



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** Since 1965

PNNL-SA-86512

Hydrogen Safety Panel

STEVEN C. WEINER

Hydrogen Program Annual Merit Review and Peer Evaluation Meeting

Arlington, VA

May 15, 2012

This presentation does not contain any proprietary, confidential or otherwise restricted information.

SCS008

An Integrated Approach to Hydrogen and Fuel Cell Safety



Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by **Battelle** Since 1965

US Canada Italy Japan
Switzerland France
Germany Greece Norway
The Netherlands UK
European Commission



Hosted by the Istituito Superiore Antincendi
(Fire Prevention Institute), Rome, Italy

Incident Reporting/
Lessons Learned and
Best Practices



IEA HIA
Task 31
Experts
Group

PNNL
SC&S
Projects

Hydrogen
Safety
Panel



HAMMER
CaFCP
Kidde Fire Trainers

The "rescue" at the Sunnyvale (CA)
Department of Public Safety

Hydrogen
Safety
Training



Hydrogen Safety Panel visits Bridgestone Firestone
in Graniteville, SC

Timeline

- First Panel meeting: December 11, 2003
- Continuing

Budget

- Funding received in FY11 = \$350K
- Planned funding for FY12 = \$500K¹



Barriers addressed²

- A. Safety data and information: limited access and availability
- C. Safety is not always treated as a continuous process
- G. Insufficient technical data to revise standards

Partners

- Panel member organizations (next slide)

¹Additional FY09 ARRA funds being utilized for Hydrogen Safety Panel work.

²Technical Plan – Safety, Codes and Standards, Section 3.7.5, Multi-Year Research, Development and Demonstration Plan, 2011.

Hydrogen Safety Panel

Steven Weiner, Program Manager	Pacific Northwest National Laboratory
Richard Kallman, Chair	City of Santa Fe Springs, CA
Addison Bain	NASA (ret)
Nick Barilo	Pacific Northwest National Laboratory
David Farese	Air Products and Chemicals
Bill Fort	Shell Global Solutions (ret)
Don Frikken	Becht Engineering
Aaron Harris	Sandia National Laboratories
Miguel Maes	NASA White Sands Test Facility
Glenn Scheffler	GWS Solutions of Tolland LLC
Andrew Sherman	Powdermet Inc.
Ed Skolnik	Energetics Incorporated
Ian Sutherland	General Motors
Robert Zalosh	Firexplo

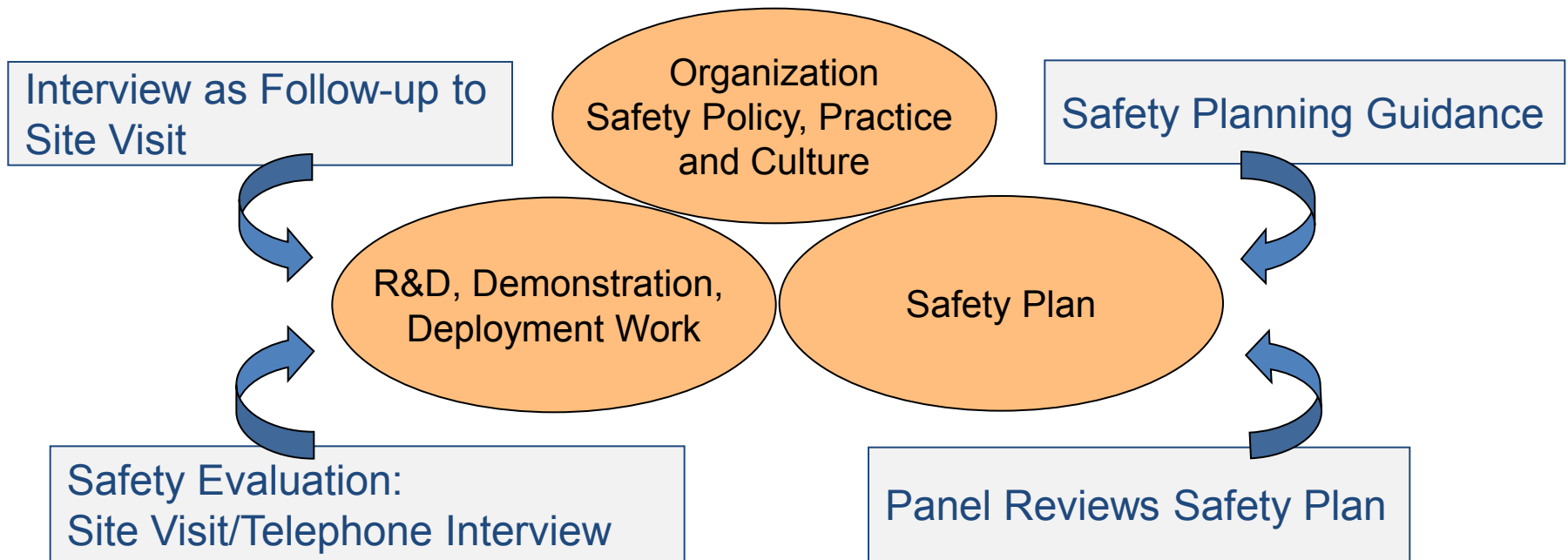
- ▶ Provide expertise and recommendations to DOE and assist with identifying safety-related technical data gaps, best practices and lessons learned.
- ▶ Help DOE integrate safety planning into funded projects to ensure that all projects address and incorporate hydrogen and related safety practices.

Safety practices, incorporating a wealth of historical experience with new knowledge and insights gained, are in place. Continuous and priority attention is being given to safety to fully support all aspects of hydrogen and fuel cell technologies: research, development and demonstration; design and manufacturing; deployment and operations.


Hydrogen Safety Panel

Engaging the Project Team

The Project



 Project team

 Hydrogen Safety Panel

Accomplishments and Progress

Safety Planning and Site Visit Reviews

▶ Safety Planning

- Reviewed 17 safety plans in the past year.
- When requested by the DOE project officer, the Panel reviews revised safety plans for responsiveness to comments.
- There continues to be a need to reach closure on more safety plans reviewed in the past two years particularly for fuel cell deployment projects.

▶ Safety Evaluation Site Visits

- Five safety evaluation site visit reports issued; four follow-up interviews conducted and reported.
- Successfully implemented content, format and cost/time savings measures for reports
- The Panel addressed: “What have we learned so far from fuel cell deployment projects?”

What have we learned so far from fuel cell deployment projects?



- ▶ There is a need for a more thorough and integrated approach to project safety planning that involves all parties: hydrogen/fuel cell/equipment suppliers, facility operators, maintenance/repair providers.
- ▶ Safety vulnerability analysis needs to consider potential incident scenarios introduced as a result of the fuel cell deployment and equipment operations and exposures, e.g., those involving industrial trucks in warehouse storage, materials handling and truck maintenance/repair areas.
- ▶ Third-party certification for equipment such as hydrogen dispensers and fuel cell forklifts is an important consideration for these developing technologies.

Measuring Outcomes from Safety Reviews

Categorizing Recommendations and Actions

...covering 14 project safety review site visits

Category	Recommendations Implemented	Partial or In Progress	No Action	Total Recommendations
Safety Vulnerability/ Mitigation Analysis	23	4	6	33
System/Facility Design Modifications	8	5	1	14
Equipment/Hardware Installation and O&M	15	6	1	22
Safety Documentation	14	7	0	21
Training	3	3	0	6
Housekeeping	14	6	1	21
Emergency Response	8	3	2	13
Total	85	34	11	130

>90% of recommendations voluntarily completed or in progress

Learning from Safety Events

A Statement from the Hydrogen Safety Panel

▶ Premise

- Hydrogen and fuel cell safety event and equipment failure information and data can serve as a rich and valuable resource if it is systematically collected, analyzed and used to enhance our knowledge.

▶ Issue

- Sharing information and data that respects the confidentiality and contractual obligations in DOE-funded projects while allowing for the Hydrogen Safety Panel's review and analysis of such information and data.

▶ Recommendation

- Identify mechanism(s) for such information sharing and analysis, and facilitate the interaction of the Hydrogen Safety Panel, DOE project management staff and a selected set of contractor project managers for the purpose of establishing the most appropriate mechanism for such work.

Accomplishments and Progress

Strategically Examining the Panel's Work

- ▶ As a first step, conducted brainstorming at 16th Panel meeting, San Francisco, CA, September 11, 2011 to support SC&S vision and goals
- ▶ Hydrogen Safety Panel joined by participating staff from DOE, DOT, Nuvera Fuel Cells, NASA White Sands Test Facility and other DOE national laboratories (LLNL, SNL, SRNL)
- ▶ “No idea goes unrecorded!” – 75 ideas ranked and collated to include current Panel initiatives worthy of additional emphasis as well as new initiative ideas to consider

Accomplishments and Progress

Strategically Examining the Panel's Work

Current Initiatives	New Initiative Ideas
<u>Safety Planning and Evaluation</u>	
Continue safety planning work, safety plan reviews, site visits	Evaluate long-term implementation of site visit recommendations
	Conduct non-DOE project site visits upon request including DOD, NASA facilities
<u>Safety Events, Best Practices and New Tools</u>	
Publish safety event learnings and best practices in technical journals	Establish a mechanism for the Panel to access all reported incidents and near-misses
Panel as technical contributors for international workshops and initiatives	Expand role of investigating H ₂ incidents beyond DOE
	New web-based tools: leak/detection sensors, QRA, maintenance practices, hydrogen properties
<u>Other</u>	
	Tie to C&S work; evaluate and propose code changes
	Support AHJs with reviewing hydrogen applications and additional training

Hydrogen Safety Panel Scorecard...

- ▶ 312 safety plans reviewed
 - *Revised safety plans responsive to review comments*
- ▶ 47 safety reviews conducted
- ▶ 17 Panel meetings held
 - *17th Meeting, Washington, DC, March 28-29, 2012*
- ▶ 14 follow-up interviews conducted
 - *90% of safety review recommendations voluntarily completed or in progress*
- ▶ 6 “good example” safety plans provided
- ▶ 6 “white paper” recommendations submitted
- ▶ 3 issues of *H2 Safety Snapshot* published
- ▶ 2 incident investigations completed

“to work jointly with others or together especially in an intellectual endeavor”¹

- ▶ International Energy Agency Hydrogen Implementing Agreement Task 31 (Hydrogen Safety)
- ▶ International Association for Hydrogen Safety (IA HySafe)
- ▶ International Conference on Hydrogen Safety (ICHS)
- ▶ Fuel Cell and Hydrogen Energy Association/National Hydrogen and Fuel Cells Codes and Standards Coordinating Committee
- ▶ Hydrogen Power Theoretical and Engineering Solutions International Symposium (HYPOTHESIS IX)

- ***Expanding and enhancing hydrogen safety knowledge***
- ***Sharing and discussing learnings from safety events***

¹Merriam Webster Online Dictionary, <http://www.merriam-webster.com/>

- ▶ DOE/NREL Hydrogen Sensor Workshop (June 2011)
 - Barilo presented “Wide-Area Sensor Needs” building on earlier Panel member work (see Publications and Presentations) and endorsement of the Fire Protection Research Foundation Hydrogen Research Advisory Council report: *Research Needs in Support of Hydrogen Safety Standards* (2009).
- ▶ University of California Center for Laboratory Safety Workshop (March 2012)
 - Workshop looked at new, more effective ways to make certain that research is performed safely.
 - Barilo participated in breakout sessions and discussion on hazard assessment and laboratory design.
 - Panel work on incidents, lessons learned and best practices was shared with attendees and potential future collaborations were discussed.

▶ Remainder of FY2012

■ Complete in-progress work

- Safety checklist for an outdoor supply system providing hydrogen for an indoor application
- Water fuel technologies review paper

■ Continue to conduct safety evaluation site visits in consultation with DOE

■ Complete final report for Panel work on American Recovery and Reinvestment Act (ARRA) fuel cell deployments summarizing findings and conclusions

▶ FY2013

■ Continue efforts to promote and ensure safety throughout the FCT project portfolio

■ Assist in transitioning safety information and knowledge into safety codes and standards with emphasis on near-term applications

Thank you

- ▶ U.S. Department of Energy
 - Fuel Cell Technologies Program (Sunita Satyapal, Program Manager; Antonio Ruiz, Safety Codes and Standards Team Leader)
- ▶ All of my colleagues at Pacific Northwest National Laboratory, the Hydrogen Safety Panel and other collaborators
- ▶ You, the audience

***Technical Back-up Slides
for
FY2012 Merit Review and Peer Evaluation***

Learning from Safety Events

A Statement from the Hydrogen Safety Panel

LEARNING FROM SAFETY EVENTS

A Statement from the Hydrogen Safety Panel

Hydrogen and fuel cell safety event information can serve as a rich and valuable resource if it is systematically collected, analyzed and used to enhance hydrogen safety knowledge. The sharing of lessons learned from safety events can serve to help prevent similar events from happening in the future. Informed analysis of leaks, fires and explosions, and equipment failure and ignition data derived from these safety events can facilitate the development of risk assessment models and help technical experts identify gaps in applicable codes and standards that can be addressed by a variety of means.

The Hydrogen Safety Panel can be a significant asset in realizing the benefits identified above through its role to provide expertise to DOE in identifying safety-related technical data gaps and lessons learned. Knowledgeable analysis through presentations and discussion at Panel meetings continues to be an important means of enhancing the understanding of safety issues for incidents both inside and outside the DOE Fuel Cell Technologies Program. While the confidentiality and contractual obligations inherent in DOE-funded projects are to be fully respected, mechanisms can be established to maintain those confidentiality while also establishing a means for the Hydrogen Safety Panel to examine, review and analyze project safety information. Such means should also allow for the Hydrogen Safety Panel's interaction with project teams to discuss the information being shared.

While the breadth of the entire program portfolio – research, development, demonstration and deployment projects – could be examined for these purposes, the current DOE-funded data collection and analysis work suggests that demonstration and deployment projects may present the most fruitful near-term opportunity for engaging the Hydrogen Safety Panel. Non-DOE industrial and transportation incidents also provide valuable data on equipment and personnel initiated releases and the effectiveness of leak detection and fire/explosion protection measures following the release.

The Hydrogen Safety Panel recommends that the DOE Fuel Cell Technologies Program identify mechanism(s) for such information sharing and analysis, and facilitate the interaction of the Hydrogen Safety Panel, DOE project management staff and a selected set of contractor project managers for the purpose of establishing the most appropriate mechanism for such work.

Respectfully submitted,
The Hydrogen Safety Panel

Safety Review Reports and White Papers 2009-2012

1. Frikken, D., Pero, M. and E.G. Skolnik, "Telephone Safety Interview Report: Development of a Novel Efficient Solid-Oxide Hybrid for Co-Generation of Hydrogen and Electricity Using Nearby Resources for Local Applications, MSRI, Salt Lake City, UT," January 6, 2009.
2. Skolnik, E.G., "Telephone Safety Interview Report: Materials Solutions for Hydrogen Delivery in Pipelines, Secat, Inc., Lexington, KY," January 13, 2009.
3. Bain, A., E.G. Skolnik, S.C. Weiner and R.G. Zalosh, "Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project, Shell Hydrogen LLC, Washington, DC," PNNL-18191, January 27, 2009.
4. Weiner, S.C. and R.A. Kallman, "Secondary Protection for 70 MPa Fueling, A White Paper from the Hydrogen Safety Panel," PNNL-18523, July 6, 2009.
5. Barilo, N.F., D. Frikken, E.G. Skolnik and S.C. Weiner, "Safety Evaluation Report: Development of a Novel Efficient Solid-Oxide Hybrid for Co-Generation of Hydrogen and Electricity Using Nearby Resources for Local Applications, MSRI, Salt Lake City, UT," PNNL-18570, July 16, 2009.
6. Sherman, A.J., E.G. Skolnik, I. Sutherland and S.C. Weiner, "Safety Evaluation Report: Investigation of Reaction Networks and Active Sites in Bio-Ethanol Steam Reforming Over Co-Based Catalysts, Koffolt Laboratories, Ohio State University, Columbus, OH," PNNL-18718, September 8, 2009.
7. Bain, A., D. Frikken, E.G. Skolnik and S.C. Weiner, "Safety Evaluation Report: Fuel Cell Testing Facility, Argonne National Laboratory, Argonne, IL," PNNL-18719, September 8, 2009.
8. Bain, A., E.G. Skolnik, S.S. Woods and S.C. Weiner, "Lead Research and Development Activity for DOE's High Temperature, Low Relative Humidity Membrane Program, University of Central Florida, Florida Solar Energy Center, Cocoa, FL," PNNL-18927, October 29, 2009.
9. Skolnik, E.G., Safety Evaluation Follow-up Report for "California Infrastructure Project: Hydrogen Fueling Station, University of California, Irvine, CA," November 5, 2009.
10. Skolnik, E.G., Safety Evaluation Follow-up Report for "Hydrogen Technology Program: Ammonia Borane Tasks, Purdue University, West Lafayette, IN," November 5, 2009.

Safety Review Reports and White Papers 2009-2012 (continued)

11. Skolnik, E.G., Safety Evaluation Follow-up Report for “Hydrogen Fuel Cell and Storage Technologies (FCAST) and Solar Hydrogen Generation Research (SHGR), University of Nevada, Las Vegas, NV,” November 9, 2009.
12. Skolnik, E.G., Safety Evaluation Follow-up Report for “Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project, Chevron Technology Ventures/Alameda Contra Costa Transit, Oakland, CA,” November 11, 2009.
13. Skolnik, E.G., Safety Evaluation Follow-up Report for “Effect of Gaseous Impurities on Long-Term Thermal Cycling and Aging Properties of Complex Hydrides for Hydrogen Storage, University of Nevada, Reno, NV,” November 12, 2009.
14. Frikken, D., A.J. Sherman, E.G. Skolnik and S.C. Weiner, “Safety Evaluation Report: Water-Gas Shift Reaction via a Single-Stage Low-Temperature Membrane Reactor, Media and Process Technology, Inc., Pittsburgh and Schenley, PA,” PNNL-19090, January 8, 2010.
15. Skolnik, E.G., Safety Evaluation Follow-up Report for “Investigation of Reaction Networks and Active Sites in Bio-Ethanol Steam Reforming Over Co-Based Catalysts, Koffolt Laboratories, Ohio State University, Columbus, OH,” February 24, 2010.
16. Skolnik, E.G., Safety Evaluation Follow-up Report for “Fuel Cell Testing Facility, Argonne National Laboratory, Argonne, IL,” March 22, 2010.
17. Skolnik, E.G., Safety Evaluation Follow-up Report for “Lead Research and Development Activity for DOE’s High Temperature, Low Relative Humidity Membrane Program, University of Central Florida/Florida Solar Energy Center, Cocoa, FL,” March 26, 2010.
18. Skolnik, E.G. and D.J. Farese, “Telephone Safety Interview Report: Oil-Free Centrifugal Hydrogen Compression Technology Demonstration, Mohawk Innovative Technologies, Inc. (MiTi), Albany, NY,” April 2, 2010.
19. Skolnik, E.G., Safety Evaluation Follow-up Report for “Water-Gas Shift Reaction via a Single-Stage Low-Temperature Membrane Reactor, Media and Process Technology, Inc., Pittsburgh and Schenley, PA,” August 6, 2010.
20. Weiner, S.C. and Blake, C.W., “Safety Knowledge Tools Enhanced by International Collaboration,” A White Paper of the International Energy Agency Hydrogen Implementing Agreement Task 19 – Hydrogen Safety, PNNL-19901, October 18, 2010.

Safety Review Reports and White Papers 2009-2012 (continued)

21. Barilo, N.F., R.A. Kallman, E.G. Skolnik and S.C. Weiner, "Safety Evaluation Report: A Joint Theory and Experimental Project in the High-Throughput Synthesis and Testing of Porous COF and ZIF Materials for On-Board Vehicular Hydrogen Storage, University of California, Los Angeles," PNNL-19900, October 19, 2010.
22. Fort, W.C., R.A. Kallman, M.J. Maes, E.G. Skolnik and S.C. Weiner, "Safety Evaluation Report: Development of Improved Composite Pressure Vessels for Hydrogen Storage, Lincoln Composites, Lincoln, NE," PNNL-20082, December 28, 2010.
23. Bain, A., N.F. Barilo, A.J. Sherman, E.G. Skolnik and S.C. Weiner, "Safety Evaluation Report: Design of Novel Multi-Component Metal Hydride-Based Mixtures for Hydrogen Storage, Northwestern University, Evanston, IL," PNNL-20280, March 28, 2011.
24. **Skolnik, E.G., Safety Evaluation Follow-up Report for "Safety Evaluation Report: A Joint Theory and Experimental Project in the High-Throughput Synthesis and Testing of Porous COF and ZIF Materials for On-Board Vehicular Hydrogen Storage, University of California, Los Angeles," May 16, 2011.**
25. **Skolnik, E.G., Safety Evaluation Follow-up Report for "Safety Evaluation Report: Development of Improved Composite Pressure Vessels for Hydrogen Storage, Lincoln Composites, Lincoln, NE," May 16, 2011.**
26. **Bain, A., A.J. Sherman, E.G. Skolnik and S.C. Weiner, "Safety Evaluation Report: New Carbon-Based Materials with Increased Heats of Adsorption for Hydrogen Storage, Northwestern University, Evanston, IL," PNNL-20406, May 17, 2011.**
27. **Fort, W.C, G.W. Scheffler, E.G. Skolnik and S.C. Weiner, "Safety Evaluation Report: H-E-B Grocery Total Power Solution for Fuel Cell-Powered Material Handling Equipment, H-E-B, San Antonio, TX," PNNL-20480, June 14, 2011.**
28. **Fort, W.C, G.W. Scheffler, E.G. Skolnik and S.C. Weiner, "Safety Evaluation Report: Fuel Cell-Powered Lift Truck Fleet Deployment, Sysco Food Services of Houston, Inc., Houston, TX," PNNL-20504, June 27, 2011.**
29. **Barilo, N.F., D. Frikken, S.C. Weiner and R.G. Zalosh, "Safety Evaluation Report: Accelerating Acceptance of Fuel Cell Backup Power Systems, Robins Air Force Base, Warner Robins, GA," PNNL-21078, January 17, 2012.**

Note: Bold font identifies reports and white papers subsequent to the 2011 Annual Merit Review and Peer Evaluation Meeting

Safety Review Reports and White Papers 2009-2012 (continued)

- 30. Weiner, S.C., “Learning from Safety Events – A Statement from the Hydrogen Safety Panel,” PNNL-SA-85153, January 17, 2012.**
- 31. Barilo, N.F., D. Frikken, S.C. Weiner and R.G. Zalosh, “Safety Evaluation Report: Fuel Cell Powered Lift Truck Fleet Deployment, Coca-Cola Bottling Co. Consolidated, Charlotte, NC,” PNNL-21079, January 18, 2012.**
- 32. Skolnik, E.G., Safety Evaluation Follow-up Report for “Safety Evaluation Report: New Carbon-Based Materials with Increased Heats of Adsorption for Hydrogen Storage, Northwestern University, Evanston, IL,” January 27, 2012.**
- 33. Skolnik, E.G., Safety Evaluation Follow-up Report for “Safety Evaluation Report: Design of Novel Multi-Component Metal Hydride-Based Mixtures for Hydrogen Storage, Northwestern University, Evanston, IL,” February 6, 2012.**
- 34. Skolnik, E.G., Safety Evaluation Follow-up Report for “Safety Evaluation Report: Fuel Cell-Powered Lift Truck Fleet Deployment, Sysco Food Services of Houston, Inc., Houston, TX,” March 20, 2012.**