, was proposed to extend this range for potential improvements in sensitivity and response times. Recent reports on GaN Schottky diode sensors (Schalwig et al 2001) and silicon carbide (SiC) FET based sensors show enhanced sensitivity at high temperature to combustion gases and suggest the potential of the technology in automotive exhaust gas monitoring applications. These and other sensor developments for automotive and aerospace applications have been recently reviewed (Mueller et. al. 2001).

Results

The results reported previously were for CO dependence at constant hydrogen concentration (35%). The data demonstrated CO sensitivity that increased with increasing temperature, but potentially interfering effects of changing H_2 concentration were not explored. The Rh gate FET sensor was sensitive to CO above 200^oC with apparent sensitivity only above 200 ppm. The Pt sensor was sensitive to CO between 50 and 500 ppm at 150^oC. The interfering effects of O_2 on the Pt sensor are substantial. The scanning and transmission electron microscopy and X-ray analysis shows no interdiffusion of contact metallization with GaN at the resolution limit of the analysis (<125Å) for process temperatures to 600^oC for all of the gate metals and the Ti/Al source/drain metallization. The yield of working devices was <25% due to the poor adhesion of the gate metal to the gallium nitride.

Recent testing of Pt sensors extended sensitivity studies for CO and H_2 to 450^oC and suggested substantial confounding effects for changes in H_2 concentration from 30-75%. Device failure occurred in the range 550^oC-750^oC probably due to oxidation of the ohmic contact metallization. Preliminary indications are sensitivity to CO is high at low levels (0-20 ppm) (see Figure 1), but more experimental precision is necessary to confirm the results. The response is nonlinear and dependent on both temperature and H_2 and measurement precision is crude (Signal to noise ~3) with the first generation electronics. In addition, gas chromatography analysis using the helium ionization detector does not have sufficient precision below about 20 ppm CO for an accurate measurement of concentration. A more sensitive detector will be needed to accurately measure CO at levels below 20 ppm. Results show H_2 sensitivity of the Pt sensor is high below 5% H_2 and no saturation to 100% (see Figure 2).

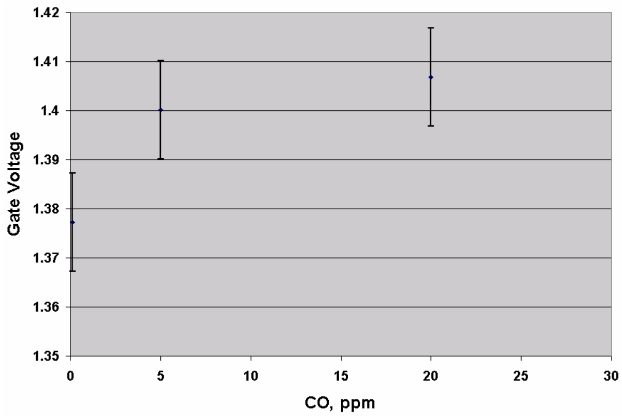

Figure 1. Pt Sensor Response with Low and Changing Concentrations CO in 35% H_2 at 450°C

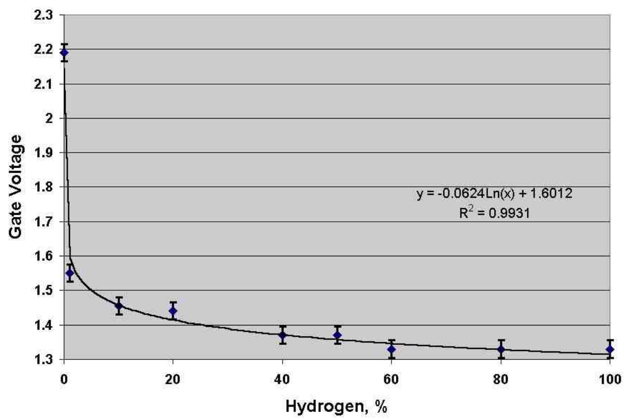

Figure 2. Pt Sensor Response with Changing H_2 at 450°C

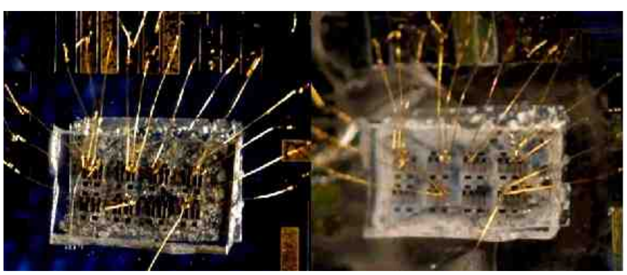

Figure 3. Comparison of Pt Sensor before and after Heating to 750°C shows the Black Rectangular Source and Drain Metallization Has Become Transparent Consistent

Sensor failure was promoted by increasing the temperature from 450°C to higher temperatures in 100°C increments in an oxidizing background gas consisting of 2% O_2, 10% CO_2, 100 ppm CO, and 100 ppm nitric oxide (NO), chosen for a more aggressive environment characteristic of combustion gas. The damage to the sensor and package is shown in a comparison of the sensor before and after heating in Figure 3.

Conclusion

- The Pt and Rh gate GaN FET sensors can be used to detect CO in the 0-100 ppm level in H_2 above 150°C
- The Pt sensor is sensitive to H_2 below 1% in N_2 and can be used for H_2 safety (0-4% in air)
- The lack of H_2 saturation suggest the Pt sensor could be useful H_2 monitoring and control
- Low CO sensitivity on Rh below 200 ppm at 200°C can be used to provide a measure of H_2 and correct the measurement of CO by Pt for changes in H_2
- Sensor failure results from oxidation of the source and drain contact metallization

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FY 2002 Publications/Presentations

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VI.A.2 Interfacial Stability of Thin Film Hydrogen Sensors

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Objectives

- Make available the technology to produce safe, reliable, sensitive, fast, lightweight, and inexpensive hydrogen sensors.
- Determine the factors affecting the stability and performance of thin film sensors in practical environments.
- Find solutions for extending the lifetime and functionality of thin film hydrogen sensors.

Approach

- Study service lifetime of sensors in ambient environments and in the presence of suspect contaminant gases.
- Investigate the effects of variations in temperature and relative humidity on sensor performance.
- Continue research on fundamental properties of sensor materials.

Accomplishments

- Constructed gas manifold with mass flow controllers (MFCs) for accurate gas proportioning.
- Investigated new protective layers to enhance protection from liquid water.
- Fundamental studies have yielded new chemochromic materials produced from electrochemical deposition techniques with controlled morphologies.
- Lifetime studies with protected sensor films indicate functional sensor lifetime has been extended to 12 months.

Future Directions

- Continue documentation of lifetimes of current sensors for realistic exposure conditions.
- Continue to optimize the thin film constructions for the protection of the palladium (Pd) catalyst.
- Improve large area sensors for visible detection and bio-hydrogen applications.

Introduction

The goal of this project is to develop safe, low cost, lightweight, reliable hydrogen sensors that can be used as safety sensors where hydrogen is used, stored, or transported. These sensors must be inexpensive enough to use several of them on a hydrogen powered vehicle, and they must be sensitive and fast enough to provide early leak detection so that action can be taken before the flammability limit in air is reached. We have chosen to work on a fiber-optic sensor configuration that stands the best chance of meeting all of these goals.

The National Renewable Energy laboratory (NREL) fiber-optic sensor consists of chemochromic (a color change produced as a result of a chemical reaction) coatings at the end of an optical fiber that sense the presence of hydrogen in air. When the coating reacts with the hydrogen, its optical properties are changed. Light from a central electro-optic control unit is projected down the optical fiber, where it is either reflected from the sensor coating back to a central optical detector, or is transmitted to another fiber leading to the central optical detector. A change in the reflected or transmitted intensity indicates the presence of hydrogen. The fiber-optic detector offers inherent safety by removing all electrical power from the test site, and it reduces signal-processing problems by minimizing electromagnetic interference. Critical detector performance requirements include high selectivity, response speed, and durability as well as potential for low-cost fabrication, meeting or exceeding most of the proposed criteria for safety sensors.

The NREL sensor shares a common link with many other hydrogen sensor concepts in that they all use Pd or one of its alloys as a catalyst. Molecular hydrogen dissociates on the catalyst surface sites forming atomic hydrogen that diffuses rapidly through the film, reacting with the underlying chemochromic layer. All the sensor configurations utilizing Pd have the potential for degradation in their performance over time as a result of their cyclic interaction with hydrogen or contamination from impurities in the environments in which they will be used. Therefore, we have chosen to focus on stability issues related to ambient exposure of Pd and cyclic exposure of Pd to hydrogen.

Approach

A number of strategies for protecting the Pd catalyst were investigated in fiscal year (FY) 2001. The most effective of these was the application of novel inorganic coatings, which could offer effective protection to the hydrogen dissociation sites. Work continued in FY 2002 on the most effective of these strategies. Tests were conducted to determine the response of the sensor films with varying temperature and relative humidity (RH). For the latter work, a new gas manifold and proportioner was constructed, as well as an environmental chamber to allow control of gas and sensor temperature.

Work was also undertaken in the application of polymeric films that provide protection against water

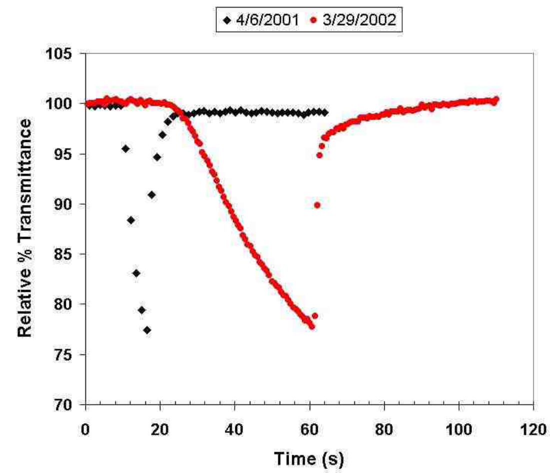

Figure 1. Response of Pd/WO_3 Sensor with Protectiv Coating, after One Year of Aging in Pollutec Atmospheres and Cycling in Hydrogen

condensation on the Pd surface, in particular for the sensors used by the NREL bio-hydrogen group. Interaction with representatives of GVD Corporation resulted in a short-term collaboration to test the efficacy of their proprietary polymer coatings. These coatings are deposited using a chemical vapor deposition technique, which results in a substantial amount of control of the film composition, density, and morphology.

In addition to innovative coatings for the protection of the hydrogen dissociation catalyst, mesoporous metal oxide layers for enhanced performance of the sensor elements were investigated. The results demonstrated the suitability of an electrodeposited tungsten oxide (WO_3) as a chemochromic layer for hydrogen detection, providing a valuable alternative to vacuum deposition.

Results

Inorganic Coatings

The study of inorganic coatings was focused mainly on the coating strategy that was found to be most effective during FY 2001. Samples made during this period were continually tested and have survived more than one year with some degradation in performance noted. An example of this performance is illustrated in Figure 1.

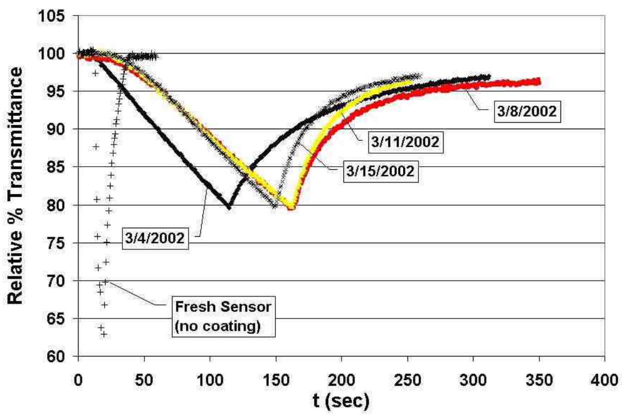

Figure 2. Response of Pd/WO_3 Sensor Coated with GVD Film after Ambient Exposure

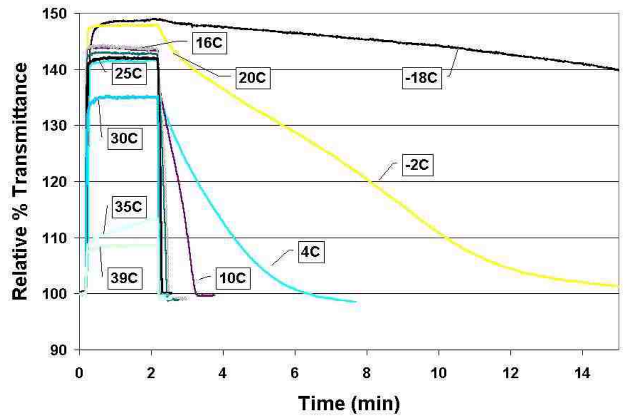

Figure 3. Pd/VO_x Sensor Tested with 4% H_2 in Air as a Function of Temperature

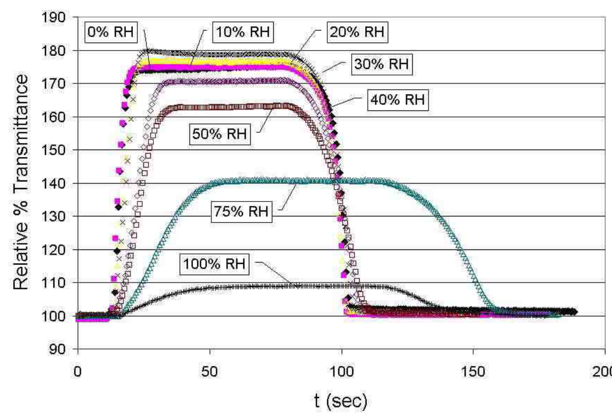

Figure 4. Pd/VO_x Sensor Response to 4% H_2 in Air as a Function of Relative Humidity

Organic Coatings

Sensor films were fabricated at NREL and sent to GVD Corporation for application of a variety of polymeric films. After coating, the films were returned to NREL for testing, and these films showed good resistance to pollutants in ambient air. Figure 2 illustrates the resistance to contamination of a sensor film over 2 months of testing. This represents a remarkable degree of protection for a polymer film and gives us an attractive avenue for exploration in the future, especially to control the ingress of water into the optically active elements of the sensor.

Sensor Response as a Function of Temperature/ Relative Humidity

The construction of a gas manifold incorporating four mass flow controllers allowed the mixing of water saturated air with dry air to produce test streams of gas with accurate RH. Measured amounts of hydrogen were then added to the test stream. An environmental test chamber was also constructed from an insulated cooler. A heating element on the test chamber and a proportional temperature controller allowed control of the gas temperature and thus the thin film temperature to within 0.1°C.

Experiments were conducted on the sensor films at various temperatures and RH values. The response of a Pd/vanadium oxide (VO_x) sensor to changes in temperature and RH is illustrated in Figures 3 and 4. The sensor exhibits degradation in performance at temperatures below 0°C and above 40°C. Response of the sensor is also slowed significantly by the presence of water vapor when the relative humidity exceeds 50%.

Mesoporous Metal Oxides

Figure 5 shows the optical response of a Pd/ electrodeposited-WO_3 sensor to 0.1% hydrogen/ nitrogen. The sensor exhibits a fast response that is comparable to that of an evaporated tungsten oxide-based sensor.

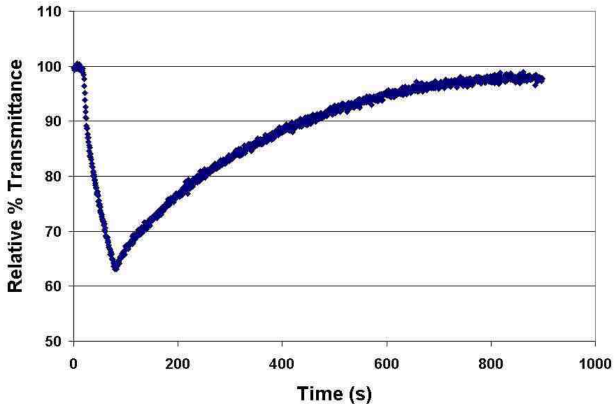

Figure 5. Optical Response of a Pd/WO_3 Sensor in which the Tungsten Oxide is an Electrodeposited Mesoporous Film

Conclusions and Future Direrctions

- Primary goals of speed, sensitivity, weight, and inherent safety have been met.
- Some sensor films have been demonstrated to be functional over one year.
- Collaboration with GVD Corporation produced promising results on organic protective coatings.
- Electrodeposited mesoporous metal oxides were investigated as chemochromic hydrogen sensor films.
- An environmental chamber was constructed to test sensor films at various temperatures.
- A gas manifold for proportioning gases and controlling relative humidity was constructed.
- Preliminary experiments indicate that both the speed and sensitivity of the sensor films vary with both temperature and relative humidity.
- Work continues on functional lifetime and response to variations in environmental conditions.

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VI.A.3 Micro-Machined Thin Film H_2 Gas Sensors

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Objectives

- Optimize micro-hotplate based H_2 sensor design and fabrication processes
- Investigate potential sensor cross sensitivities and degradation mechanisms
- Demonstrate an extrapolated sensor lifetime greater than 3 years

Approach

- Investigate the use of alternative micro-hotplate geometries to increase power density and reduce heat loss
- Develop surface treatment processing to minimize the contact resistance between the sensing layer and the underlying metal contact
- Construct test manifolds and signal-conditioning circuitry for advanced sensor testing
- Study sensor response to H_2 in the presence of contaminant gases
- Evaluate sensor response performance for an extended time period

Accomplishments

- Designed new micro-hotplates for low voltage (5 V), low power (5 mW) operation
- Evaluated the effectiveness of protective coatings against high-level H_2 exposure
- Demonstrated working sensors in atmospheres containing low-level contaminant gas - 100 ppm CO, 20 ppm H_2S, or 600 ppm isopropyl alcohol (IPA)
- Collected long-term sensor performance data over a three-month period

Future Directions

- Implement advanced micro-fabrication processing methods and statistical process control
- Evaluate environment-tolerant protective coatings
- Investigate catalytic chemistry at sensor surface
- Examine the phase transformation mechanism of the sensing materials
- Develop integrated system solution

Introduction

The reputation of hydrogen as the next generation energy delivery agent, supplementing today's electricity, is firmly established. Multifaceted use of hydrogen will play a crucial role in future communities. However, hydrogen is a gas at atmospheric conditions and can escape from its containment to cause an explosion hazard. Safe storage and delivery of hydrogen is a necessity for public acceptance of hydrogen as an energy medium.

The ability to detect and quantify the amount of gaseous hydrogen present is fundamental to all aspects of hydrogen processes. In addition to safety needs, hydrogen sensing is also required as a means of monitoring and controlling hydrogen-based processes used in fuel cells. The demand for hydrogen sensors is very great in terms of quantity and variety because each application may have specific requirements for sensor characteristics. The quantity demand also translates into a requirement for low production cost so that needs, rather than costs, are the determining factor for sensor use.

Approach

Essential features required for H_2 sensor applications include fast response, high sensitivity, and amenability to large-volume manufacturing, to name a few. Micro-machined thin film hydrogen gas sensors were developed at ATMI to meet these needs. These sensors combine novel H_2 responsive materials and micro-hotplate structures based on proven silicon technology. Our implementation of the micro-hotplate is a surface micro-machined thermal isolation structure with an embedded polycrystalline silicon resistive heater where elevated temperature can be achieved with ease (Semancik, et al., 2001). A typical ATMI micro-hotplate structure is shown in Figure 1.

A rare earth metal thin film over-coated with a palladium-based capping film serves as the active sensing layer. Detection of H_2 is based on the phase transformation induced by hydrogenation of rare earth metals. The rare earth metal reacts with hydrogen upon exposure, leading to a change in electrical resistance that scales with hydrogen concentration in the gas phase. When this sensing

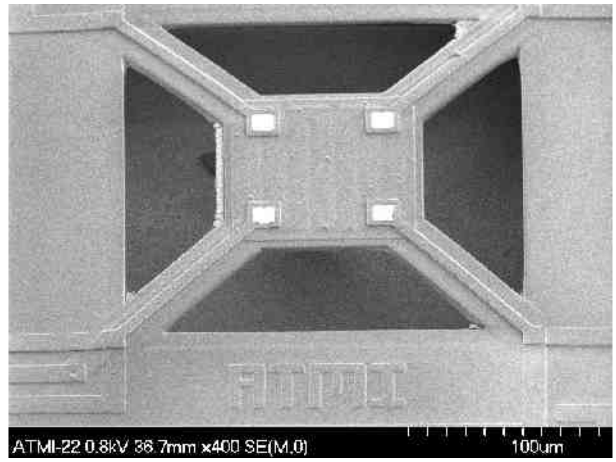

Figure 1. SEM Photo of a Released Micro-Hotplate Thermal Isolation Structure

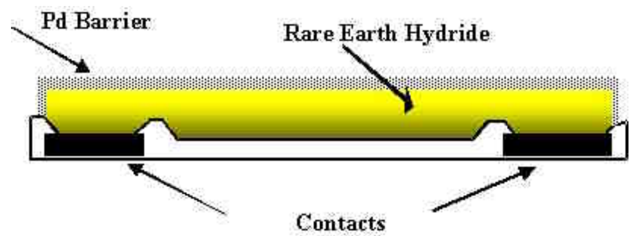

Figure 2. Schematic of Functional Layer Stack on a Micro-Hotplate Platform

layer is coated on the surface of a micro-hotplate, as shown in Figure 2, the reaction kinetics can be engineered by the micro-hotplate temperature.

Results

Designed for safety applications, our micro-machined thin film H_2 sensors have been tailored for H_2 concentrations at half of the lower explosive limit (4% in air for H_2) or lower. In this concentration range, we have demonstrated an extremely fast response and large signal-to-noise ratio.

Sensor operation in real applications is usually affected by the interference from common contaminant gases. These contaminant gases are known to cause false alarms or outright failure of sensors based on existing technology. To examine sensor performance in the presence of contaminant gases, sensors were exposed to low-level contaminant gases in a background of air. The first experiment was performed without H_2 in the gas stream. Dry air was used as the purge gas, and low-

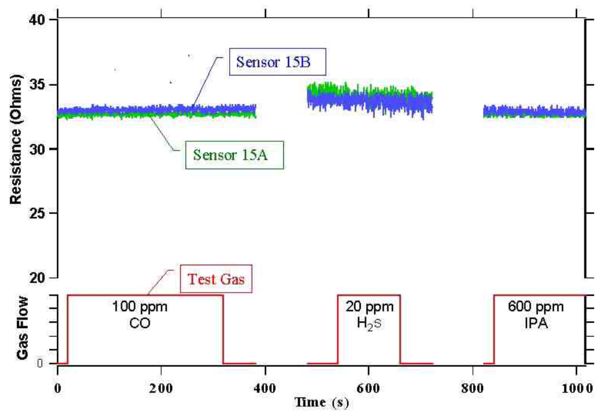

Figure 3. Response of a Sensor to Low-Level Contaminant Gases in Air

level contaminant gas was blended in air as test gas. A set of representative data is shown in Figure 3. The sensors did not respond to the presence of the contaminant test gas in the absence of hydrogen and thus caused no false alarms.

The next experiment was performed with H_2 in the gas stream during the test cycle. Low-level contaminant gas - 100 ppm CO, 20 ppm H_2S, or 600 ppm IPA - was blended with 0.5% H_2 as the test gas. A set of representative data is shown in Figure 4. The first, third, fifth, and the last subsets of data were collected with 0.5% H_2 in dry air with no contaminant gas, providing a reference background. The sensor exhibited enhanced response in the presence of CO and H_2S. The sensor remains functional during and after repeated exposure to any of these contaminant gases.

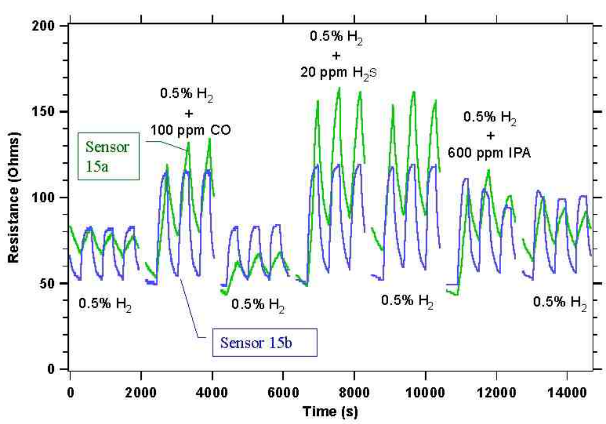

Figure 4. Response of a Sensor to 0.5% H_2 in the Presence of Contaminant Gases in Air

An experiment was carried out where a sensor was exposed to H_2 over a three-month period. The temporal sequence of the gas stream included a 24-hour dry air purge followed by a 10-minute exposure to 1% H_2. Figure 5 shows the long-term test results. The sensor remains fully functional after approximately three months of repeated exposure to H_2. This observation, while it does not directly provide a measure of sensor lifetime, is encouraging.

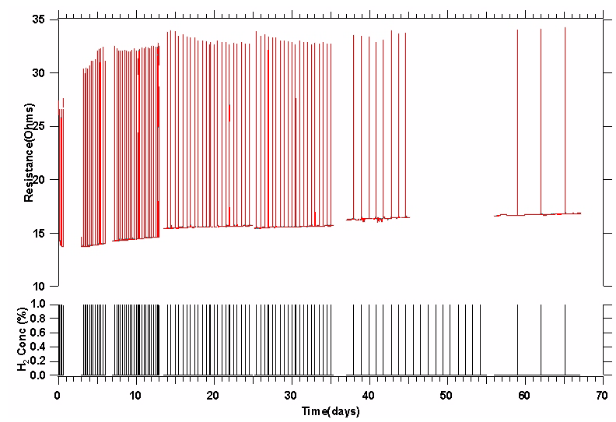

Figure 5. Response of a Sensor Under Repeated Exposure to 1% H_2 Over a 3-Month Period

Conclusions

- The sensors tested do not respond to contaminant gases
- The sensors exhibited enhanced response to H_2 in the presence of CO and H_2S
- The sensors continued to operate after exposure to contaminant gases
- Long-term performance at low-level H_2 exposure shows no intrinsic failure mode during normal operation

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Presentations

1. "Advanced Gas Sensor R&D at ATMI" presented at ATMI's Emerging Technologies

Lunch at SESHA (Semiconductor Environmental, Safety, and Health Association) 24th Annual Symposium, April 4-6, 2002, Palm Springs, California.

2. "MEMS Based H_2 Gas Sensors" presented at symposium AL1 (Sensing In Industrial And Extreme Applications) of The Electrochemical Society 201st Meeting in Philadelphia, Pennsylvania, May 12-17, 2002.

VI.B Codes & Standards

VI.B.1 Hydrogen Infrastructure Activities Codes and Standards: Hydrogen Codes and Standards Outreach

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Objectives

- Bring industry experts together to establish technical criteria for hydrogen energy components and systems nearing commercialization.
- Continue to advance U.S. industry positions in the international arena, including the International Standards Organization Technical Committee 197 (ISO TC 197) and the International Electrochemical Committee Technical Committee for Fuel Cells (IEC TC 105).
- Work closely with the International Code Council (ICC) Ad Hoc Hydrogen Committee (AHC) to include hydrogen and hydrogen energy systems in the model codes in the United States.
- Identify code and standard organizations that can begin to or are in the process of developing hydrogen codes and standards.
- Pull industry experts together to assure technical accuracy and consistency of these codes and standards.
- Report on the activities to a wide audience, assuring information transfer regarding the status of efforts and technical (and sometimes political) issues remaining.
- Working with the National Renewable Energy Laboratory (NREL), the National Hydrogen Association (NHA) also seeks to facilitate the coordination of hydrogen codes and standards activities through the Hydrogen Codes and Standards Coordination Committee (HCSCC), and disseminate timely information about these efforts through a monthly electronic publication, the “Hydrogen Safety Report”.

Approach

- Hold technical conferences with industry, academia, national laboratories, government laboratories, code officials and code organizations to develop and write new standards for hydrogen technologies, including storage tanks, fueling nozzles, connectors, safety equipment, and other key components and integrated systems needed to move hydrogen into the energy sector.
- Participate in the International Standards Organization and its Technical Committee 197, which is responsible for the presentation and approval of the developed standards.
- Publish Codes and Standards (C&S) Workshop Proceedings online - available to the public.

- Support the International Code Council in their efforts to review, develop and promulgate new codes for the use of hydrogen. This includes providing experts, technical reports, data and other information needed by the code officials to complete the development of these new codes.
- Present the U.S. hydrogen positions at international forums and participate in international meetings that are of benefit to the whole hydrogen community in the areas of hydrogen safety, codes and standards.
- Publish and present pertinent hydrogen safety, codes and standards information at a variety of forums, including Global Parks conference to be held in September in Michigan; American Society of Nondestructive Testing (ASNT) conference held in March in Portland, Oregon; and SAE (Society of Automotive Engineers) Fuel Cell Transportation Technology Summit II in Michigan in April.
- Keep its members informed of progress in the development of hydrogen safety, codes and standards through publication in its Quarterly Newsletter, the *NHA News* and by posting sensitive draft information, including draft standards, on the NHA *Members Only* website.
- Conduct safety codes and standards outreach in an open, non-competitive manner by conducting workshops; participate in the development efforts of other organizations; work with the HCSCC to coordinate the efforts; present hydrogen safety, codes and standards activities at conferences and workshops; and make information available in a timely manner to all interested parties.

Accomplishments

- The NHA hosts two Hydrogen Safety Codes and Standards Workshops per year. The most recent one was held February 26, 2002. Proceedings were available on-line through the electronic newsletter and on the NHA website within 2 weeks of the workshop. The “Hydrogen Safety Report” has been published by the 15^{th} of each month since December 2001, and it is free to all interested parties through the NHA website (www.HydrogenUS.com) and on its own site at (www.HydrogenSafety.info).
- The ICC AHC has proposed changes for including hydrogen energy systems and the NHA participated in all the hydrogen-related hearings. The two proposed code changes to the International Fire Code were approved, with modifications.
- ISO TC 197 and IEC TC 105 working group meetings and plenaries were held in June, 2002 in Montreal in conjunction with the World Hydrogen Energy Conference (WHEC). NHA has organized three technical sessions at WHEC on hydrogen safety, codes and standards.
- The U.S. TAG meeting for ISO TC 197 was held in Washington, DC during the third week of May, 2002. NHA discussed and proposed a new work item on charged metal hydrides.
- The NHA presented hydrogen codes and standards activities at the DOE Fuel Cell Summit at the end of May.
- The ICC process has recently brought a number of associations that serve the petroleum and natural gas industries to the fold, all in support of developing codes and standards for hydrogen energy systems.
- In October 2001, the NHA had a large article published in the U.S. General Services Administration (GSA) publication “Vehicle News”.

Future Directions

- The next NHA C&S Workshop is to be held in Fort Worth, Texas on September 30, 2002 -in conjunction with the BOCA - ICBO - SBCCI Joint Annual Conference.

- Information dissemination remains crucial to building consensus and developing a national and international dialog. The NHA would like to expand on these efforts to develop informational materials, presentations, and forums for targeted audiences, such as code officials; regulators; early adopters for transportation, stationary, and portable power applications; and the public. It is important to educate the public on several levels. For example, the tax payers must understand hydrogen in order to support efforts to purchase and operate hydrogen buses, then the general public must feel safe and good about riding in them. The benefits of hydrogen technologies need to be clearly articulated. For example, with hydrogen fuel cells running auxiliary power in a vehicle, it is possible to have air conditioning running without the engine operating. There are many value-added benefits that can help prepare the market for these emerging technologies.

Introduction

The mission of the National Hydrogen Association (NHA) is to foster the development of hydrogen technologies and their use in commercial and industrial applications and to promote the role of hydrogen as a major energy carrier of the future.

The NHA holds technical conferences with industry, academia, national laboratories, government laboratories, code officials and code organizations to bring experts together in a focused activity to develop and write new standards for hydrogen technologies. This includes such items as storage tanks, fueling nozzles, connectors, safety equipment, and other key components and integrated systems needed to move hydrogen into the energy sector. The NHA has members and staff who are active participants in the International Standards Organization and its Technical Committee 197, which is responsible for the presentation and approval of the developed standards.

Approach

The NHA works with DOE, NREL, and others to coordinate codes and standards activities to avoid duplication of effort and enable hydrogen systems to be sited. This requires coordination with industry groups and standards organizations such as the International Organization for Standardization, American Society of Mechanical Engineers, IEC TC 105, the U.S. Fuel Cell Council, the Society of Automotive Engineers, Fuel Cell Propulsion Institute, National Fire Protection Association, and the DOE Fuel Cell Codes and Standards Summit.

NHA staff publishes and presents pertinent hydrogen safety, codes and standards information at a variety of forums, including Global Parks conference to be held in September in Michigan; ASNT conference held in March in Portland, Oregon; and SAE Fuel Cell Transportation Technology Summit II in Michigan in April.

The NHA keeps its members informed of progress in the development of hydrogen safety, codes and standards through publication in its Quarterly Newsletter, the *NHA News* and by posting sensitive draft information, including draft standards, on the NHA *Members Only* website. This allows NHA members an opportunity to review the work of other organizations who have requested collaboration with the hydrogen community but can not make these items publicly available. The general articles published in the newsletter are made available to the public on the NHA website and mailed to NHA members. In addition, we produce a monthly electronic newsletter dedicated to hydrogen safety issues. It is available on the NHA website, and also has its own dedicated site. Anyone can sign up to receive email notification each month when it is posted online. In this way, the information is distributed broadly, and interested parties are given an opportunity to get involved in the standards development process.

Results

The NHA presented hydrogen codes and standards activities at the DOE Fuel Cell Summit at the end of May, 2002. The NHA has successfully encouraged industry experts to join the NHA C&S Committee and the US TAG for ISO TC 197. The ICC process has recently brought a number of

Figure 1. Next Generation Fuel Cell ZEBus

Figure 2. Ford Focus Fuel Cell Vehicle

associations that serve the petroleum and natural gas industries to the fold, all in support of developing codes and standards for hydrogen energy systems. In October 2001, the NHA had a large article published in the GSA publication "Vehicle News". Photos from that article showed sample demonstration vehicles and refueling station projects for which safety codes and standards are needed.

Figure 1 shows the XCELLSiS Zebus (Zero Emission Bus) and Honda's FCX fuel cell vehicle at the SunLine Transit Agency hydrogen refueling station in the Coachella Valley. SunLine plans to have a number of fuel cell buses by 2003.

Ford Motor Company delivered the world's first production prototype, direct-hydrogen powered fuel cell vehicle (Ford Focus, Figure 2) to the California Fuel Cell Partnership in November 2000.

Figure 3 depicts the hydrogen fueling station at the California Fuel Cell Partnership's West

Figure 3. CaFCP Hydrogen Refueling Station

Sacramento Headquarters Facility, which was jointly designed and installed by five of the world leaders in energy and industrial gas supply: Air Products and Chemicals, BP, Praxair, Shell, and Texaco. The station is used to fill vehicles with gaseous hydrogen.

The NHA hosts two Hydrogen Safety Codes and Standards Workshops per year. The most recent one was held February 26, 2002, in conjunction with a WSRC Hydrogen Storage Workshop. Over thirty experts gathered to exchange information on the status of these efforts and how to participate in them. Proceedings were available on-line through the electronic newsletter and on the NHA website within 2 weeks of the workshop. The "Hydrogen Safety Report" has been published by the 15th of each month since December 2001 and is free to all interested parties through the NHA website (www.HydrogenUS.com), and on its own site at (www.HydrogenSafety.info). Over 300 interested parties receive email notification when a new issue is posted, with a hotlink to the information.

In December 2001, the National Hydrogen Association launched a monthly electronic newsletter on hydrogen safety, called the Hydrogen Safety Report (Figure 4). It is available to all interested parties on the Internet at www.HydrogenSafety.info.

Figure 4. Hydrogen Safety Report

Another major effort has been garnering industry support for the ICC hearings in Pittsburgh in April, 2002. The ICC AHC has proposed changes for including hydrogen energy systems. The NHA participated in all the hydrogen-related hearings. The two proposed code changes to the International Fire Code were approved, with modifications. There was huge support for the need to put something in the code now, knowing we have the next 18 months to work out the details, and include exceptions as appropriate. Only one person stood up in opposition claiming "hydrogen is a very dangerous gas and scares the living daylights out of me". It was a very touch-and-go situation, and we all learned quite a bit about process, and how important it is to have built support across communities, and have assistance, real-time, from those familiar with procedure. F176-02 was approved as modified. The modifications are consistent with SE/SW Fire Chiefs' recommendations to AHC. In addition, all four (4) exceptions to Section 2209.3 were deleted. F-177-02 also passed as amended, with issues of venting to be worked out. F177-02 was approved as modified. IFC Committee Chair ruled AHC modification 'editorial'.

All International Fuel Gas Code proposals were disapproved by the IFGC committee; however floor action was taken on each. Support for the changes was overwhelming, and the committee recommendation along with the floor action will go on to the Final Action Consideration at the end of September. The NHA is working with the HCSCC to coordinate information dissemination to voting members and industry as well as technical support to the ICC AHC.

Some interesting developments in Europe have necessitated an open dialog on the U.S. position in the development of international standards. This has implications both technically and politically, and relates to proposed European-wide regulations which are likely to be proposed as global regulations, despite lack of U.S. involvement in setting the framework.

ISO TC 197 and IEC TC 105 working group meetings and plenaries were held in June, 2002, in Montreal in conjunction with the World Hydrogen Energy Conference (WHEC). NHA organized three technical sessions at WHEC on hydrogen safety, codes and standards and actively participated by serving on the Technical Committee for these sessions, co-chairing a session, presenting a paper, and coordinating with speakers.

The U.S. TAG meeting for ISO TC 197 was held in Washington, DC during the third week of May. NHA proposed a new work item on charged metal hydrides.

Conclusions

The need to develop a U.S. position on the international level must go well beyond the current efforts. The NHA supports efforts to assure that decisions are made by consensus using international standards bodies and that U.S. interests are not disadvantaged.

In addition, with such excellent cooperation developing on a national level, the current efforts must continue, with additional support for coordinated activities, such as those of the HCSCC. The NHA is poised to lead efforts best led by the hydrogen industry, and play an active role in broader efforts.

There is a very meaningful international role for the U.S. Department of Energy (DOE):

- Make sure that U.S. interests are involved and adequately represented in the standards making process; and
- Make sure that the U.S. government speaks with the same voice in presenting U.S. interests internationally (WP29), as the consensus position of U.S. industry speaks with in international standards organizations.

The National Hydrogen Association will hold its next Hydrogen Safety, Codes and Standards Workshop on September 30, 2002 in Fort Worth, Texas (Figure 5). (For more information, visit www.HydrogenUS.org.) The NHA would like to expand on these efforts to develop informational materials, presentations, and forums for targeted audiences, such as code officials, regulators, early adopters for transportation, stationary, and portable power applications, and the public. The benefits of hydrogen technologies need to be clearly articulated.

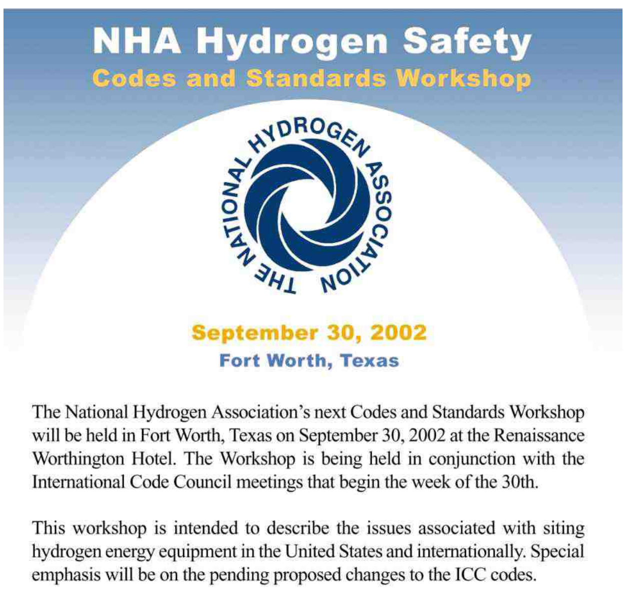

Figure 5. Workshop Announcement

References

1. Hydrogen Codes and Standards – NHA's presentation for the 2002 DOE Hydrogen Program Peer Review.

FY 2002 Publications/Presentations

1. Peer Review Presentation and Paper: NHA-DOE Cost Shared Activities: Hydrogen Codes and Standards Outreach
2. DOE Fuel Cell Summit Presentation: International Standards Activities in Hydrogen Technologies
3. Paper for Global Powertrain Conference: Hydrogen Power - Driving Our Future
4. AIAA Joint Propulsion Conference presentation: Safety Siting of Commercial Hydrogen Facilities
5. NHA Hydrogen Codes and Standards Workshop Proceedings – February 26, 2002
6. SAE Fuel Cell Transportation Summit II: NHA Fueling and Infrastructure
7. ASNT 2002 Spring Conference: NDE Issues for Hydrogen Energy Systems
8. HTAP Safety Summit: NHA Codes and Standards Activities

Special Recognitions

1. Outstanding Contribution to The Hydrogen Planet, 14^{th} World Hydrogen Energy Conference

VI.B.2 Codes and Standards Analysis

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Objectives

Task A - California Fuel Cell Partnership (CaFCP) Building Safety Analysis

- Determine whether garage door should be opened when hydrogen is detected.
- Quantify the risk of hydrogen ignition in the air conditioning (A/C) system during pressure relief device failure.
- Determine whether risk due to pressure relief device failure could be reduced by restricting vehicle location.
- Determine whether risk during pressure relief device failure could be reduced by relocating air conditioning return duct.
- Determine the severity of ignition of hydrogen leaking in bay.
- Determine the severity of ignition of hydrogen leaking under a large vehicle.

Task B - Development of Method to Determine Hydrogen Sensor Placement

- Develop a method to visualize the motion of gases from a hydrogen leak to aid in determining optimized hydrogen sensor locations for safety applications.

Task C - Safety and Analysis for Writing of Codes and Standards

- Determine the effect of hydrogen flame impingement on gypsum board.
- Determine the effect of hydrogen gas leakage from a residential refueler.

Approach

- Identify questions concerning safety of hydrogen installations or safety concerns of authors of codes and standards.
- Design tests or computer models to answer questions identified.
- Conduct tests to directly answer questions or verify computer model.

Accomplishments

- Implemented conclusion that CaFCP garage door should not be opened upon detecting hydrogen in bay.
- Determined that pressure relief device failure could cause hydrogen ignition in the CaFCP air conditioning system.
- Determined that restricting vehicle location to prevent the above scenario would reduce usable CaFCP bay space by 50%.

- Implemented conclusion that lowering air conditioning duct by eight feet would reduce the likelihood that pressure relief device failure would lead to hydrogen ignition in the CaFCP air conditioning system.
- Determined the maximum-recorded overpressure created by a 38.5 SCFM hydrogen leak in the bay was 0.17 psi at a distance of 1.5 ft from the centerline of the leak.
- Determined the maximum-recorded overpressure created by a 13 SCFM hydrogen leak under the full-scale model of the front half of a hydrogen-fueled bus was less than 0.03 psi.
- Developed a machine to produce a stream of helium-filled bubbles to track conservative path of rising gas.
- Determined maximum temperature rise on the backside of gypsum board during hydrogen flame impingement was 144°F.
- Determined residential garage could undergo 12 SCFM leak of hydrogen with proper venting and electrical restrictions.

Future Directions

- Determine proper separation distances for hydrogen facilities.
- Determine additional costs incurred when constructing hydrogen facilities.

Introduction

The goals and objectives of this work effort were developed anticipating the needs of various projects and authors of codes and standards. This work addresses potential safety concerns due to hydrogen leakage in three areas of hydrogen utilization. These safety concerns affect the widespread use of hydrogen in the private sector. The three areas of hydrogen utilization are as follows:

- Task A -- Safety Analysis of California Fuel Cell Partnership Building
- Task B -- Development of Method to Determine Hydrogen Sensor Placement
- Task C -- Safety Analysis for Writing of Codes

Approach

As noted in the above list of objectives, nine different questions were addressed in this year's work. The six questions of Task A dealt with potential modifications to the existing CaFCP building. Computer models of various accident scenarios involving hydrogen leaks inside the building resulted in two modifications. The models were used to define the problem and also to investigate potential solutions. Task B was the design and construction of a device to aid in hydrogen sensor placement. This was done by creating a helium soap bubble machine that created a stream of single helium soap bubbles. Running the machine, positioned at the location of a potential hydrogen leak, allows the operator to visualize a conservative estimate of how the gas cloud is affected by air circulation inside the enclosure. Task C employed experimental measurements of temperature rises produced by hydrogen flames impinging on gypsum board and the same computer modeling approach as used in Task A to aid in determining the effects of hydrogen gas leakage from a residential refueler.

Results

Examples of some of the results are shown in Figures 1 - 5. Figure 1 shows that a burnable cloud of hydrogen surrounds the electric motor, which opens the garage door, at the time the motor would be opening the door. The motor would likely ignite the cloud. The original hydrogen detection protocol was changed to prevent the problem. Figure 2 shows a burnable cloud of hydrogen filling the CaFCP A/C system (top of figure). Note the burnable mixture exiting the A/C vents on the floor. Since the A/C system would probably ignite the cloud, the A/C return duct was lowered to prevent the problem. Figure 3 shows the ignition of a 38.5 CFM leak of

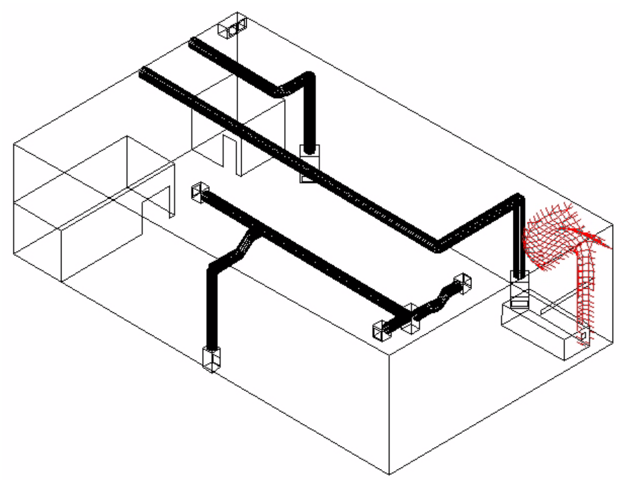

Figure 1. 4.1% Hydrogen Constant Concentration Surface for an 80 SCFM Leak after 16 Seconds with the A/C Off and 2100 SCFM

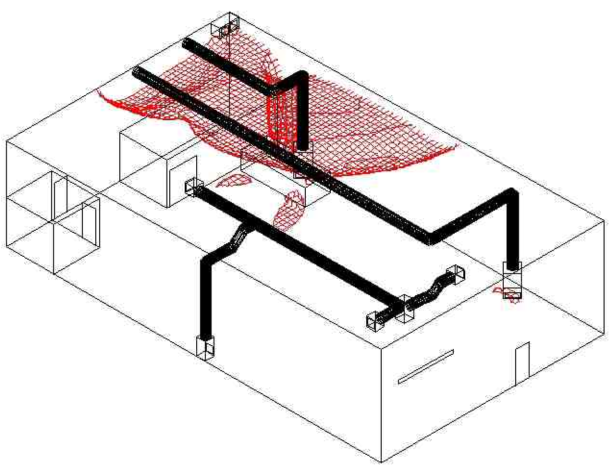

Figure 2. 4.1% Hydrogen Constant Concentration Surface for a PRD Failure after 10 Seconds with 4400 SCFM A/C Flow and 2100 SCFM Exhaust Fan Flow

hydrogen inside the bay. Resulting pressure rises were less than would result from bursting a child's balloon by overfilling it. Figure 4 shows the helium soap bubble machine designed to aid in visualizing hydrogen leakage and to assist in hydrogen sensor placement. Figure 5 shows hydrogen flames impinging on a gypsum board enclosure. Maximum temperature rise was 144°F.

Conclusions

- CaFCP Building - keep garage door in it's current position when hydrogen is detected

Figure 3. Ignition of 38.5 SCFM Hydrogen Leak in Bay

Figure 4. Helium Bubble Machine

to prevent motor from becoming ignition source.

- CaFCP Building - lower air-conditioning return duct to greatly reduce likelihood of hydrogen entering air-conditioning system.
- Hydrogen leaks up to 38.5 SCFM in buildings will not produce dangerous

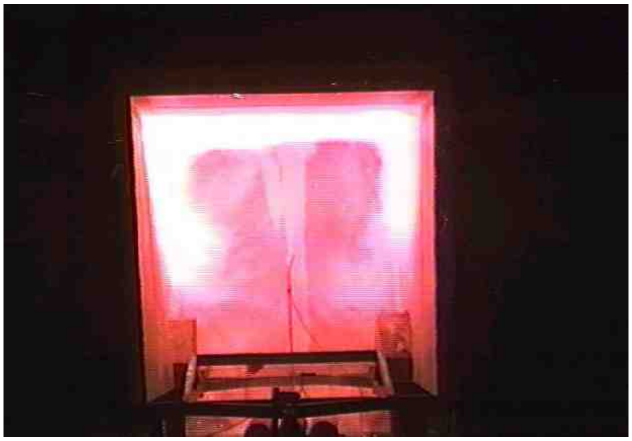

Figure 5. Gypsum Board Flame Impingement Test

overpressures if ignited as long as the building is ventilated well enough to prevent accumulation of hydrogen at the ceiling.

- Hydrogen leaks up to 13.0 SCFM under a vehicle will not produce dangerous overpressures if ignited as long as the hydrogen is not allowed to enter the vehicle and the undercarriage is properly shaped to vent hydrogen.
- A stream of helium filled soap bubbles can be utilized to visualize hydrogen leakage in an enclosure.
- Gypsum board resisted hydrogen flame impingement.
- Leakage of hydrogen from residential refueling system can be removed from garage with proper ventilation.

FY 2002 Publications/Presentations

1. "Hydrogen Leakage into Simple Enclosures", Swain, M.R., Filoso, P., Grilliot, E.S. and Swain, M.S., in publication in the International Journal of Hydrogen Energy

2. Invited Speaker, "The Safe Use of Hydrogen", National Fire Protection Association (NFPA), Anaheim California, May 12-16, 2001

3. Invited Panelist, "Hydrogen Venting" International Code Council (ICC) Ad hoc Committee, Denver Colorado, June 4-5, 2001

4. Invited Panelist, "CaFCP Building Safety Analysis", California Fuel Cell Partnership (CaFCP), Sacramento California, June 6-7, 2001

5. Invited Panelist, "Hydrogen Usage in Residential Garages", International Code Council (ICC) Ad Hoc Committee, Houston Texas, October 2-3, 2001

6. Invited Lecturer, for ICC Educational Session, Greensboro North Carolina, October 30-31, 2001

7. Invited Speaker, International Code Council draft code presentation, Pittsburgh Pennsylvania, April 18-19, 2002

VI.B.3 Hydrogen Codes and Standards

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Objectives

- Expedite hydrogen infrastructure development.
- Coordinate infrastructure development activities, especially codes and standards, for the DOE Hydrogen, Fuel Cells, and Infrastructure Technologies Program.
- Incorporate hydrogen safety considerations into existing and proposed national and international codes and standards in order to facilitate market acceptance and penetration of the hydrogen technologies.

Approach

- Coordinate a collaborative national effort by government and industry to prepare, review, and promulgate hydrogen codes and standards.
- Bring together experts to address key issues and needs in national codes and standards workshops.
- Serve as a database repository, clearinghouse, and gatekeeper for the codes and standards activities being conducted within the DOE through the Hydrogen Codes and Standards Coordination Committee (HCSCC).

Accomplishments

- Established the DOE Hydrogen Codes and Standards Coordinating Committee (HCSCC) and conducted monthly conference calls and quarterly meetings.
- Aided the Hydrogen Ad Hoc Committee (HAHC) of the International Code Council (ICC) in developing and establishing support for the proposed changes to the ICC model codes regarding hydrogen.
- Completed first draft of a Hydrogen Codes and Standards Matrix and Database.
- Initiated work on a collaborative project with National Fire Protection Association (NFPA) to develop publications to assist local code officials.
- Assisted in the creation of the Hydrogen Technical Advisory Panel (HTAP) Hydrogen Safety Committee, contributing to the adoption of a charter, mission statement, and action plan.

Future Directions

- Continue the work of the HCSCC as the DOE focus for (a) coordinating codes and standards development efforts; (b) identifying and addressing codes and standards gaps and deficiencies; (c) identifying barriers with respect to getting codes and standards implemented; and (d) working with codes and standards development organizations to overcome such barriers.
- Facilitate incorporation of changes in the family of ICC model codes proposed by the HAHC.

- Continue working with the Society of Automotive Engineers (SAE) and NFPA to facilitate development and dissemination of standards for transportation and stationary applications, respectively.

Introduction

The development and promulgation of codes and standards are essential if hydrogen is to become a significant energy carrier and fuel; codes and standards are critical to establishing a market-receptive environment for commercializing hydrogen-based products and systems. DOE's Hydrogen, Fuel Cells, and Infrastructure Technologies Program and the National Renewable Energy Laboratory, with the help of some key stakeholders, are coordinating a collaborative national effort by government and industry to prepare, review, and promulgate hydrogen codes and standards needed to expedite hydrogen infrastructure development.

Approach

This project involves coordinating codes and standards development efforts on a number of fronts, including: (1) working collaboratively with codes and standards developing organizations; (2) keeping track of the development of hydrogen technology for various applications; (3) working collaboratively with technology developers to identify critical codes and standards needs; (4) articulating codes and standards needs, and working to get needed efforts underway; and (5) conducting technology transfer activities targeted at building-code and fire-safety officials, local/state/Federal policymakers and other strategic stakeholders.

Results

International Code Council's Hydrogen Ad-Hoc Committee

The International Code Council (ICC) is a joint venture of the three major code councils in the U.S., established to develop uniform national model building codes. The existing ICC model codes do not include hydrogen as an energy source or fuel cells as either power-generating devices or as appliances. To address this limitation, the ICC has established an Ad-Hoc Committee (HAHC) on hydrogen technologies. The HAHC is working with a diverse group of technical and advisory parties to review current codes and standards applicable to hydrogen, to determine the adequacy of its coverage in the ICC International Codes, and to propose changes as necessary. The HAHC has prepared proposed amendments to the ICC model Building, Fire, Electrical, Mechanical, and Fuel Gas codes for hydrogen that will be up for final consideration at the ICC Code Hearing in October 2002.

DOE Hydrogen Codes and Standards Coordination Committee

The DOE Hydrogen Codes and Standards Coordination Committee (HCSCC) was established with the mission of coordinating the development and implementation of a consistent set of hydrogen-related codes and standards that will ensure the safe production, delivery and use of hydrogen, and facilitate the accelerated commercialization of hydrogen technologies. Since its creation, the HCSCC has held monthly conference calls to update participants on current activities and to discuss key issues. The HCSCC has also convened two quarterly meetings in Washington, D.C. The HCSSC is planning to conduct workshops, which will provide a forum for organizations involved in hydrogen codes and standards development to identify the activities, gaps, and opportunities in this effort.

DOE Hydrogen Technical Advisory Panel

The Hydrogen Technical Advisory Panel (HTAP) Safety Committee was established in 2001 to provide a national forum to discuss critical issues in hydrogen safety, including codes and standards. Over the last year, the committee held both an annual and regional Hydrogen Safety Summit to define the current baseline on hydrogen safety capability and to identify critical codes and standards needs and priorities. At the national Hydrogen Safety Summit, scheduled for October 2002, the committee plans to present and discuss a National Hydrogen Safety Agenda.

Partnership for Advancing the Transition to Hydrogen

The DOE is sponsoring the Partnership for Advancing the Transition to Hydrogen (PATH) to coordinate codes and standards activities among key countries outside of the European Union. To date, Canada, Japan, and the U.S. have made commitments to join PATH. An organizational meeting was held at the World Hydrogen Energy Conference (WHEC) in June 2002. The DOE is funding the administrative costs for at least the first year of PATH and providing technical support.

Outreach

Public education and information dissemination on hydrogen safety are key components of the DOE hydrogen effort. As a continuing part of its coordination effort, the DOE is providing support to the National Hydrogen Association (NHA) to publish a monthly electronic letter covering codes and standards activities and issues for the U.S. hydrogen community. The DOE co-sponsored a new educational video, Hydrogen Energy: The Safe and Clean Alternative, which is targeted at the general public and was premiered at the WHEC. The DOE is also sponsoring outreach efforts to building and fire code officials by developing seminars, training, and handbooks on permitting hydrogen facilities.

Conclusions

- The DOE has supported a growing and increasingly important effort to coordinate the development and promulgation of hydrogen codes and standards.
- In addition to supporting specific projects to develop codes, such as that of the ICC/HAHC, and standards, such as that of ISO TC197, the Program is supporting the coordination of many other efforts so that codes and standards can be developed and adopted as efficiently as possible and so that the lack of codes and standards will not be a barrier to the commercialization of hydrogen technologies.
- There are many government and non-government organizations independently involved in generating codes and standards, thus support of codes and standards efforts will remain an important part of the Hydrogen, Fuel Cells, and Infrastructure Technologies Program for many years to come.

VI.B.4 SAE Fuel Cell Codes and Standards Initiative

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Objectives

- Facilitate and accelerate the development of codes, standards, and recommended practices for fuel cell powered vehicles in order to smoothly and uniformly transition fuel cell vehicles into the marketplace.

Approach

- Directly support the SAE Fuel Cell Committee and its seven working groups and establishment of new groups where required.
- Develop liaisons, collaborations, and cooperative working agreements with technical topic area organizations (e.g. U.S. Fuel Cell Council, National Fire Protection Association, The Methanol Institute).
- Directly support Cooperative Research Projects for development and verification of pre-competitive data for use in codes, standards and recommended practices.
- Support workshops and meetings to facilitate expert advisor input
- Support technical expert advisors as needed by the SAE Standards Committee, working groups and SAE Cooperative Research Projects.

Accomplishments

- J2572, Recommended Practice for Measuring the Exhaust Emissions, Energy Consumption and Range of Fuel Cell Powered Electric Vehicles Using Compressed Gaseous Hydrogen (draft)
- J2574, SAE Information Report - Fuel Cell Electric Vehicle Terminology (published)
- J2578, Recommended Practices for General Fuel Cell Vehicle Safety (published)
- J2579, Recommended Practices for Hazardous Fluid Systems in Fuel Cell Vehicles (draft)
- J2594, Fuel Cell Recyclability Guidelines (in ballot)
- J2600, Compressed Hydrogen Vehicle Fueling Connection Devices (published)
- J2601, Compressed Hydrogen Vehicle Fueling Communication Devices (draft)
- J2615, Performance Test Procedures of Fuel Cell Systems for Automotive Applications (final draft)
- J2616, Performance Test Procedures for the Fuel Processor Subsystem of Automotive Fuel Cell System (draft)
- J2617, Performance Test Procedures of PEM Fuel Cell Stack Subsystem for Automotive Applications (final draft)

- Agreement with the IEC TC105 WG-#6
- Memorandum of Understanding (MOU) with the JEVA (Japanese Electric Vehicle Association)
- Working Relationship with the EIHP-II (European Integrated Hydrogen Project)
- Inclusion of the SAE within the dialogue of the GCG (Global Cooperation Group)
- MOU with the National Fire Protection Association

Future Directions

- The intent of this activity is to assist in providing a safe, reliable product to the public by way of a responsible, industry friendly climate that is environmentally sound, i.e., development of Standards, Codes and Recommended Practices that enable commercialization of automotive fuel cell applications.

Introduction

As with any new technology that is attempting to move towards commercialization, the establishment of standards, codes and recommended practices is a major concern. If done through a widely accepted consensus process that leads credence to industry endorsed, globally accepted rule making-- then standards development becomes the leveraging shoehorn that allows for the perfect fit, and enables marketplace acceptance and ease of commercialization.

In early 1999, the fuel cell literate world had no clear, defined direction or globally accepted leadership in standards development for transportation applications of fuel cells. In fact, the major standards development organizations, both domestic and international, were anticipating a “not recommended landscape” of work duplication, mismatched data, non-consensus documents and chaos that would certainly inhibit commercialization and negatively impact rulemaking.

The introduction in mid-1999 of the SAE Fuel Cell Standards Initiative and establishment of the SAE Fuel Cell Standards Forum changed the climate of standards development for vehicles. Not only did the U.S. outlook take on a positive source of urgency, but also the SAE Fuel Cells Forum was quickly recognized as the global leader by the European and Pacific concerns.

Approach

The SAE will initiate, facilitate, develop and publish required standards and standards processes for fuel cell powered vehicles.

The SAE has formed and will form relationships with sectors, organizations and committees that effect or are affected by fuel cell technology for vehicles. These include, but are not limited to, vehicle manufacturers and their suppliers, fuel cell manufacturers and their suppliers, energy providers and their suppliers, national and international government agencies and other organizations involved with the development of the necessary and ancillary infrastructure and support facilities/ structures.

Deliverables will include draft recommended practices and codes and standards as applicable that are necessary for the operation of fuel cell powered vehicles (Figures 1 and 2).

SAE will utilize a fuel cell standards group and others to accomplish deliverables. The Fuel Cell Standards Group will be chartered on the following premise:

> To establish standards and test procedures for fuel cell powered vehicles. The standards will cover safety, performance, reliability and recyclability of fuel cell systems in vehicles with emphasis on efficiency and environmental impact. The standards will also establish test procedures for uniformity in test results for the

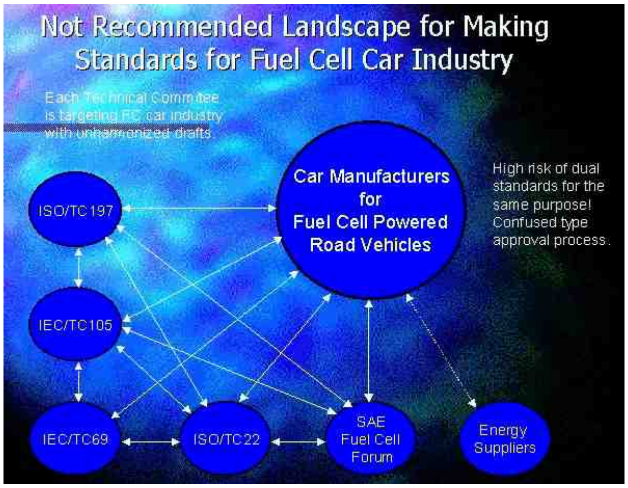

Figure 1. Not Recommended Landscape for Vehicle Standards Development

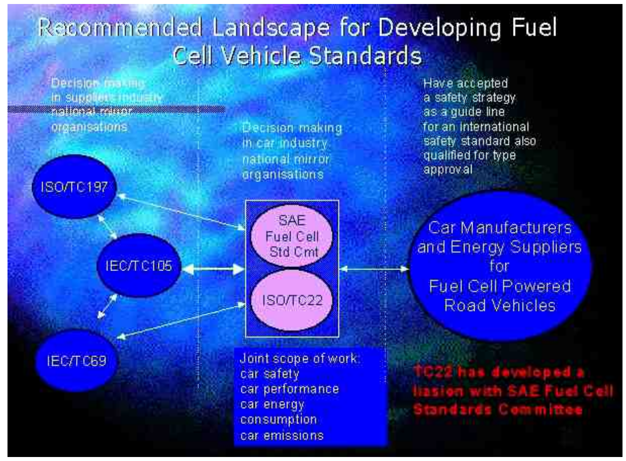

Figure 2. Recommended Landscape for Vehicle Standards Development

vehicles/systems/components performance, and define interface requirements of the systems to the vehicles.

The Fuel Cell Standards Group includes the following working groups: safety, performance, emissions, interface, terminology, and recyclability. These working groups include representatives from automotive original equipment manufacturers (OEMs), automotive OEM suppliers, fuel cell developers/manufacturers, fuel cell manufacturer suppliers, energy suppliers, energy supplier providers, government agencies and national and international organizations that are related to fuel cell industry and infrastructure.

The SAE Fuel Cell Standards Group will collaborate or liaison directly with ISO/TC22 and ISO/TC 22 SC21, IEC/TC105, IEC/TC105 WG6, IEC/TC 69, ISO/TC 197, and ISO/TC 58. The SAE Fuel Cell Standards Group will work cooperatively with U.S. Fuel Cell Council, National Hydrogen Association, Canadian Hydrogen Association, Japanese Electric Vehicle Association (JEVA), American Petroleum Institute, Underwriters Laboratory, CSA International, US Air Force, US Army, National Laboratories, US Air Force Research Labs, and the US Air Force Alternate Fuel Initiative among others directly or indirectly involved in fuel cells for transportation applications and its support infrastructures.

Results

The Emissions & Fuel Consumption working group's mission is to establish standards and test procedures for measuring emissions and fuel consumption for fuel cell powered vehicles. The standards and test procedures to be created will provide methods for measuring exhaust and evaporative emissions, plus the fuel consumption measurement for the fuel cell vehicle. The goal is to establish methodology for uniformity in test results for all designs of fuel cell vehicles, and allow a comparison with conventional vehicles. J2572 is the first document that this working group is completing. This document is for fuel cell vehicles using compressed hydrogen gas supplied by an off-board source and stored as a compressed gas onboard. The procedure includes hybrid (use of a storage battery for traction power) versions of fuel cell vehicles. The working group will address fuel cell vehicles that have a reformer on-board to produce hydrogen once J2572 is completed.

The Interface working group was created to develop standards to coordinate between fuel suppliers and vehicle manufacturers to ensure safe, efficient and customer friendly delivery of fuel to fuel cell powered vehicles. Topics to be covered include fuel supply, infrastructure, fuel storage, fuel processor and vehicle interface. The Interface working group has two draft standards in progress, J2600 and J2601. J2600, Compressed Hydrogen

Vehicle Fueling Connection Devices, defines the geometries of the receptacles for different pressure levels. It has been successfully balloted, with a 98% APPROVAL rating and NO DISAPPROVAL ballots. J2601, Compressed Hydrogen Vehicle Fueling Communication Devices, will define the different fueling strategies and document their advantages and disadvantages with respect to type III and IV tanks. It will also develop the strategies and protocols for what refueling with and without communications should look like. In addition, it will identify what technology wireless communication should utilize to be most effective in an automotive environment. Data is being collected for this draft standard. It is targeted is to be completed in the second quarter of 2003.

Developing a guidance document that incorporates and summarizes existing recyclability measurement techniques and identifies recyclability issues associated with fuel cells in End of Life Vehicles (ELVs) is the goal of the Recyclability working group. J2594, Fuel Cell Recyclability Guidelines is currently under final pre-ballot review by the Fuel Cell Standards committee.

To recommend design and construction, operation, emergency response and maintenance practices for the safe use of fuel cell vehicles by the general public is the goal of the Safety working group. J2578 is the first safety document that covers the general safety of the vehicle. J2578 has already been successfully balloted. However, in the attempt to address all participating comments, the committee has agreed to incorporate, where applicable, this new information. The document is currently under its second ballot and is expected to be APPROVED by a unanimous ballot (100% approval rating). J2579, Fuel Systems for Fuel Cell Vehicles, is the second document the safety working group currently has under work.

The first document of the SAE Fuel Cell Standards Committee to be completed was developed by the Terminology working group. J2574, Fuel Cell Terminology Report, was balloted in September 2001. It is used world wide as a reference source and foundation document for all of the Vehicle Fuel Cell Standards efforts. This report defines terminology for fuel cell powered vehicles.

The mission of the Performance working group is to develop procedures for testing the Proton Exchange Membrane (PEM) fuel cell system and its major subsystems for automotive applications. The working group currently has three draft standards under development, J2615, J2616 and J2617. The Performance task group is defining performance and measured parameters for three test subjects: PEM fuel cell system, fuel processor and PEM fuel cell stack. Major subsystems of the PEM fuel cell system are the following: fuel processor, fuel cell stack, air processor, thermal management, water management and electronic controller. Test procedures are being developed for both steady state and transient (start-up and load following) performance measurements. Instrumentation to be used, pre-test procedures to ensure safety in testing, limitations of test procedures and methods of calculating and reporting results will all be addressed in the documents. The target completion date for these three documents is 2002.

Conclusions

The continued work of the SAE Fuel Cell Standards committee and its working groups, has provided the single point of reference to all agencies, U.S. or global, in regards to standards pertaining to transportation/mobility applications. As the proliferation of fuel cell vehicles gains momentum, the need for standardization becomes critical. Regulation and rule-making, coupled with growing interest in global technical regulations (GTRs) in many countries, cause an urgent demand for foundation data and documents. The SAE committee remains the best near term solution to address and provide this needed data and source documentation.