2009 BFRL Project Description

Project Title: Hydrogen Flammability, Detection, and Fire Safety

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BFRL Program: Reduced Risk of Fire Spread in Buildings

Objective: To develop measurement science tools (data, predictive methods, and test protocols) to characterize, detect, prevent, and mitigate fire hazards associated with an accidental hydrogen release from a hydrogen fuel-cell vehicle in a residential garage and to provide a technical basis for standards and codes development to enable safe, efficient use of hydrogen in confined structures.

Problem:

What is the problem? The safe utilization of hydrogen as an energy carrier and the timely realization of the envisioned hydrogen economy require many technical, non-technical, and societal barriers to be overcome. While many safety aspects of hydrogen are well documented, knowledge gaps still exist in many applications pertinent to the hydrogen economy. One of the many technical challenges and research needs identified in the 2003 DOE report[1], the 2004 NAS report[2], the Fire Protection Research Foundation report[3,4], European Commission (EC) hydrogen program[5], and DOE Hydrogen, Fuel cells & Infrastructure Technologies Program[6] is to understand and characterize the dispersion of hydrogen in a confined space. In particular, the potential fire/explosion hazard due to an accidental release of hydrogen from a fuel-cell vehicle parked inside a residential garage. The lack of high quality scientific and technical data and validated fire models hinders the development of codes and standards in this application. Sensors that detect hydrogen gas in spaces where gas accumulation is possible allow for hazard mitigation through automatic and human means but lack standard test protocols for proper characterization in real-life applications.

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[1] Basic Research Needs for the Hydrogen Economy, Office of Science, U.S. Department of Energy, 2003.
[2] The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs, National Academy of Sciences, 2004.
[3] A Research Agenda for Hydrogen Technology Safety, Fire Protection Research Foundation, 2005.
[4] Research Needs in Support of Hydrogen Safety Standards, Fire Protection Research Foundation, 2008.
[5] Introducing Hydrogen as an Energy Carrier, Safety, Regulatory and Public Acceptance Issues, EUR 22002, European Commission, 2006.
[6] Hydrogen, Fuel cells & Infrastructure Technologies Program, Energy Efficiency and Renewable Energy, U.S. Department of Energy, 2005.

Why is it hard to solve? Hydrogen fire hazards are unique because thermo-physical properties of hydrogen (e.g., density, mass diffusivity, flammability, detonability) are sufficiently different from those of other fuels that it is unclear that existing measurement science for treating fuels such as natural gas or propane can be simply extended to hydrogen. Non-technical barriers include public perception and awareness of hydrogen safety and how to gain public acceptance of hydrogen as an energy carrier[6]. In addition, the measurement science is challenged by difficulties in the characterization of many different non-unique release and dispersion scenarios, which depend on garage ventilation and leakage, hydrogen release rate and location, environmental conditions, and garage geometry.

How is it solved today, and by whom? Today, hydrogen fire safety is addressed by hydrogen manufacturers partnered with their respective industrial users. The DOE hydrogen standards, codes, and safety program has recently initiated research programs at several DOE national laboratories, including Sandia National Laboratories (SNL) and the National Renewable Energy Laboratory (NREL), to conduct research to facilitate the development and international harmonization of standards and codes for the safe use of hydrogen in the emerging hydrogen economy. These ongoing efforts mainly focus on safe operations in the industrial sector, primarily manufacturing, storage, and distribution, fire fighting operations, and public outreach. Fire safety for the residential and commercial applications has mostly been conducted in Europe[5], Japan[7], and Canada[8].

Why NIST? BFRL is a world leader in providing fire measurement and fire modeling tools in fire protection and fire spread within buildings and has the experienced staff and facilities to perform these tasks. BFRL traditionally plays an active and objective role in fire safety codes and standard development activities. Research findings presented by NIST/BFRL will gain public trust and confidence and will help to alleviate public concern and perception in hydrogen fire safety, which could otherwise be a major impediment to enabling a future hydrogen economy. This project directly fits in BFRL's mission[9] and vision[10] and is consistent with the Fire Prevention and Control Act of 1974.[11] The objectives of this project are directly aligned with BFRL's strategic priority area on *Measurement Science for Innovative Fire Protection* and leverages BFRL's core competency on f*ire protection.*

Approach:

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[7] The Japanese National Project on Hydrogen and the Japanese Hydrogen & Fuel Cell Demonstration Project.

[8] Canadian Hydrogen Safety Program, International Journal of Hydrogen Energy 32 (2007) 2134-2143.

[9] BFRL's mission is "to promote U.S. innovation and competitiveness by anticipating and meeting the measurement science, standards, and technology needs of the U.S. building and fire safety industries in ways that enhance economic security and improve the quality of life." BFRL addresses standards and technology needs through its measurement science research.

[10] BFRL's vision is "To be the source for creating critical solution-enabling tools - metrics, models, and knowledge - and promoting performance-based standards that are used by the U.S. building and fire safety industries to establish global leadership."

[11] The Fire Prevention and Control Act of 1974 specifically calls for research on "design concepts for providing increased fire safety consistent with habitability, comfort, and human impact in buildings and other structures."

What is the new technical idea? The new idea is to develop innovative metrology and validated computer models necessary to prevent, characterize, detect, and mitigate fire hazards associated with accidental release of hydrogen in residential garages. Design tools will be developed for practicing engineers as the profession adapts to the emerging hydrogen economy. The emphasis is to ensure that the scientific and technical knowledge gained from this project can be readily and effectively disseminated to facilitate standard and code development. This research project focuses on the development of the measurement science to determine (1) how hydrogen, if leaked from its container, is dispersed in a confined space with natural infiltration and/or mechanical ventilation, (2) whether the dispersed hydrogen concentration levels can form a flammable/explosive mixture with air and subsequently lead to deflagration/detonation upon ignition, and (3) how hydrogen sensors perform in this real-world situation.

Why can we succeed now? We can succeed now because NIST/BFRL has developed a wealth of technical and scientific knowledge that can be readily extended and applied to address fire safety problems in a hydrogen economy. In addition, there is growing global interest and investment in hydrogen technology[12] and increasing international and domestic efforts allowing synergistic collaboration among interested parties (such as the International Partnership for the Hydrogen Economy (IPHE) and our collaboration with SNL and NREL).

What is the research plan?

Hydrogen Fire Safety in Confined Spaces

A reduced-scale (1/4 -scale) garage test facility designed to allow for careful control and characterization of experimental conditions will be used to simulate hydrogen release and dispersion employing helium (an inert gas) as a safe surrogate. Helium experiments will also be conducted using a real-scale residential garage to better understand the effects of winds and outdoor temperatures on the dispersion behavior inside the garage. The experimental data will be used to assess the effectiveness of the NIST Fire Dynamics Simulator (FDS), a computer fire model, for predicting the dispersion behavior of a buoyant gas and to identify any necessary modifications to the model, which in turn will be used to provide design guidance for subsequent dispersion experiments, including the appropriate number of sampling sites and their locations and the required time resolution. Experiments using hydrogen will also commence. Since such experiments cannot be safely conducted at NIST, investigating the mixing, ignition, and burning/explosion behaviors of hydrogen released within a real-scale garage will use an off-site test facility.

Experiments to study hydrogen mixing and dispersion within a real-scale garage without burning will be completed in order to characterize differences between helium and hydrogen mixing and to provide the data necessary for further validating FDS. The findings from the studies and FDS simulations to delineate hydrogen concentrations within its detonability limits will be used to guide the subsequent series of experiments within the enclosure involving hydrogen burning and potential detonation.

[12] Hydrogen Posture Plan, An Integrated Research, Development and Demonstration Plan, U.S. DOE and DOT, December 2006.

Experiments will be conducted to fully characterize ignition behavior, rapid deflagration, and potential detonation when hydrogen is released, dispersed, and subsequently ignited in a garage under conditions commensurate with real-world scenarios. An off-site test facility will be used for these experiments (either Southwest Research Institute, FM Global, SRI International, or US Navy Chesapeake Bay Detachment).

Performance Characterization of Hydrogen Gas Sensors

The test apparatus designed for hydrogen gas sensors (termed HyDEE which stands for Hydrogen Detector Environment Evaluator, a more compact apparatus than the fire emulator/detector evaluator (FE/DE) used in preliminary hydrogen sensor evaluations) will be characterized for hydrogen gas sensor performance testing. Long term tests will gather data on ambient hydrogen sensor background readings in indoor and outside locations. Diurnal and seasonal trends will be identified along with humidity, temperature variations and other unspecified effects. Performance testing of sensors using the HyDEE will continue by examining the effects of ambient conditions, including various gases and vapors representing nuisance and obfuscating or sensor poisoning substances, on the sensors. The results from the long-term tests will be used to develop baseline ambient tests. A finalized testing protocol for sensors deployed in residential structures will be proposed.

Data Dissemination

BFRL will work with standards and codes organizations to provide technical and scientific support for the examinations and the necessary revisions of existing building and fire codes to accommodate the safe use of hydrogen fuel. Results will be disseminated more widely to the scientific and engineering communities by publication of research findings in archival journals and through active collaboration with outside organizations (such as SNL, NREL, and NFPA). The knowledge gained from this project can be extended to applications in several key areas, namely public parking facilities, commercial or residential fuel-cell power plants, and service and refueling stations.

Recent Results:

- ***Output:*** Formed strategic research partnerships with SNL and NREL.
- ***Output:*** Reviewed four European Commission HyApproval (Handbook for Approval of Hydrogen Refuelling Stations) projects to support DOE international standards and codes harmonization effort.
- ***Output:*** Expanded partnership with academia through a new fire grant to augment research on hydrogen flammability in the presence of hot metal surfaces.

- ***Output:*** Published three journal papers (two accepted[13,14], one in review[15]) and delivered one invited keynote,[16] four conference presentations[17,18,19,20]and one poster presentation[21].
- Completed preliminary assessment of FDS for helium and hydrogen dispersion in confined spaces.
- Completed a series of reduced and full-scale garage experiments using helium.
- Developed a bench-scale calibration flow cell for baseline hydrogen sensor calibration and response time determination.
- ***Outcome:*** Completed the modification of the fire emulator/detector evaluator (FE/DE) for hydrogen sensor evaluation.
- ***Output:*** Continue to play a science advisory role to assist NASFM (National Association of State Fire Marshals) / HELP (Hydrogen Executive Leadership Panel) in their strategic planning activities.

Standards and Codes: Project staff serve on the NFPA-2 Committee on Hydrogen Technologies and Safe Energy Science Advisory Committee of NASFM/HELP and on UL-2075 for Fire Detection. We have established working relationships with hydrogen safety researchers at SNL and NREL and officials in the DOE Hydrogen Codes and Standards program. We will work through them, and directly with appropriate organizations, to ensure that NIST findings are widely disseminated to the appropriate standard and code committees.

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[13] Yang, J.C. and Huber, M.L., "Analysis of Thermodynamic Processes Involving Hydrogen," International Journal of Hydrogen Energy, accepted for publication (2008).
[14] Linteris, G. and Babushok, V.I., "Promotion of Hydrogen-Air Ignition by Iron-Containing Compounds,".32nd International Symposium on Combustion, Montreal, Canada, August 2008.
[15] Yang, J.C., "Material-Based Hydrogen Storage," International Journal of Hydrogen Energy, in review (2008).
[16] Yang, J.C., "Hydrogen Fire Safety Research Activities at NIST," the 4th Fire Science and Engineering Conference, Beijing, China, October 2007.
[17] Linteris, G.T., "Promotion of Hydrogen-Air Ignition by Iron Compounds," Fall Technical Meeting, Eastern States Section of the Combustion Institute, University of Virginia, October, 2007.
[18] Marsh, N. and Cleary T.G., "Preliminary Performance Assessment of Commercially-Available Hydrogen Sensors," Proceedings of the International Symposium on Materials Issues in a Hydrogen Economy, Richmond, VA November, 2007.
[19] Yang, J.C., "Hydrogen Fire Safety Research at NIST," Annual Fire Conference, Gaithersburg, MD, March 2008.
[20] Marsh, N. and Cleary, T.G., "Towards a Test Method for Hydrogen Sensor Performance," National Hydrogen Association Meeting, Sacramento, CA, March 2008.
[21] Prasad, K., Bryner, N., Cleary, T.G., Hamins, A., Marsh, N., Pitts, W.M., and Yang, J.C., "Numerical Simulation of Hydrogen Leakage and Mixing in Large Confined Spaces," National Hydrogen Association Meeting, Sacramento, CA, March 2008.