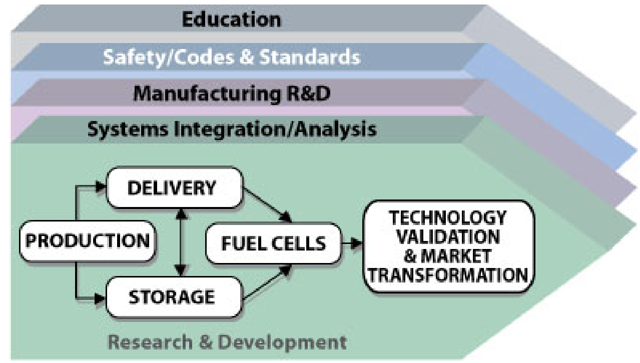
3.8. Hydrogen Safety



Safe practices in the production, storage, distribution and use of hydrogen are essential to sustain safety across the Hydrogen Program. The Safety subprogram develops and promotes safe practices in all hydrogen applications across the DOE Hydrogen Program and elsewhere.

Like other fuels in use today, hydrogen can be used safely with appropriate handling and systems design. The risk level of hydrogen fuel at atmospheric pressure is similar to that of fuels, such as natural gas and liquid petroleum gas. However, because of the smaller size of the molecule and the greater buoyancy of the gas, hydrogen requires different storage, handling and use techniques. The Safety subprogram seeks to assure the safe use of hydrogen and to coordinate with the Education and all subprograms to provide information on the safety hazards related to the use of hydrogen. The Safety subprogram also participates in DOE collaborations with the International Partnership for the Hydrogen Economy (IPHE) and the International Energy Agency (IEA) to promote safety.

The overall goal of the Safety subprogram is to understand, develop and promote the practices that will ensure the safe handling, storage and use of hydrogen. By promoting hydrogen safety procedures, supporting a research program, and developing information resources, the Safety subprogram seeks to help form the basis for the safe use of hydrogen as an energy carrier, now and in the future.

3.8.1 Goal and Objectives

Goal

Develop and implement the practices and procedures that will ensure safety in the operation, handling and use of hydrogen and hydrogen systems for all DOE hydrogen projects and utilize these practices and lessons learned to promote the safe use of hydrogen.

Objectives

- By 2007, develop a comprehensive safety plan in collaboration with industry that establishes Program safety policies and guidelines. DOE will utilize the Hydrogen Safety Panel's expertise and assistance in conducting safety evaluations and identifying areas of additional research.
- By 2008, publish a Best Practices for Hydrogen Safety Manual. The Manual will be a "living" document that will provide guidance for ensuring safety in DOE hydrogen projects, while serving as a model for all hydrogen projects and applications.
- By 2012, develop hydrogen leak detection technologies such as sensors.
- Develop a robust supporting research and development program to provide critical hydrogen behavior data, develop leak detection technologies and develop a detailed understanding of hydrogen combustion and safety across a range of scenarios. These data will support the

establishment of setback distances in building codes and minimize the overall data gaps in codes and standards development.

- Promote widespread sharing of safety-related information, procedures and lessons learned with first responders, authorities having jurisdiction and other stakeholders.

3.8.2 Approach

Safety Management

The continued safe operation, handling and use of hydrogen and related systems require comprehensive safety management. In response to recommendations by the National Research Council, the Safety subprogram will develop a comprehensive safety plan to outline protocols to promote safety in all DOE-funded hydrogen projects through communication among DOE Hydrogen Program management, subprograms and projects.

In addition to the efforts of the subprograms and individual project managers, DOE pursues project safety through the efforts of the Pacific Northwest National Laboratory (PNNL) and its Hydrogen Safety Panel. Supported by the Hydrogen Safety Panel, PNNL provides recommendations on safety and hazard mitigation to the DOE Hydrogen Program on its activities and projects. With experts from the insurance, fire safety, fuel provider, automaker, aerospace, engineering and other industries, the Panel possesses well over 100 years of collective safety experience. Its objectives are to help identify safety concerns; determine current status of regulations, policies, codes, standards and guidelines and provide a platform to discuss critical hydrogen safety issues. Through independent assessments of safety plans, telephone interviews and site visits, the Panel identifies alternative safety practices and needs for additional analysis or review.

Safety Research and Development

Data and its classification present a number of challenges for hydrogen use. For example, the way hydrogen is classified throughout the world is inconsistent. Some countries, including the U.S., currently classify hydrogen as a hazardous material without the necessary regulations in place that allow the common use of it as a fuel. The subprogram will work to develop the scientific basis to promote the adoption of hydrogen regulations that facilitate its use as a fuel, as is done with other common fuels such as gasoline. (Fuels such as gasoline are also considered hazardous materials, but regulations are in place that allow the common use of it as a fuel.)

Additional data needs exist for the commercial use of hydrogen beyond its historical use as a feedstock chemical. In addition, safety-related information, often corresponding to company-specific chemical processes and handling procedures, has been treated as proprietary. The widespread availability and communication of safety-related information will be crucial to ensure safe operation of future hydrogen fuel systems.

Although safety-by-design and passive mitigation systems are preferred, it will still be necessary to develop technologies to detect hydrogen releases and system failures. This subprogram will develop hydrogen sensors with the appropriate response time (See Table 3.8.2), sensitivity and accuracy for use in safety applications to reduce risk and help establish public confidence.

Safety Information Resources

The chemical and aerospace industries have a long history of safe hydrogen use, but the introduction of hydrogen as a commercial fuel for use by the general public introduces a host of new safety issues that must be addressed. During this phase of rapid innovation, it is in the entire hydrogen industry's best interest to share knowledge of risks and promote safety in hydrogen energy systems.

The Safety subprogram seeks to share hydrogen safety information through publicly available online resources. In 2006, the Safety subprogram published databases on hydrogen incidents and on current and historical hydrogen safety literature. Through the expertise of the Hydrogen Safety Panel and PNNL, DOE will synthesize the raw incidents and near-miss data and compile lessons learned to develop a Best Practices Manual for Hydrogen Safety by 2008. This information will be shared through the DOE Web site, communication between the DOE Hydrogen program and its projects, and through the networks of the FreedomCAR and Fuel Partnership.

Accidents or other system failures within today's conventional fuel infrastructure can and do occur. Thus, the Safety subprogram takes steps to prepare for accidents or other failures in the event that they occur within the laboratory, hydrogen vehicle or fuel infrastructure systems. For any fuel, a suitably trained emergency response force is essential to minimize safety-related incidents. Training first responders is particularly important to successfully implement hydrogen technologies, especially in the early years. A loss in public confidence could derail the adoption of hydrogen technologies.

Finally, the Safety subprogram coordinates with the entire Hydrogen Fuel Cells and Infrastructure Technologies Program and, in particular, with the Education and Codes and Standards subprograms to develop training, safety information materials and practices to foster the safety of projects and technologies.

3.8.3 Status

Safety Management

With the expertise of the Hydrogen Safety Panel and PNNL, in October 2005 DOE published the "Guidance for Safety Aspects of Proposed Hydrogen Projects" protocol. This resource is available on the DOE Web site, www.eere.energy.gov/hydrogenandfuelcells/.

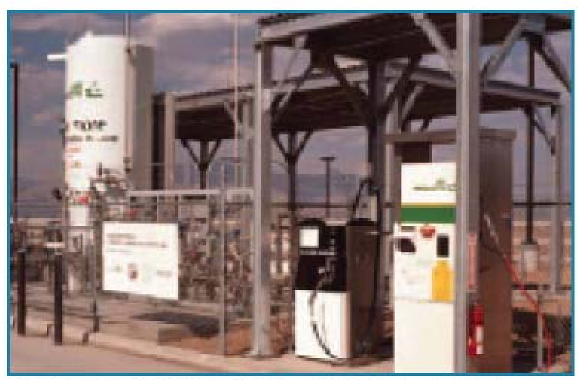


Figure 3.8.1 Air Products Hydrogen Fueling Station in Las Vegas, Nevada

This document details the safety plans that must be submitted for each DOE-funded project. Systematic application of safety assessment methodologies reduces the likelihood that a potential risk may be overlooked and allows for a consistent measure of safety across all DOE-supported hydrogen projects. The safety plans for all DOE-supported hydrogen projects and the overall lessons learned under the Technology Validation subprogram will play an important role in developing safe practices for future commercialization.

In March 2004, the Hydrogen Safety Panel conducted its first site visit at the Las Vegas Hydrogen Energy Station in Nevada, shown in Figure 3.8.1. Review teams, consisting of Panel members, work with principal investigators and their teams through scheduled site visits and provide their evaluations to PNNL, which then reports to and provides safety recommendations to DOE. Project teams draw on the Panel's expertise to help resolve safety issues associated with the use of hydrogen and hydrogen-related systems. By the end of March 2006, the Panel had completed thirteen site visits. The Hydrogen, Fuel Cells & Infrastructure Technologies Program, PNNL and the Panel will continue to select a portfolio of projects for safety review.

Safety Research and Development

To provide technical data for hydrogen codes and standards, the Safety subprogram supports research such as the materials compatibility, hydrogen behavior and risk assessment studies conducted by Sandia National Laboratory. The online Technical Reference for Hydrogen Compatibility of Materials contains data collected from the literature and generated from materials testing. Information for 15 material classes will be published in 2007 and made available at www.ca.sandia.gov/matlsTechRef/. Sections on pressure vessel steels, pipeline steels and aluminum alloys will be added in the future. Sandia also conducts research on the behavior of hydrogen releases and develops quantitative risk assessments to evaluate credible hydrogen safety scenarios.

Information Resources

The Safety subprogram also focuses on information, materials and training facilities that are critical for the commercialization of hydrogen energy technologies. To help fill the void of publicly available hydrogen safety data, in 2006 DOE published two online hydrogen safety information resources: the Hydrogen Incidents Database and the Safety Bibliographic Database. The Hydrogen Incidents Database, developed by PNNL, catalogs all hydrogen incidents and near-misses at DOE-funded projects and elsewhere. All the reports include details of the incidents and are non-attributed to ensure anonymity. This resource is available at www.h2incidents.org.The Safety Bibliographic Database, developed by the National Renewable Energy Laboratory, was established in response to a recommendation from the National Research Council. The Safety Bibliographic Database contains over 400 publicly available hydrogen safety-related reports, papers, and presentations, allowing researchers, code officials, and stakeholders to learn from the experiences of others, and is available at www.hydrogen.energy.gov/biblio_database.html.

Current safety related activities are summarized in Table 3.8.1.

Table 3.8.1 Current Activities for Hydrogen Safety

Activity	Objective	Organizations
Safety Management		
DOE Hydrogen Program Safety Plan	Office-wide communication protocols for safety management.	DOE
Safety Guidance	Conducts ongoing safety assessment of DOE projects through site visits and safety plan reviews.	PNNL, Hydrogen Safety Panel
Safety Research and Development		
Safety Protocols	Conduct literature search to help establish, in consultation with industry, protocols to identify failure modes and identify the areas where additional research is needed.	SNL
Risk Assessment	Develop an accident classification system, risk assessment methodology, and publish report on common accident scenarios.	SNL
Sensors	Develop leak detection technologies, such as sensors.	To be determined
Holistic Safety Design	Explore systems approaches and "holistic" design strategies for development of systems that are inherently safer.	NREL
Information Resources		
Incidents Database	Develop and maintain a comprehensive repository for hydrogen safety incidents	PNNL
Safety Bibliographic Database	Develop and maintain a comprehensive repository for hydrogen safety literature and presentations	NREL
Best Practices Manual	Compile and publish lessons learned and case studies on the use of hydrogen and on hydrogen applications.	PNNL
Training Hardware	Develop appropriate hydrogen safety props for emergency response training	PNNL

3.8.4 Challenges

Developing a comprehensive safety plan is a challenge, in part, because the safety information on hydrogen components and systems is often limited to industrial practice. Companies develop practices to comply with federal regulations and meet the criteria of their insurance providers. Therefore, the scientific and technical basis for established industrial training practices is not always publicly available, perhaps because of proprietary or liability concerns. In addition, any new safety information and practices may not be published.

Hydrogen's tendency to leak presents a challenge to its storage and delivery. As a flammable gas, leakage creates a safety hazard. The Safety subprogram works with other subprograms to eliminate leakage, develop robust, reliable hydrogen leak detection technology with rapid response times and operability over a range of environmental conditions and develop design principles that mitigate the effects of hydrogen leakage.

There is a general lack of understanding of hydrogen and hydrogen safety needs among local government officials, fire marshals and the general public. In some cases, public opposition to siting hydrogen refueling stations has occurred, at times preventing operation of a facility. In other cases, the local regulatory authority may view one or more hydrogen properties (e.g. hydrogen gas is flammable at low concentrations) in isolation without considering other characteristics that could mitigate danger (e.g., hydrogen's tendency to rapidly disperse once released). Failure to comprehensively consider hydrogen's properties may lead to over-restrictive policies that preclude implementation.

The general public may be receiving limited or inaccurate information. To date, there is no comprehensive handbook containing best practices for hydrogen safety. Once mandatory reporting is established for safety and reliability, training will be required to educate government officials. Additionally, the data assessing the safety of hydrogen systems must meet the needs of insurance providers and other stakeholders. This subprogram is working to fill these gaps through R&D, training and tracking of safety-related incidents and lessons learned to help foster best practices.

The technical challenges discussed elsewhere in this RD&D program plan must be overcome with solutions that are reliable, safe and cost-effective. System safety must be convincingly communicated to crucial enablers of the technology, such as regulatory authorities and the public at large.

Targets

Most hydrogen safety R&D projects are exploratory in nature and do not have technical targets. In the U.S., this safety data is then voluntarily adopted into codes and standards through a consensus-based, industry-led process (see Section 3.7). An exception to the lack of targets is the R&D of hydrogen safety sensors, for which performance targets can be set (see Table 3.8.2).

Table 3.8.2. Targets for Hydrogen Safety Sensor R&D
• Measurement Range: 0.1%-10% • Operating Temperature: -30 to 80°C • Response Time: under one second • Accuracy: 5% of full scale • Gas environment: ambient air, 10%-98% relative humidity range • Lifetime: 10 years • Interference resistant (e.g., hydrocarbons)

Barriers

This section details the barriers that must be overcome to achieve the goal and objectives of the Safety subprogram.

A. Limited Historical Database

Only a small number of hydrogen technologies, systems and components are in operation. Only limited public data is available on the operational and safety aspects of these technologies.

B. Proprietary Data

Many hydrogen technologies, systems and components are still in the pre-commercial development phase. Only limited non-proprietary data is available on the operational and safety aspects of these technologies.

C. Validity of Historical Data

The historical data used in assessing safety parameters for the production, storage, transport and utilization of hydrogen are several decades old. Validating this data and assessing its use may prove useful in the development of a hydrogen infrastructure.

D. Liability Issues

Potential liability issues and lack of insurability are serious concerns that could affect the commercialization of hydrogen technologies.

E. Variation in Standard Practice of Safety Assessments for Components and Energy Systems

Variations in safety practices and lack of standardization across similar hydrogen technical projects increase the risk of safety related incidents.

F. Safety is Not Always Treated as a Continuous Process

Safety practices will need to be maintained and updated as required throughout the duration of the project.

G. Expense of Data Collection and Maintenance

Principal Investigators need to pursue the detailed collection and maintenance of all safety data and information despite the added expense.

H. Lack of Hydrogen Knowledge by Authorities Having Jurisdiction

Officials responsible for approving the safety of hydrogen technologies and installations often have insufficient knowledge of hydrogen properties and characteristics to complete the approval.

I. Lack of Hydrogen Training Facilities for Emergency Responders

A suitably trained emergency response force is essential for preventing the escalation of a hydrogen incident. Responders have little experience with hydrogen technologies, in part because there are no training materials specific to hydrogen emergency response.

3.8.5 Task Descriptions

Task descriptions are presented in Table 3.8.3.

Table 3.8.3 Technical Task Descriptions

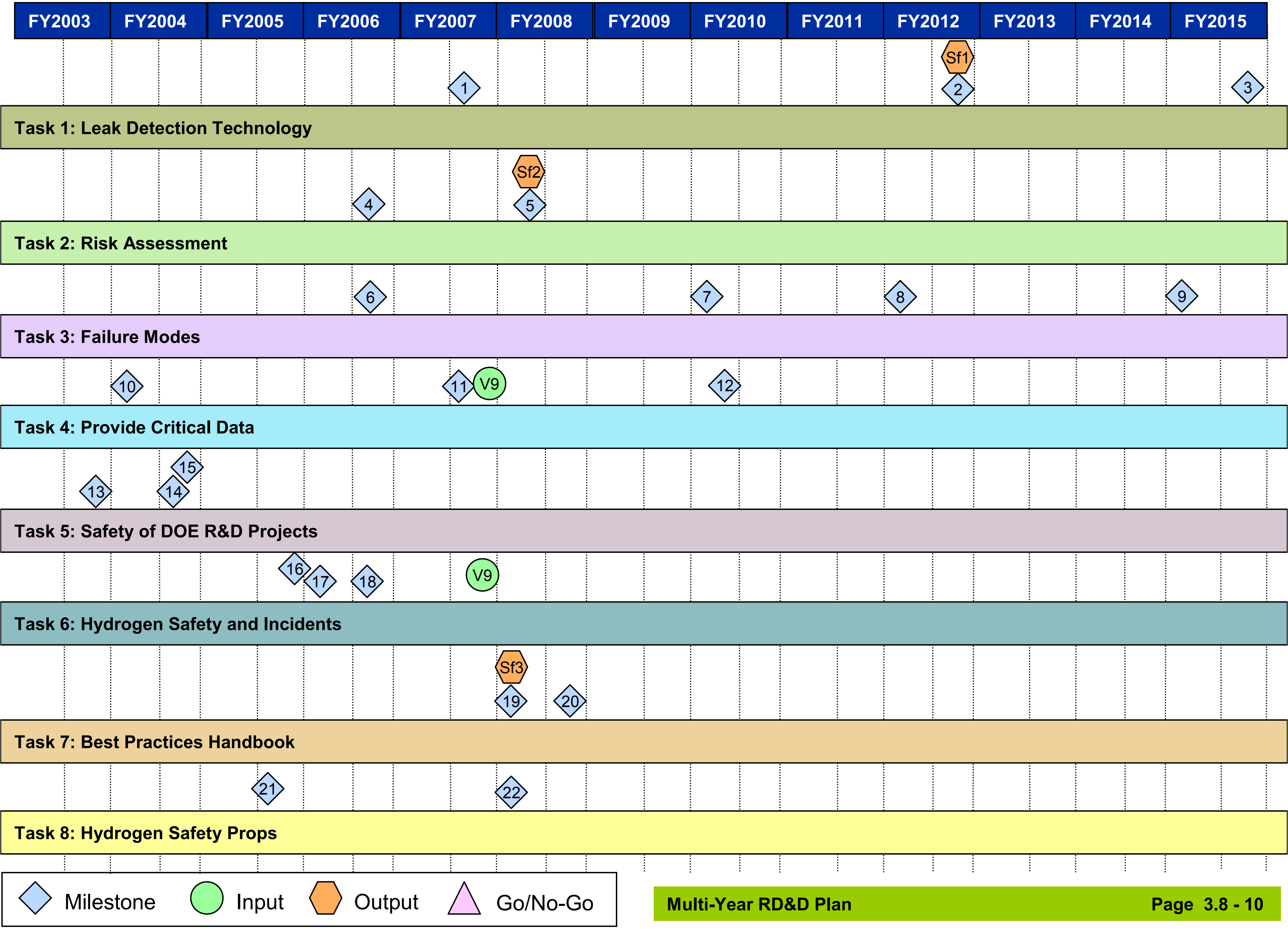
Task	Description	Barriers
1	**Develop leak detection technologies, such as sensors**	D, E
2	**Conduct risk assessment and compile key data** ▪ Develop a system for classifying accident types. ▪ Develop a methodology for estimating accident likelihood. ▪ Develop and release a report of the most common accident scenarios.	A, B, C, G
3	**Establish protocol to identify failure modes and mitigate risks** ▪ Draft protocol for identifying potential failure modes and risk mitigation. ▪ Work with industry experts to review and revise the protocol. Release consensus protocol to become part of program solicitations.	A, B, C, G
4	**Develop supporting research program to provide critical data and technologies** ▪ A supporting research program will be developed to provide missing data. The literature search performed to identify failure modes will be evaluated to identify the areas where additional research is necessary. ▪ Explore systems approaches and "holistic" design strategies for development of systems that are inherently safer.	A, B, C, E, G

Table 3.8.3 Technical Task Descriptions (continued)		
Task	**Description**	**Barriers**
5	**Safety of DOE R&D Projects** ▪ Conduct ongoing safety assessment of DOE projects through site visits and safety plan reviews. ▪ Develop, update, and maintain guidelines for all DOE funded projects to include safety planning in all aspects of the project, including safety incident tracking. ▪ Publish guidelines. ▪ Coordinate with all subprograms to communicate relevant safety-related activities and apply lessons learned. ▪ Include the comprehensive safety plan into the annual review process	E, F, G
6	**Develop comprehensive information resources on hydrogen safety and incidents** ▪ Develop and maintain a comprehensive repository for hydrogen safety data and information. ▪ Publish safety bibliography and incidents databases.	A, B, C
7	**Develop comprehensive handbook on Best Practices** ▪ Compile information material from databases and safety assessments ▪ Publish final Best Practices Manual for Hydrogen Safety and support the adoption of these practices.	A, B, C, D, E, F, G, H, I
8	**Develop appropriate hydrogen safety props for emergency response training**	H, I

3.8.6 Milestones

The following chart shows the interrelationship of milestones, tasks, supporting inputs and outputs from other subprograms from FY 2003 through FY 2015. This information is also summarized in Appendix B.

Safety Milestones Chart



Task 1: Leak Detection Technology	
1	Conduct workshop to identify key performance parameters for hydrogen sensors and leak detection devices. (3Q, 2007)
2	Develop sensors meeting technical targets. (4Q, 2012)
3	Develop leak detection devices for pipeline systems. (4Q, 2015)

Task 2: Risk Assessment	
4	Conduct workshop to review risk assessment. (3Q, 2006)
5	Publish a report of common accident scenarios. (2Q, 2008)

Task 3: Failure Modes	
6	Prepare draft failure modes and risk mitigation protocol. (3Q, 2006)
7	Complete risk mitigation analysis for baseline transportation infrastructure systems. (1Q, 2010)
8	Complete investigation of safe refueling protocols for high pressure systems. (1Q, 2012)
9	Complete risk mitigation analysis for advanced transportation infrastructure systems. (1Q, 2015)

Task 4: Provide Critical Data	
10	Initiate collaboration with NASA, DOT, and other agencies to establish and publish an interagency plan on the cooperation of hydrogen safety R&D. (1Q, 2004)
11	Develop design protocol that employs passive system or holistic design techniques. (3Q, 2007)
12	Complete research needed to fill data gaps on hydrogen properties and behaviors. (2Q, 2010)

Task 5: Safety of DOE R&D Projects	
13	An independent panel of experts in hydrogen safety will be assembled to provide expert technical guidance to funded projects. (4Q, 2003)
14	First DOE annual review incorporating new emphasis on safety. (3Q, 2004)
15	Publish guidelines for hydrogen safety planning and inclusion in procurements. (4Q, 2004)

Task 6: Hydrogen Safety and Incidents	
16	Evaluate available data on hydrogen incidents and H_2 safety publications. (4Q, 2005)
17	Identify user needs for safety bibliography and incident databases. (1Q, 2006)
18	Publish safety bibliography and incident databases. (3Q, 2006)

Task 7: Best Practices Handbook	
19	Publish a Best Practices Handbook. (1Q, 2008)
20	Update peer-reviewed Best Practices Handbook. (4Q, 2008)

Task 8: Hydrogen Safety Props	
21	Conduct first hydrogen safety class (non-prop) offered at HAMMER. (3Q, 2005)
22	Complete first life-size prop for hands-on training of emergency responders. (1Q, 2008)

Outputs

Sf1 Output to Program: Develop sensors meeting technical targets (4Q, 2012)

Sf2 Output to Program: Report of common accident scenarios (2Q, 2008)

Sf3 Output to Program: Best Practices Handbook on Hydrogen Safety (1Q, 2008)

Inputs

V9 Final report on safety and O&M of three refueling stations (4Q, 2007)