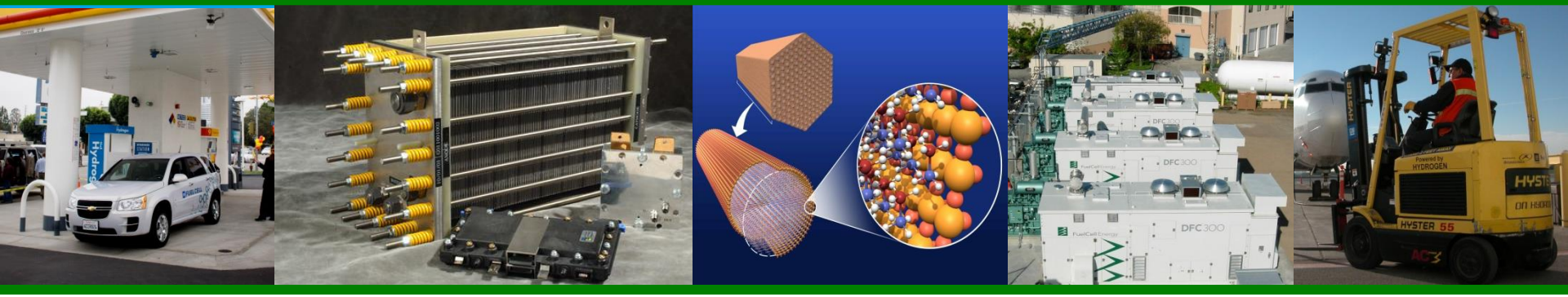
U.S. DEPARTMENT OF ENERGY



What Can We Learn from Hydrogen Safety Event Databases?

Webinar Moderator:

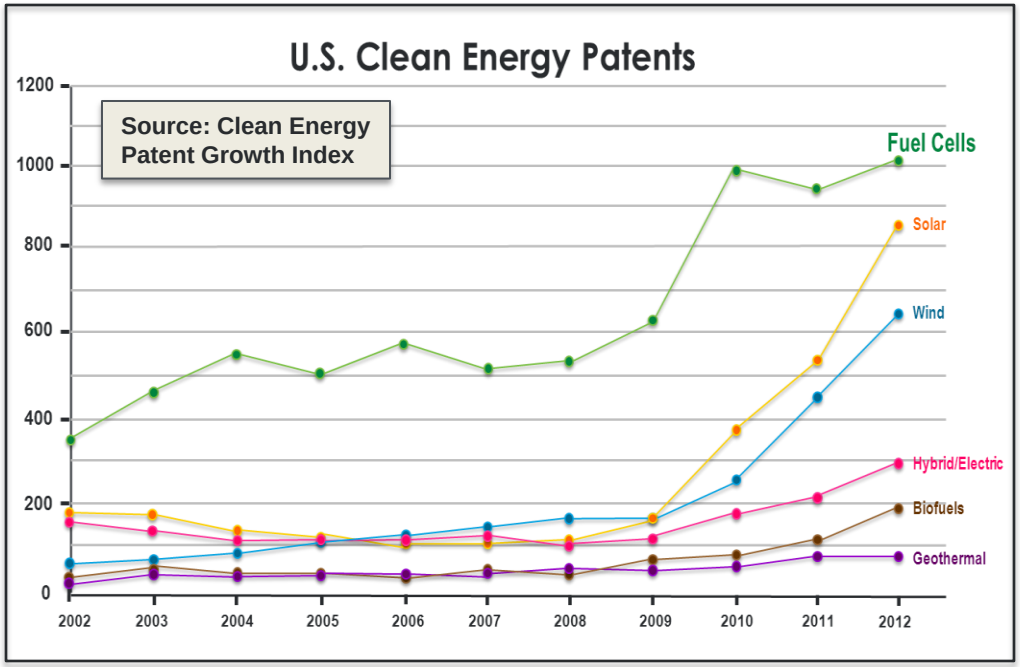
Jay Keller

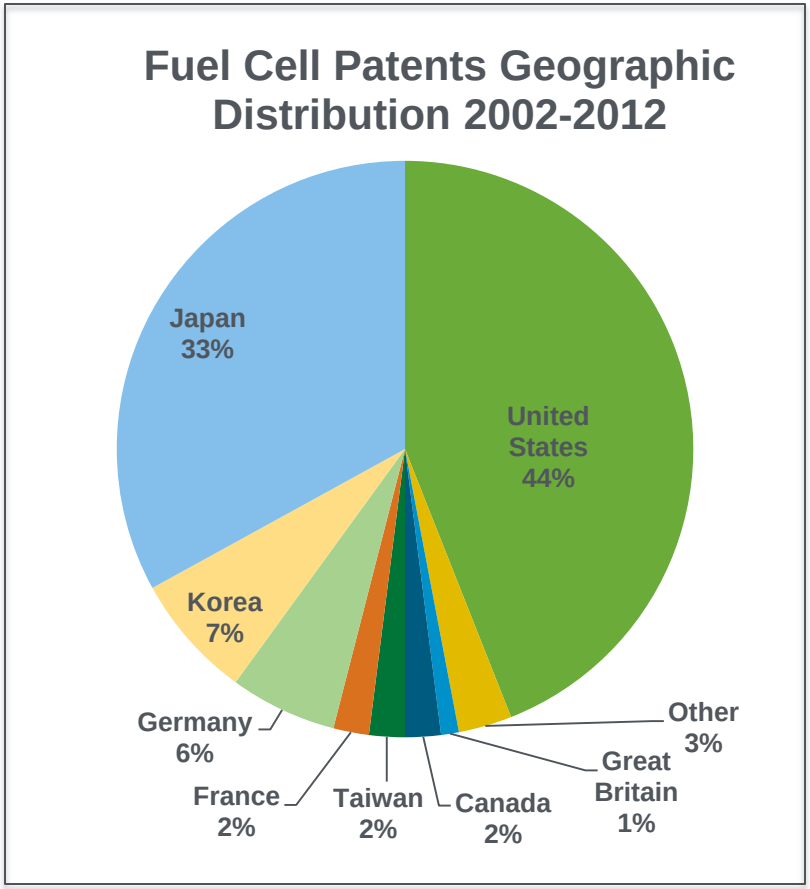
Consultant

U.S. DOE Fuel Cell Technologies Office
Safety, Codes and Standards

September 10, 2013

Fuel Cells – An Emerging Global Industry





Top 10 companies for fuel cell patents: GM, Honda, Toyota, Samsung, UTC Power, Nissan, Ballard, Panasonic, Plug Power, Delphi Technologies

- Clean Energy Patent Growth Index[1] shows growth in all clean energy technology patents
- More than 1,000 fuel cell patents issued in 2012

[1] http://cepgi.typepad.com/heslin_rothenberg_farley_/2013/03/clean-energy-patent-growth-index-2011-year-in-review.html

Worldwide Commitment to FCEVs

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Interest in fuel cells and hydrogen is global, with more than $1 billion in public investment in RD&D annually. The world's leading automakers have committed to develop FCEVs.

Major Auto Manufacturers' Activities and Plans for FCEVs

General Motors
- >120 vehicles deployed since 2007 in Project Driveway
- 2012: Technology readiness goal for FC powertrain

Toyota
- 2010-2013: U.S. demo fleet of 100 vehicles
- "FCHV-adv" can achieve 431-mile range &68 mpgge
- 2015: Commercialize cars at <$100K

Honda
- Clarity FCX named "World Green Car of the Year"; EPA certified 72mpgge; leasing up to 200 vehicles
- 2015: Launch all-new fuel cell electric model sequentially in Japan, U.S. and Europe.

Daimler
- Plans for tens of thousands of FCEVs/year in 2015 – 2017 and hundreds of thousands a few years after
- Partnership with Linde to develop fueling stations.
- ***Moved up commercialization plans to 2014***

Hyundai-Kia
- 2012-2013: 2000 FCEVs/year
- 2015: 10,000 FCEVs/year
- "Borrego" FCEV has achieved >340-mile range.

Volkswagen
- Expanded demo fleet to 24 FCEVs in CA
- Recently reconfirmed commitment to FCEVs

SAIC (China)
- SAIC Motor Company is planning 20-30 prototypes in 2013 and >1,000 FCEVs in 2015.

Nissan
- Commercial FCEVs planned for 2016. FCEVs are key part of "Nissan Green Program." Announced strategic partnership with Daimler on FCEVs.

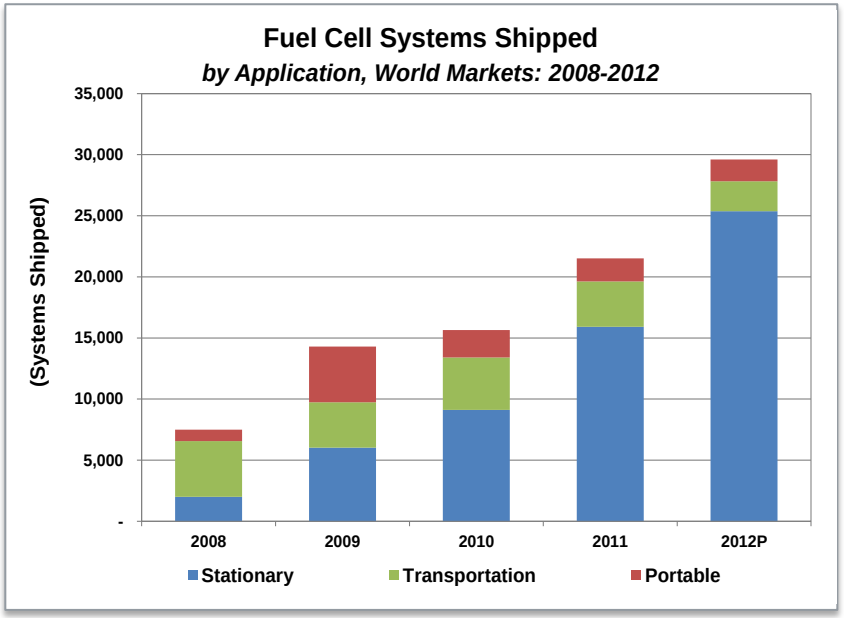
BMW
- Fielding a fleet of "F-Cell" vehicles in the U.S. 40 currently leased with another 20 on the way.

Based on publicly available information during 2011 – 2012. Ford involved through Ballard-Daimler partnership (AFCC).

Market Growth & Potential

Fuel cell markets continue to grow
- **~30,000 units shipped in 2012 (~35% increase)**
- **48% increase in global MWs shipped**

Independent analyses show global markets could mature in the next 10–20 years, producing revenues of:
- **$14 – $31 billion/year for stationary power**
- **$11 billion/year for portable power**
- **$18 – $97 billion/year for transportation**



Sources: Navigant Research, DOE Fuel Cells Market Report

IPHE[1] - Proposed Hydrogen Safety Information Portal & Webinar

Safety Information Portal

- Information Portal will serve as a central point for access to the hydrogen safety lessons learned and best practices information.

- IPHE will consolidate information into a single, global, open-source, searchable information resource.

Webinars

- Regular IPHE webinars will serve as another pathway to share information while utilizing the resources, knowledge and experience of IPHE members and partners.

- Webinars will cover topics of interest to the global hydrogen and fuel cell community.
  - ✓ **Safety information sharing**
  - ✓ H2 resource availability analysis (IEA HIA[2] Task 30) results
  - ✓ Status of infrastructure deployments
  - ✓ Policy Examples to Promote H2 and FCs

- Two webinars per year

[1]IPHE – International Partnership for Hydrogen and Fuel Cells in the Economy
[2]IEA HIA – International Energy Agency Hydrogen Implementing Agreement

Webinar

Webinar Objective: To Share U.S. and E.U. information as it pertains to Hydrogen Safety and Best Practices, Lessons Learned and Available Databases

- Each speaker up to 15 minutes for formal remarks
  - We will entertain panel discussion questions at the end of the formal presentations for 20 minutes
  - Webinar is being recorded and will be posted approximately 10 days after the webinar. This will be through the U.S. DOE Fuel Cell Technologies Office homepage.

    www1.eere.energy.gov/hydrogenandfuelcells/webinar_archives_2013.html

Example – H2 Information Sharing

- **Safety Information helps guide R&D.**
- **It is critical to collect and disseminate relevant information.**

Equipment	Total Incidents
Piping/Fitting/Valves	102
Hydrogen Storage	49
Vehicle & Fueling System	40
Safety Systems	25
Ventilation System	22
Laboratory Equipment	19
Pressure Relief Devices	16
Motive Power Systems	15
Heating Equipment	14
Electrical Equipment	14
Process Equipment	14
Batteries and Related Equipment	13

Database web address – www.h2incidents.org

Examples:

- Piping (36)
- Valve (36)
- Flexible Tubing (8)
- Gasket (6)
- Bolts (6)

Cross–Search Categories :

- Settings
- Damage and Injuries
- Probable Causes
- Contributing Factors

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PNNL-SA-97884

What Can We Learn from Hydrogen Safety Event Databases? H2Incidents.org

STEVEN C.WEINER

Battelle Washington Office

Washington, DC

The Premise

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"*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*…"

Ref: *Learning from Safety Events*, A Statement from the Hydrogen Safety Panel, January 17, 2012.

What is H2Incidents.org?

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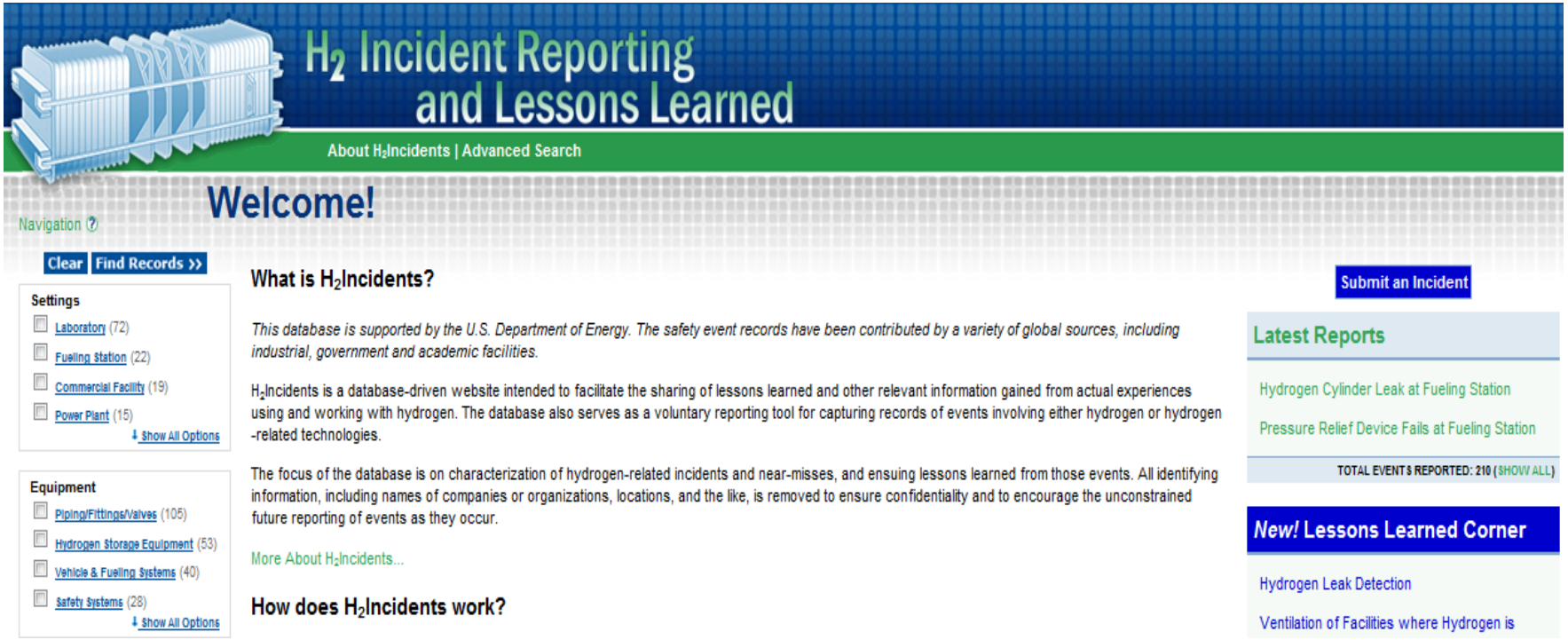
- Database-driven website to facilitate the sharing of lessons learned and other relevant information gained from actual experiences using and working with hydrogen.
- Focus on characterization of hydrogen-related incidents and near-misses, and ensuing lessons learned from those events.



H2Incidents.org History

- Launched in 2006 to store information and analysis of hydrogen-related safety events including describing the event, its setting and equipment, its characteristics, causes and contributing factors
  - 210 Safety event records to date
  - Voluntary reporting tool for capturing records of events involving hydrogen or hydrogen-related technologies.

- Key Attributes
  - Search Incidents
  - Enter Incidents
  - New Lessons Learned

The road to "H2incidents.org" began in Pisa….

Capturing the Event Focusing on Lessons Learned

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Each safety event record contains

- Description
- Severity (Was hydrogen released? Was there ignition?)
- Setting
- Equipment
- Characteristics (High pressure? Low temperature?)
- Damage and Injuries
- Probable Cause(s)
- Contributing Factors
- Lessons Learned/Suggestions for Avoidance/Mitigation Steps Taken

Lessons learned content enhanced by links to “H2best practices.org”


Tube Trailer Rollover


Gas Chromatograph Piping Leak and Explosion

Two Looks at H2incidents.org

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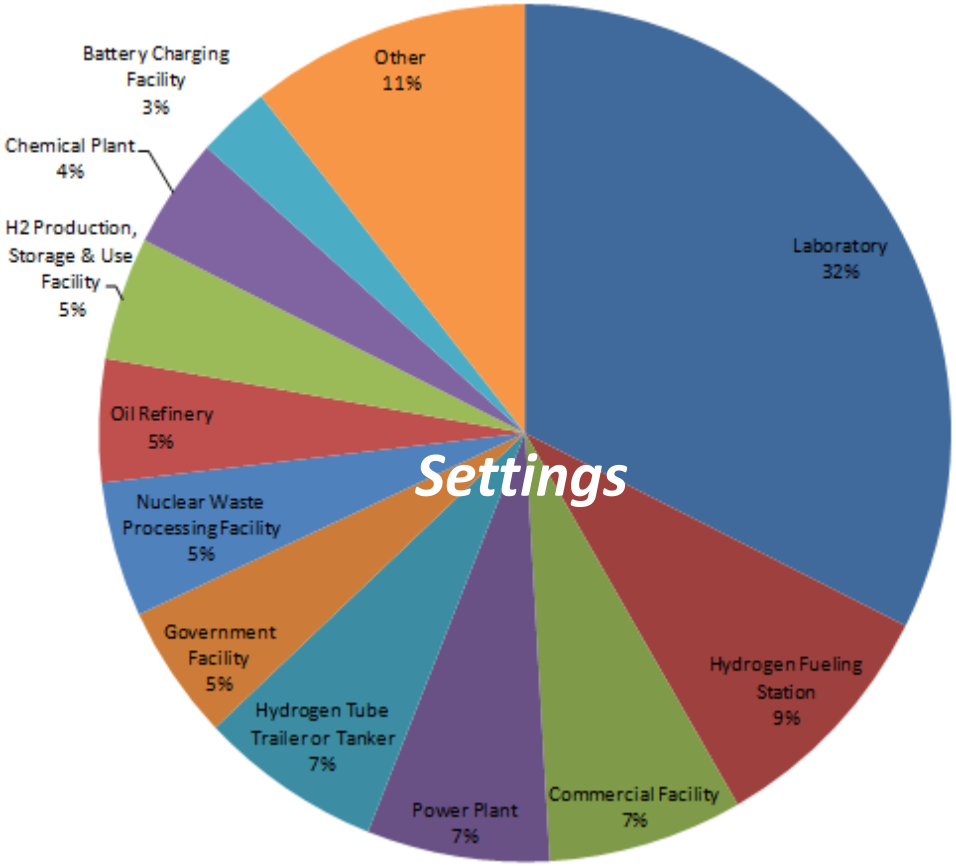

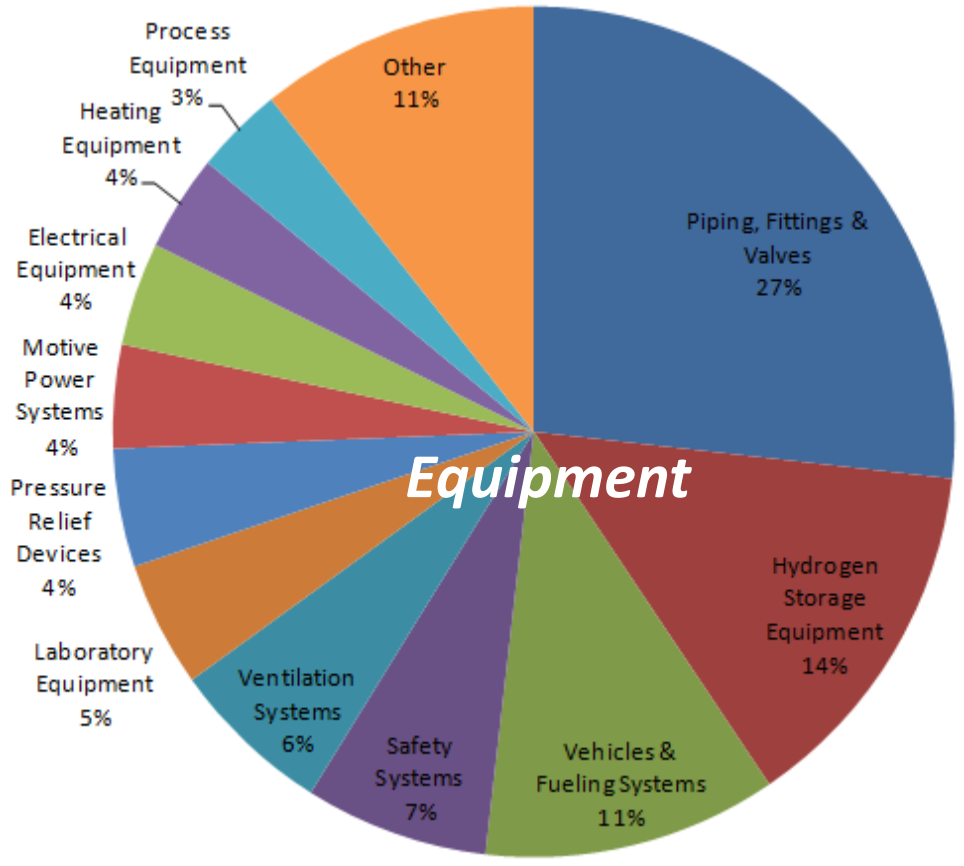

Search capabilities allow the user to seek information of interest.

Developing Safety Event Records

- Both incidents and near-miss records are sought
- Encourage self-submittal through an easy-to use online form
- Identify potential records through other means, e.g. media reports and other databases
- Work with “incident owners” and other submitters
  - Discuss, encourage and reach agreement for the submittal of a safety event record
  - Discuss, clarify and edit description, information and lessons learned.
  - Ensure anonymity in the safety event record itself
  - Obtain organizational approval for posting
- Provide expert review of safety event records by the Hydrogen Safety Panel and other subject matter experts.

H2incidents.org
Emphasizing Lessons Learned

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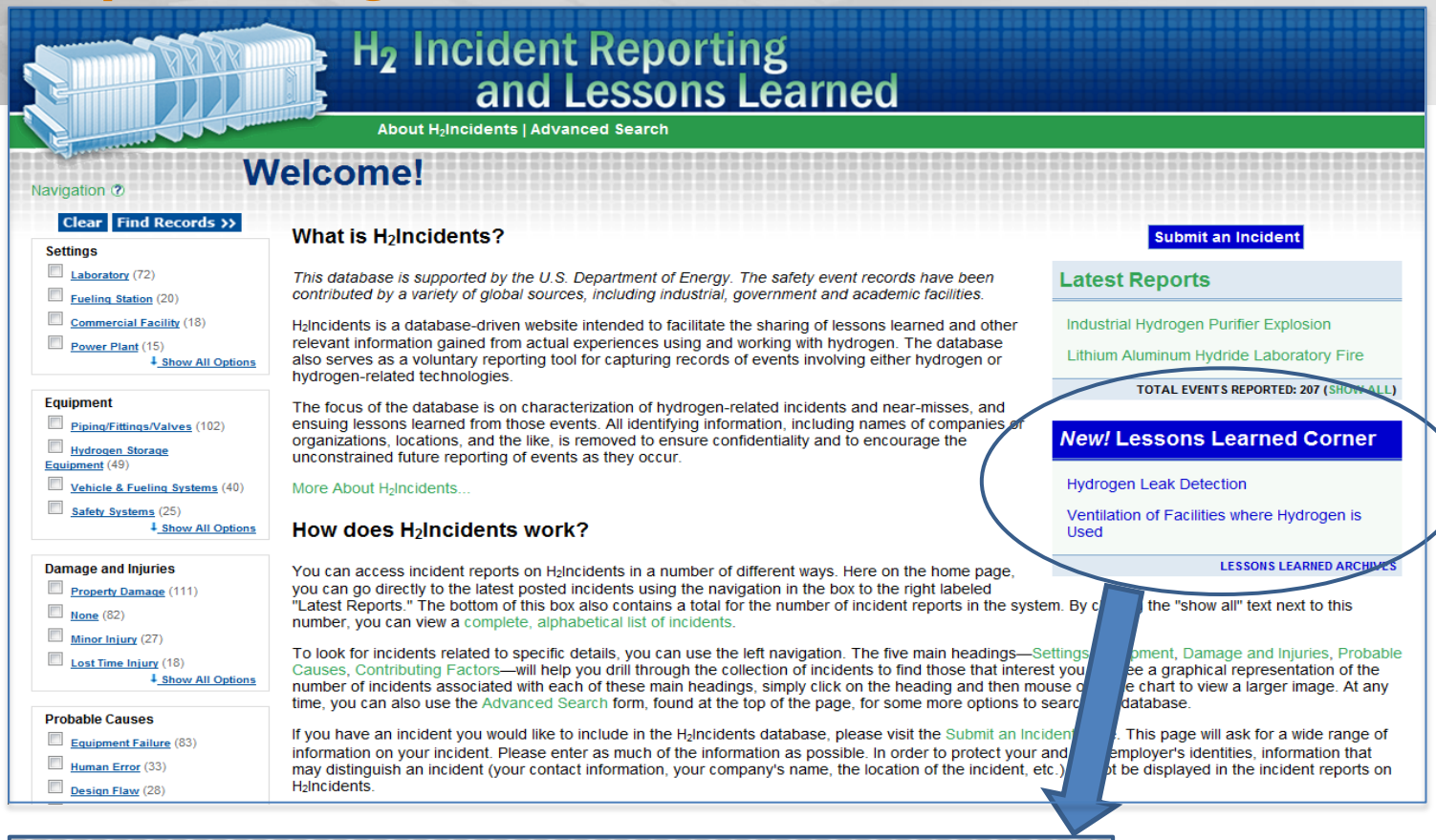

Lessons Learned Corner *Archives*

- Hydrogen leak detection
- Ventilation of facilities where hydrogen is used
- Hydrogen compatibility of materials
- Learning from burst disk failures
- Adequate ventilation of battery charging facilities
- Hydrogen use in anaerobic chambers
- The importance of purging hydrogen piping and equipment
- Working with reactive metal-hydride materials in the laboratory
- Management of change

Linking H2incidents.org and H2bestpractices.org Enhancing the Value of Both

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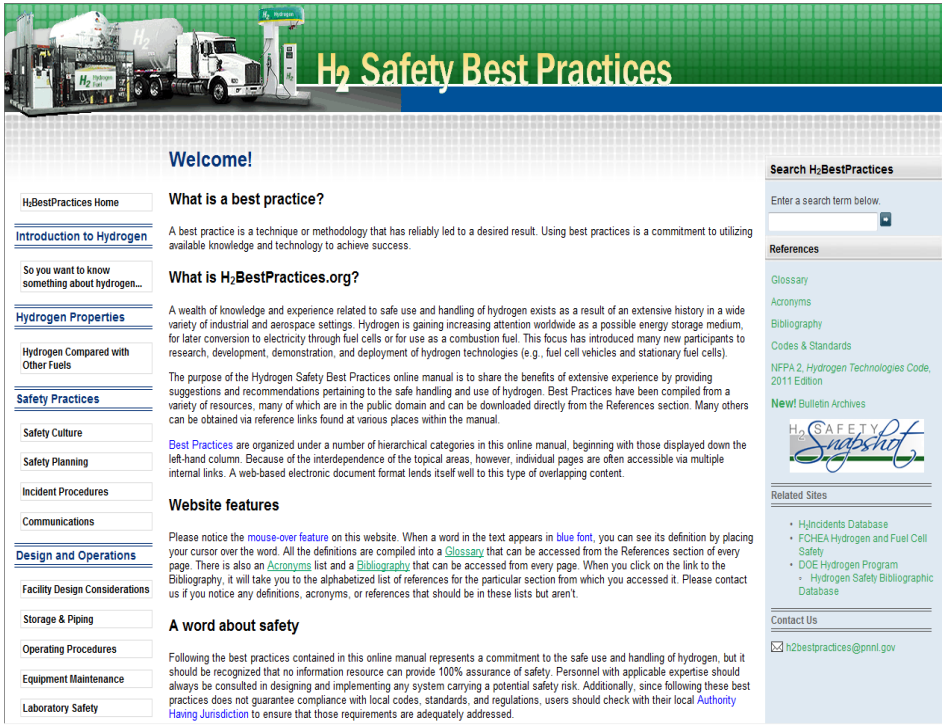
Safety event links illustrate what can go wrong if best practices are not followed.



Safety event lessons learned content enhanced by links to best practices and/or LLC content.

Just one example….

- A recent event that is relevant to the focus on deployment of hydrogen and fuel cell technologies
- Root causes for PRD failure
  - Incompatible materials
  - Improper assembly
  - Over-hardening of inner assembly materials
- But there is usually something else one can learn from the incident
  - Timely communication during emergency events
  - Training of personnel focused on improving response time
  - Effective communication between employees, first responders and suppliers

HYDROGEN TOOLS
...available now for your mobile devices!

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- **First mobile app targeted for AHJs, end-users and other stakeholders**
  - Integrates H_2incidents.org, H_2bestpractices.org and other resources into a single, searchable iPad and iPhone application
  - Features include safety planning guidance and checklists

Announced by the U.S. Department of Energy September 2013

What More Can We Learn?

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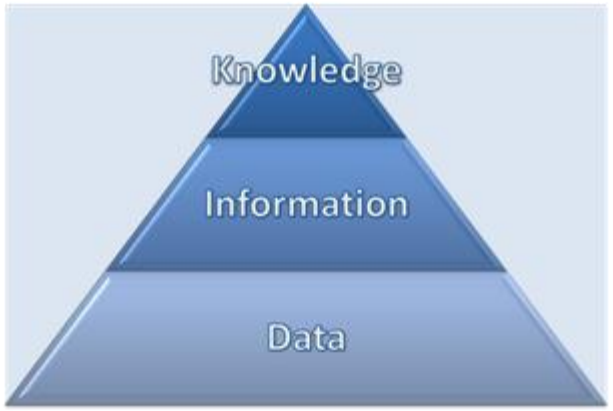
"…*Informed analysis of leaks, fires and explosions, and equipment failure and ignition data derived from these safety events can facilitate the development of risk assessment models and help technical experts identify gaps in applicable codes and standards that can be addressed by a variety of means.*"

Ref: Learning from Safety Events, A Statement from the Hydrogen Safety Panel, January 17, 2012.

Concluding Thoughts

- Safety knowledge tools such as “H2incidents.org” provide a powerful resource for conveying data, information and knowledge
- Content must be current, relevant to the community being served and valuable to the user
- Prompt and timely responses to user feedback and inquiries to h2incidents@pnnl.gov are important
- Progress is being made but there is more to be done!



Acknowledging….

- Fuel Cell Technologies Office (Sunita Satyapal, Director) and Staff, U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy
- All those who have contributed safety event information, knowledge and lessons learned to our database
- International Conference on Hydrogen Safety

Contacts

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Related References

- Weiner, S.C., Kinzey, B.R., Dean, J., Davis, P.B. and Ruiz, A., “Incident Reporting: Learning from Experience,“ PNNL-SA-56185, International Conference on Hydrogen Safety, San Sebastian, Spain, September 11-13, 2007.
- 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.
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- Weiner, S.C., “Advancing the Hydrogen Safety Knowledge Base,” PNNL-SA-91531, International Conference on Hydrogen Safety, Brussels, Belgium, September 9, 2013.

HIAD
The EUROPEAN HYDROGEN INCIDENT & ACCIDENT DATABASE

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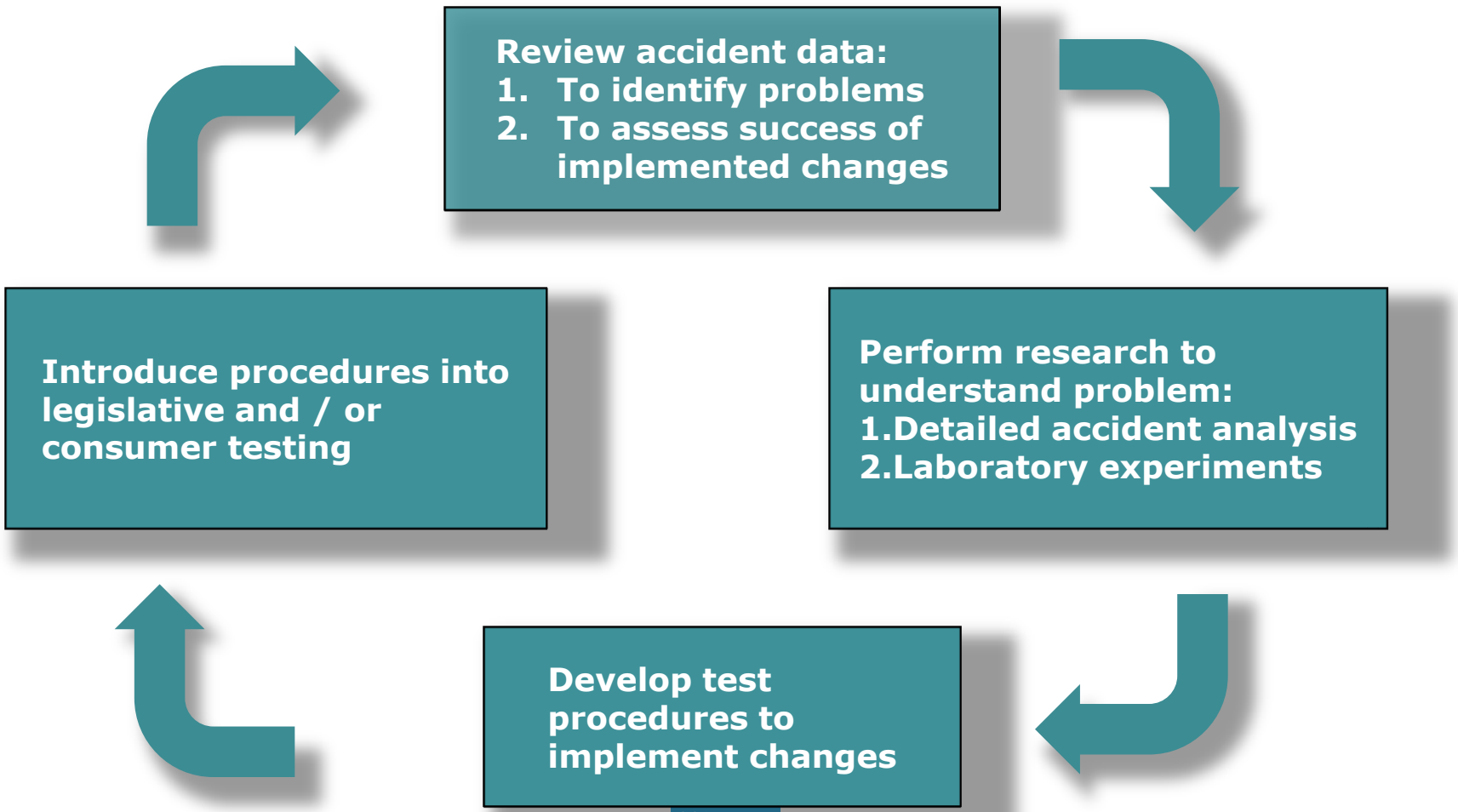
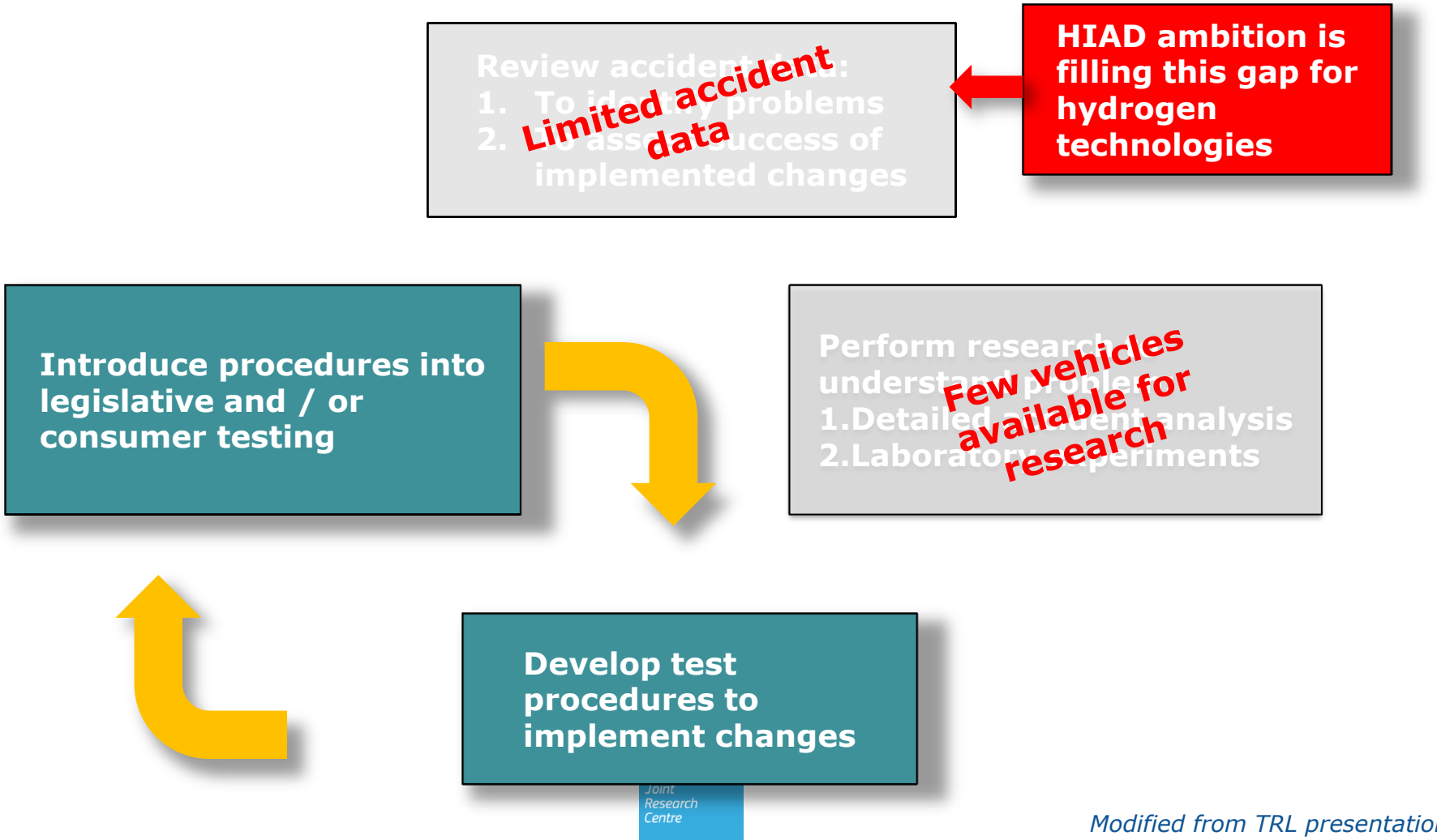
Typical (vehicle) safety research cycle



Modified from TRL presentation

Safety research cycle for low carbon vehicles



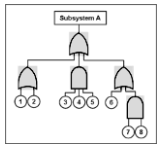
Modified from TRL presentation

What is HIAD?

HIAD aims to be an repository of any accidental even related to hydrogen technology

- Originally designed to be a multi-task tool:

Open platform for lessons learned and risk communication



Data source of information to assist risk assessment approaches

- Fully operational with about 250 events published

Joint Research Centre

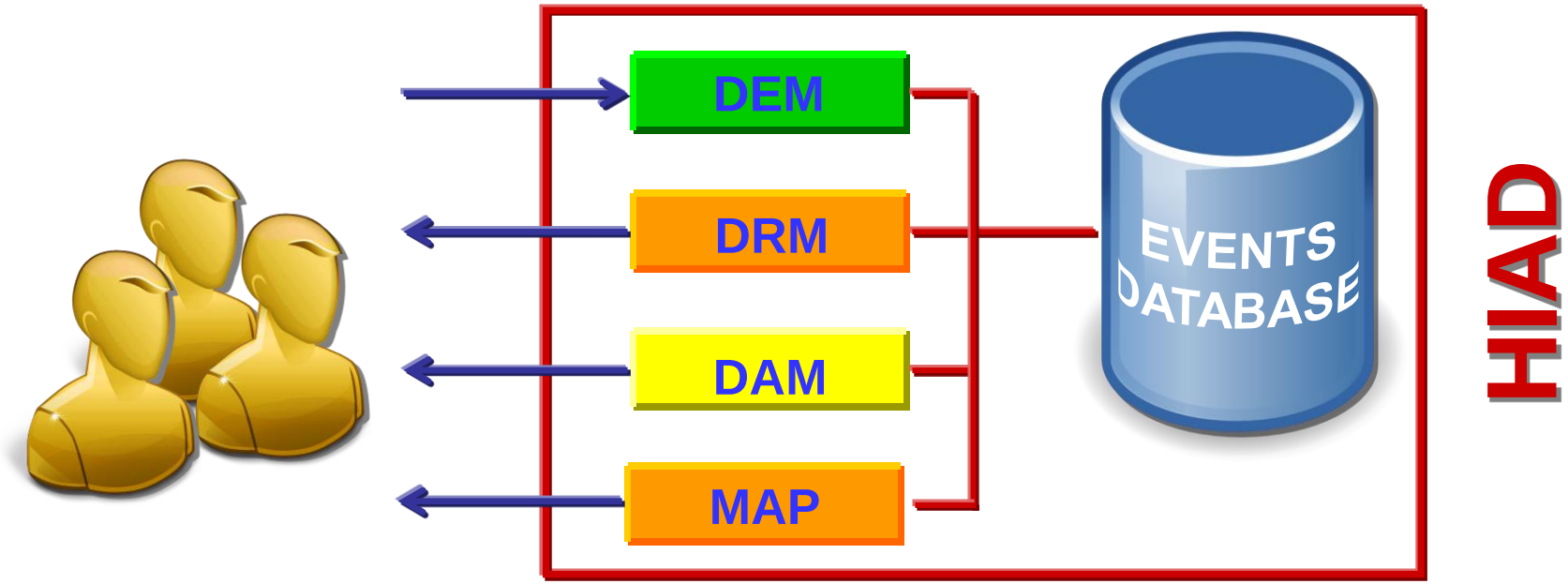
HIAD history

HIAD was originally developed in the European Network of Excellence for Hydrogen Safety (**HySafe** 2004-2009).

After the end of HySafe, the International Association for Hydrogen Safety **IA-HySafe** became the focal point for all hydrogen safety related issues. HIAD was further developed with an analysis module.

HIAD is maintained, updated and funded by the **Joint Research Centre**, and is available at https://odin.jrc.ec.europa.eu/.

HIAD Structure – 4 modules



DEM – Data Entry Module: Users can register as "event provider" and insert/update events directly on the database

DRM – Data Retrieval Module: Allows the user to access hydrogen events recorded on HIAD

DAM – Data Analysis Module: Is a tool for conducting online simple analyses of the data recorded into the database

MAP: a GIF based tool which links events to their geographical distribution

Event structure

Pre-event conditions: Date/time of event, Weather conditions, Geographical location, applications, Operation phase or mode.

Nature of event: Systems and components affected or involved, Chain of events, Causal relations, Relevant safety systems and emergency response, Release, fire and explosion specifications/details.

Consequences of event: Fatalities and injuries, Property, environment and economical loss and damage.

Post-event actions: Clean-up and restoration, Legal/legislation initiatives, Lessons learned, Investments made.

References: Hyperlinks/references to files and documents, web-sites, etc., Specification of attachments, e.g. maps, drawings, photos, etc.

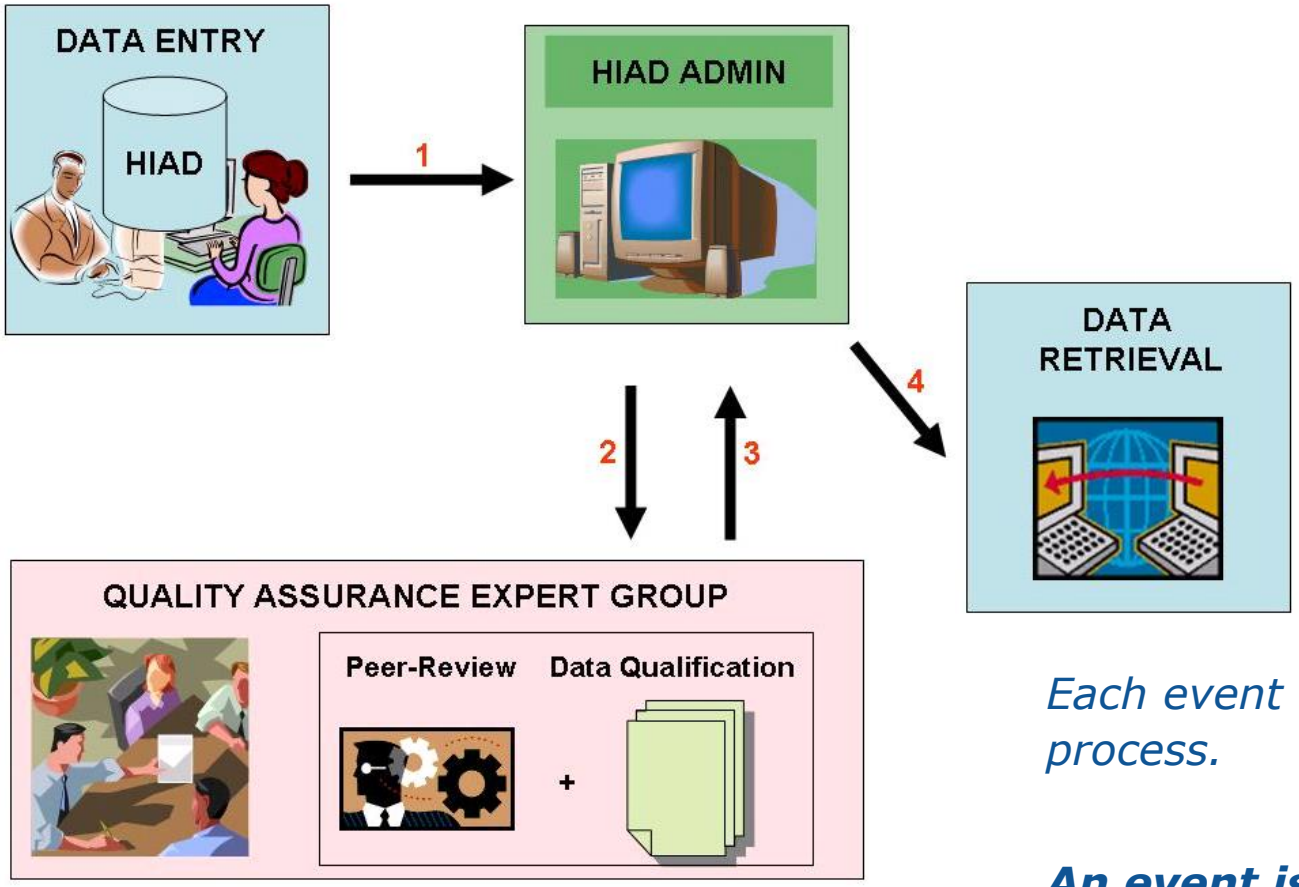
DEM = Data Entry Module Inputs

Users can enter events into HIAD in two ways:

- *Users can e-mail the event to JRC who can insert it on behalf of the users*
- *Alternatively users can register as "event provider" and insert/update events directly on the database, using the DEM.*

Only fields describing the dynamics of the event are mandatory. All other fields are not mandatory and the event can be introduce as a **completely anonymous event** without any information on location, company, etc.

Quality Assurance Process

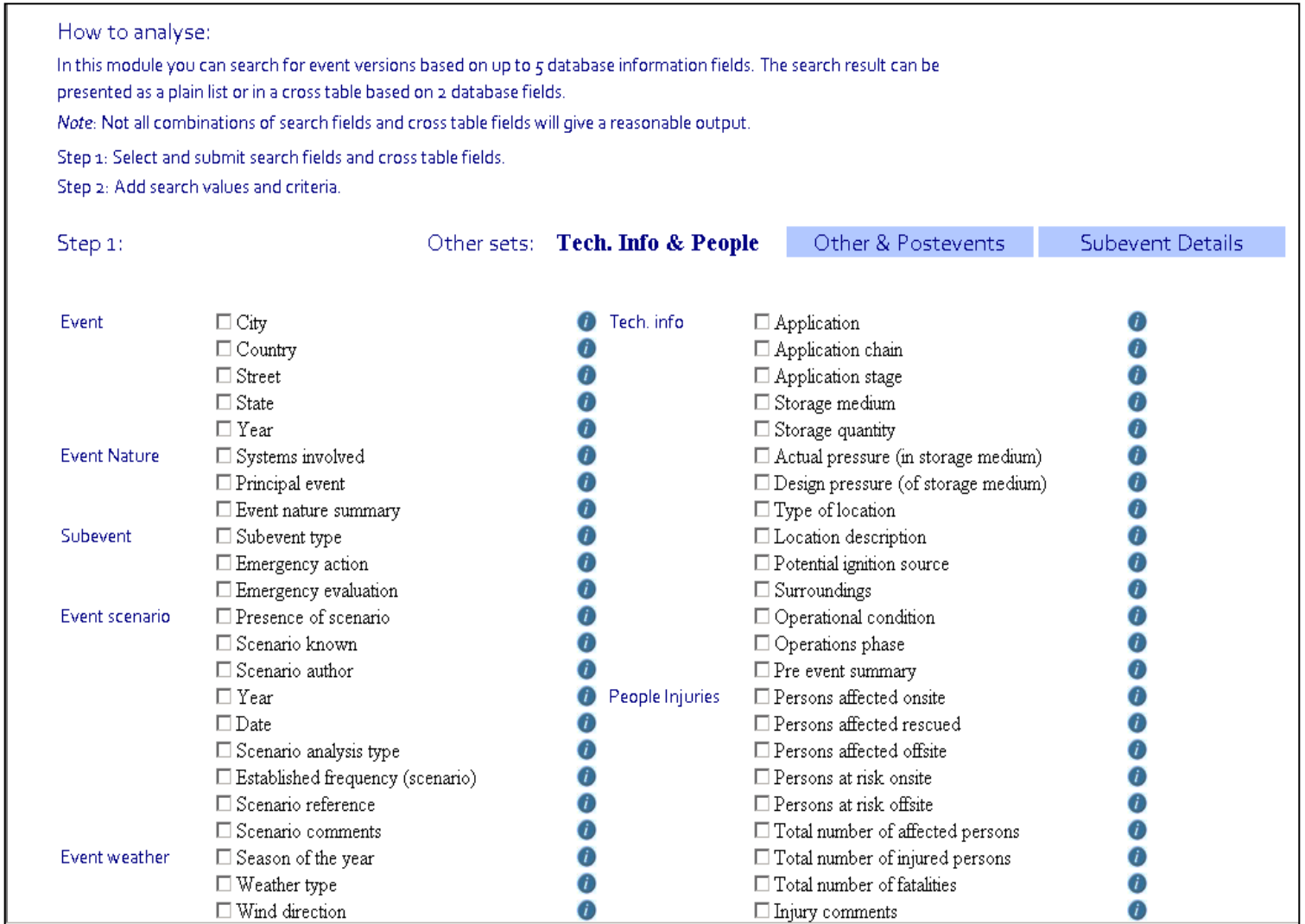


Each event undergoes a QA process.

An event is published (visible) in HIAD only after QA process.

DAM = Data Analysis Module

Online analysis of the events



How to analyse:

In this module you can search for event versions based on up to 5 database information fields. The search result can be presented as a plain list or in a cross table based on 2 database fields.

Note: Not all combinations of search fields and cross table fields will give a reasonable output.

Step 1: Select and submit search fields and cross table fields.

Step 2: Add search values and criteria.

Step 1: Other sets: **Tech. Info & People** | Other & Postevents | Subevent Details

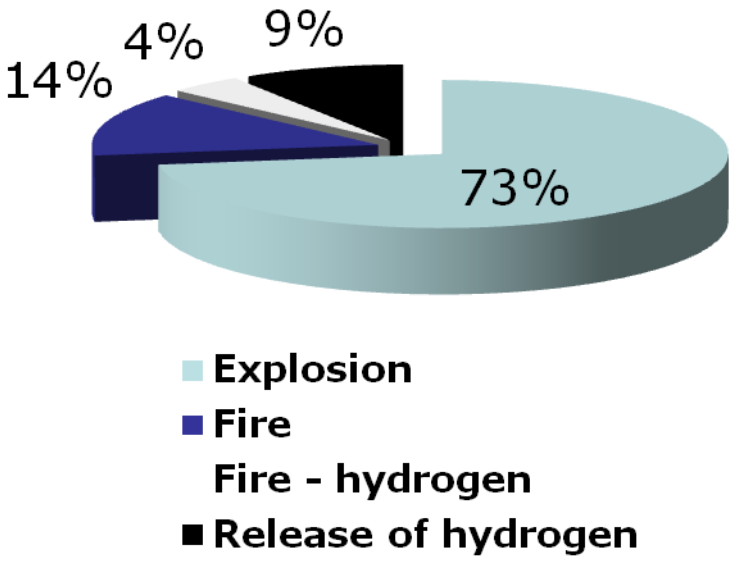
Event	☐ City		Tech. info	☐ Application
	☐ Country			☐ Application chain
	☐ Street			☐ Application stage
	☐ State			☐ Storage medium
	☐ Year			☐ Storage quantity
Event Nature	☐ Systems involved			☐ Actual pressure (in storage medium)
	☐ Principal event			☐ Design pressure (of storage medium)
	☐ Event nature summary			☐ Type of location
Subevent	☐ Subevent type			☐ Location description
	☐ Emergency action			☐ Potential ignition source
	☐ Emergency evaluation			☐ Surroundings
Event scenario	☐ Presence of scenario			☐ Operational condition
	☐ Scenario known			☐ Operations phase
	☐ Scenario author			☐ Pre event summary
	☐ Year		People Injuries	☐ Persons affected onsite
	☐ Date			☐ Persons affected rescued
	☐ Scenario analysis type			☐ Persons affected offsite
	☐ Established frequency (scenario)			☐ Persons at risk onsite
	☐ Scenario reference			☐ Persons at risk offsite
	☐ Scenario comments			☐ Total number of affected persons
Event weather	☐ Season of the year			☐ Total number of injured persons
	☐ Weather type			☐ Total number of fatalities
	☐ Wind direction			☐ Injury comments

Data Analysis example: total number of involved people

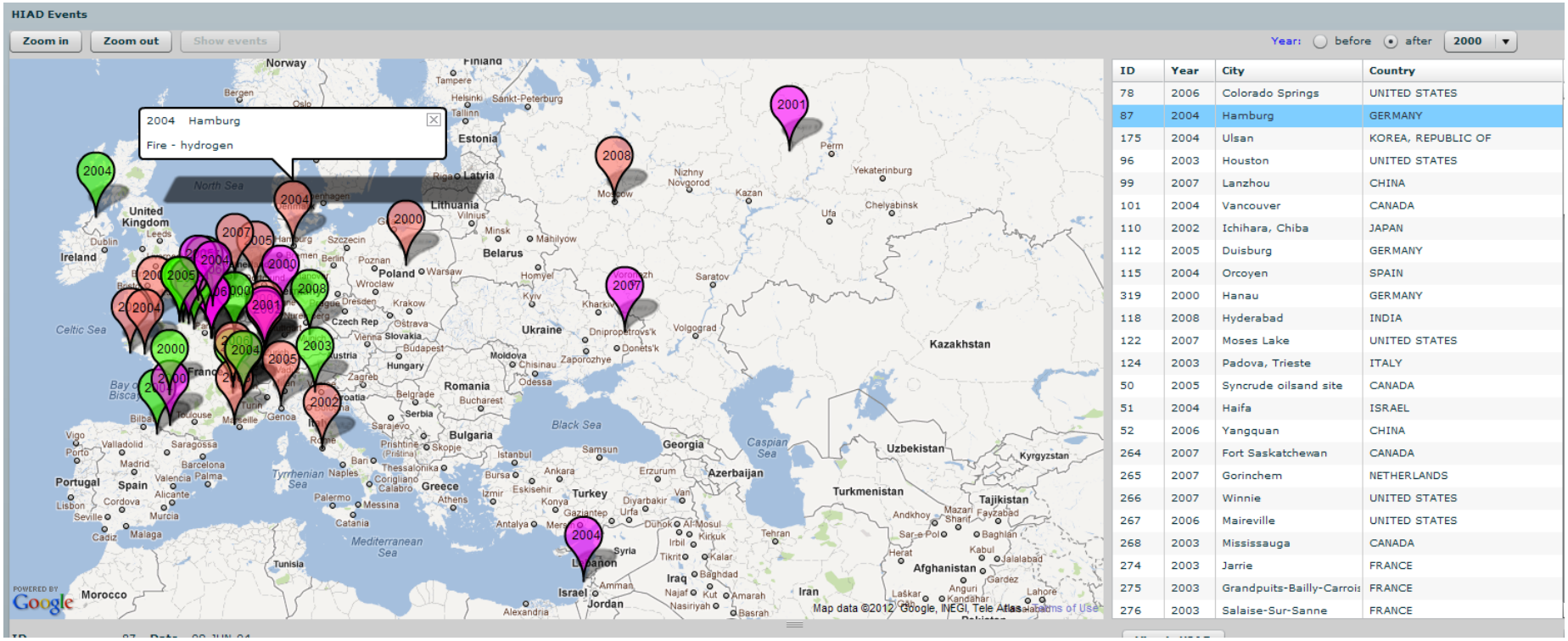
Total number of affected perso -> *Change*

Year - Principal event	Burst of tank	Explosion	Fire	Fire - hydrogen	Pipe rupture	Release of hydrogen	**Total**
1985	0	2	0	0	0	0	2
1986	0	7	0	0	0	0	7
1987	0	8	0	0	0	0	8
1988	0	3	0	0	0	0	3
1989	0	124	15	7	0	0	146
1990	0	1	0	0	0	0	1
1991	0	26	0	0	0	70	96
1992	0	24	0	0	0	0	24
1993	0	4	0	4	0	0	8
1994	0	0	0	0	0	0	0
1995	0	24	0	0	0	0	24
1996	0	2	0	0	0	0	2
1997	0	73	4	0	0	0	77
1998	0	0	0	3	0	0	3
1999	0	53	0	1	0	0	54
2000	0	0	0	1	0	0	1
2001	0	21	7	4	0	0	32
2002	0	188	0	0	0	0	188
2003	0	2	0	0	0	0	2
2004	0	3	0	1	0	0	4
2005	0	23	0	0	0	0	23
2006	0	12	3	5	0	0	20
2007	0	1	88	9	0	3	101
2008	0	6	0	0	0	3	9
Total	**0**	**607**	**117**	**35**	**0**	**76**	**835**

Events 1985-2008: total number of involved people.



MAPS module



ID	Year	City	Country
78	2006	Colorado Springs	UNITED STATES
87	2004	Hamburg	GERMANY
175	2004	Ulsan	KOREA, REPUBLIC OF
96	2003	Houston	UNITED STATES
99	2007	Lanzhou	CHINA
101	2004	Vancouver	CANADA
110	2002	Ichihara, Chiba	JAPAN
112	2005	Duisburg	GERMANY
115	2004	Orcoyen	SPAIN
319	2000	Hanau	GERMANY
118	2008	Hyderabad	INDIA
122	2007	Moses Lake	UNITED STATES
124	2003	Padova, Trieste	ITALY
50	2005	Syncrude oilsand site	CANADA
51	2004	Haifa	ISRAEL
52	2006	Yangquan	CHINA
264	2007	Fort Saskatchewan	CANADA
265	2007	Gorinchem	NETHERLANDS
266	2007	Winnie	UNITED STATES
267	2006	Maireville	UNITED STATES
268	2003	Mississauga	CANADA
274	2003	Jarrie	FRANCE
275	2003	Grandpuits-Bailly-Carrois	FRANCE
276	2003	Salaise-Sur-Sanne	FRANCE

The screen shows you the HIAD events as they are scattered over the globe. Only events where the city or town is known are displayed. Events where only the country/continent is known are not displayed.

impression.

Lesson learned and improvement actions

A database such as HIAD is an essential reference and qualitative/quantitative tool for

- ☞ A structured dissemination of information
- ☞ An optimisation of safety for an emerging technology.

It will increase importance and expand usage with increasing technology deployment.

To this purpose, the experience with HIAD of the past years has generated improvement needs…

Lesson learned

Requirement 1 - commitment to reporting:

First responders or facility owners do not have as a duty a HIAD input.

Therefore a commitment to reporting also to HIAD should be required by licensing bodies. A 'distributed', European-wide network of data providers should be in place.

Requirement 2 - availability of accurate event reports:

☞Event description providers tend to input a minimal number of information, and many fields remain empty.

☞ Local journal articles almost never provide data with the required quality and resolution.

Therefore final internal accident reports should be made available for HIAD input (a very good example: the Emeryville accident report).

Improvement actions so far

1. Since 2013 all the European FCH JU projects, and especially the Demo projects are committed to report safety related events in HIAD

A similar commitment is wished also from commercial installations

2. The US and the European databases 'speak' to each others, and a small exchange of events has started

Improvement actions to come

Improve end-user usefullness

HIAD has been written for expert operators, not for end users; the level of details of the data expected/required must take into account the average availability of data.

Solution: restructuring of HIAD interface is planned for the coming 2 years

Improve quality assurance service

A broader and permanently available, quality assurance group is required, also for the interaction with the event provider.

Solution: not available at the moment; joining forces between databases could be a way forward.

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Thank You

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