Development of H_2 Safety Expert Groups and due diligence tools for public awareness and trust in hydrogen technologies and applications

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Date of this document:

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Contents

1 Timing Release

The official H_2TRUST website includes diverse information available to visitors, some of them are:

- description of the project aims and the benefits expected from the coordination and support action;
- general information about H_2TRUST consortium and the activities carried out during the development of the project itself as well;
- updated news and events about hydrogen safety aspects, H_2 safety updates, events and international initiatives;
- online tools and features specifically developed for the purpose of the H_2TRUST project;
- an online library, where references related to hydrogen are available;
- deliverables from the H_2TRUST project (these deliverables will be uploaded once they are approved by the FCH JU).

The website is available at the URL http://h2trust.eu/ since September 2013 (M4).

H_2TRUST resources, findings and deliverables are made available on-line on the portal, which is being integrated as an extension of the FAST/EHA internet presence, with the intention of becoming the standard reference for safety matters in the FCH industry.

2 Online portal structure

2.1 Home page

The Home Page represents the “landing page” of the project from external access and its main window to the outer world.

It contains the elements of the graphic representation of the project (project logo and graphics), as well as required EU-FCH Disclaimers.

The Home Page presents the main information of the project in a user-friendly manner, in order to facilitate navigation and of main contents.

Graphics have been studied since the beginning to be compatible and in line with EHA/FAST websites, where the H_2TRUST will be integrated, with the view of ensuring sustainability and follow-up after the project duration.

Main parts of the Home Page are:

- **Menu**
- **H_2ighlights**
- **Main body (central part of the Home page)**
- **Contacts Link**
- **Registration link**

In the following pages we explain more in detail each of the above-mentioned parts.

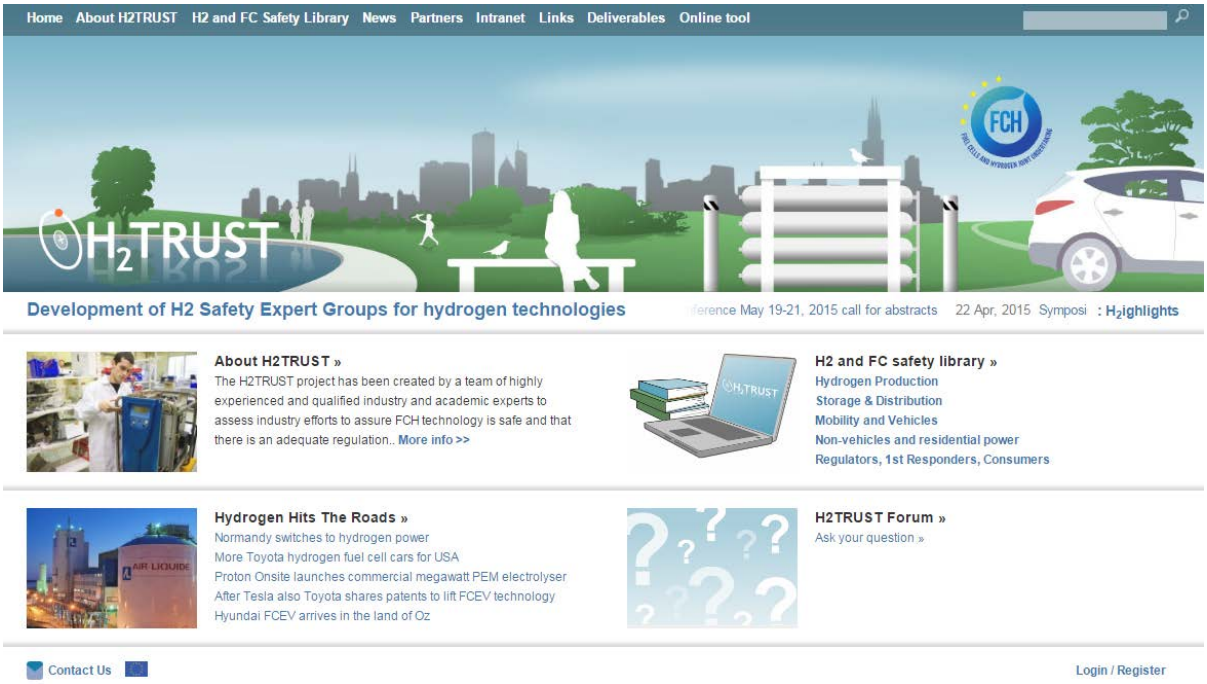


Figure 1. H_2TRUST Home Page

2.2 Menu and Main sections

As stated at the beginning of this section, the H_2TRUST online portal is composed by the Home page and the other main sections.

From the Home Page, visitors can use the **Menu**, placed horizontally on the top of the page, just below the header, to access the different sections and subsections.

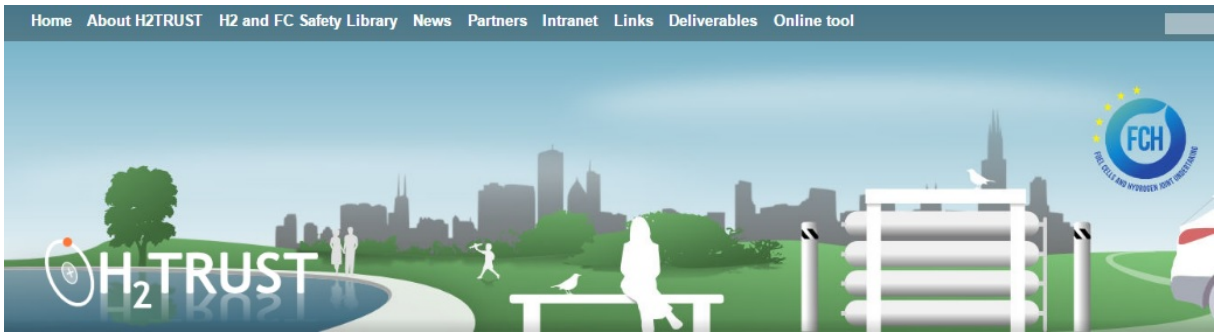


Figure 2. H_2TRUST Menu

In the following of the paragraph the contents of each section of the Menu are described.

2.2.1 Section "About H_2TRUST"

This first section describes the main content of the H_2TRUST project, to let the user understand about general and specific project objectives and main goals.

Figure 3. About H_2TRUST

2.2.2 Section "H_2 and FC Safety Library"

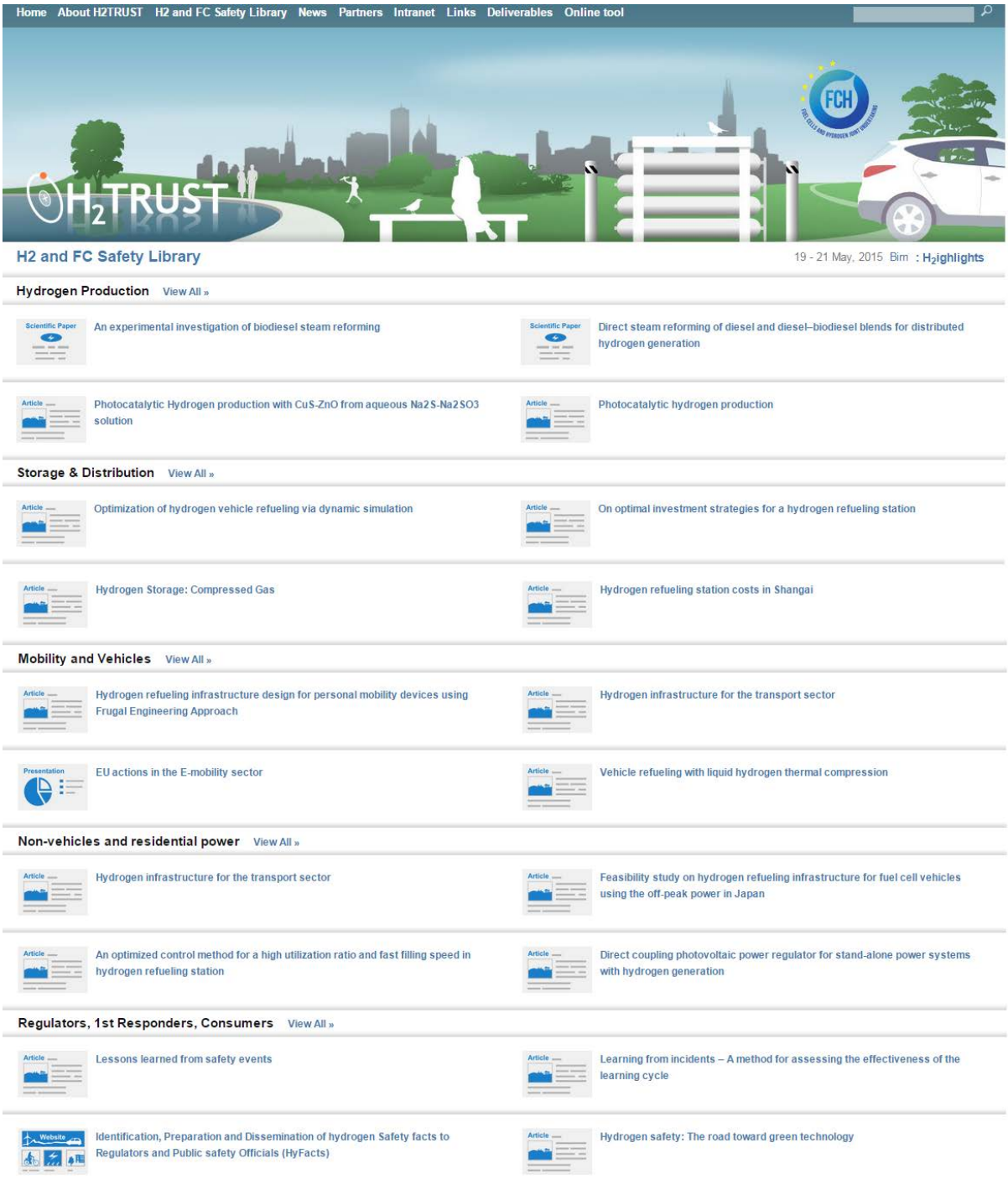


Figure 4. H_2 and FC Safety Library

In this section, hydrogen related documents can be found taking into account the following classification: Hydrogen Production, Storage & Distribution, Mobility and Vehicles, Non-Vehicles and Residential Power, and Regulators, 1st Responders, Consumers. By clicking in the corresponding section ("View all"), all the related references will appear (see Figure 5-9). The contents of the H_2 and FC Safety Library are connected with the task 2.3 Literature study and discovery, focused on the creation of the online project reference source. The on-

line library is including 145 documents. The layout of each section of the on-line library shows the title and an icon which explains the type of the document.

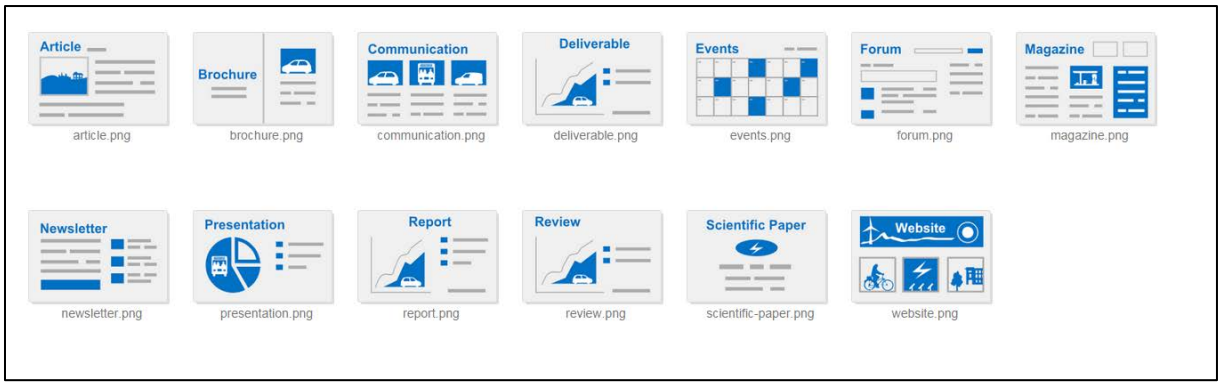


Figure 5 Library - document types icons

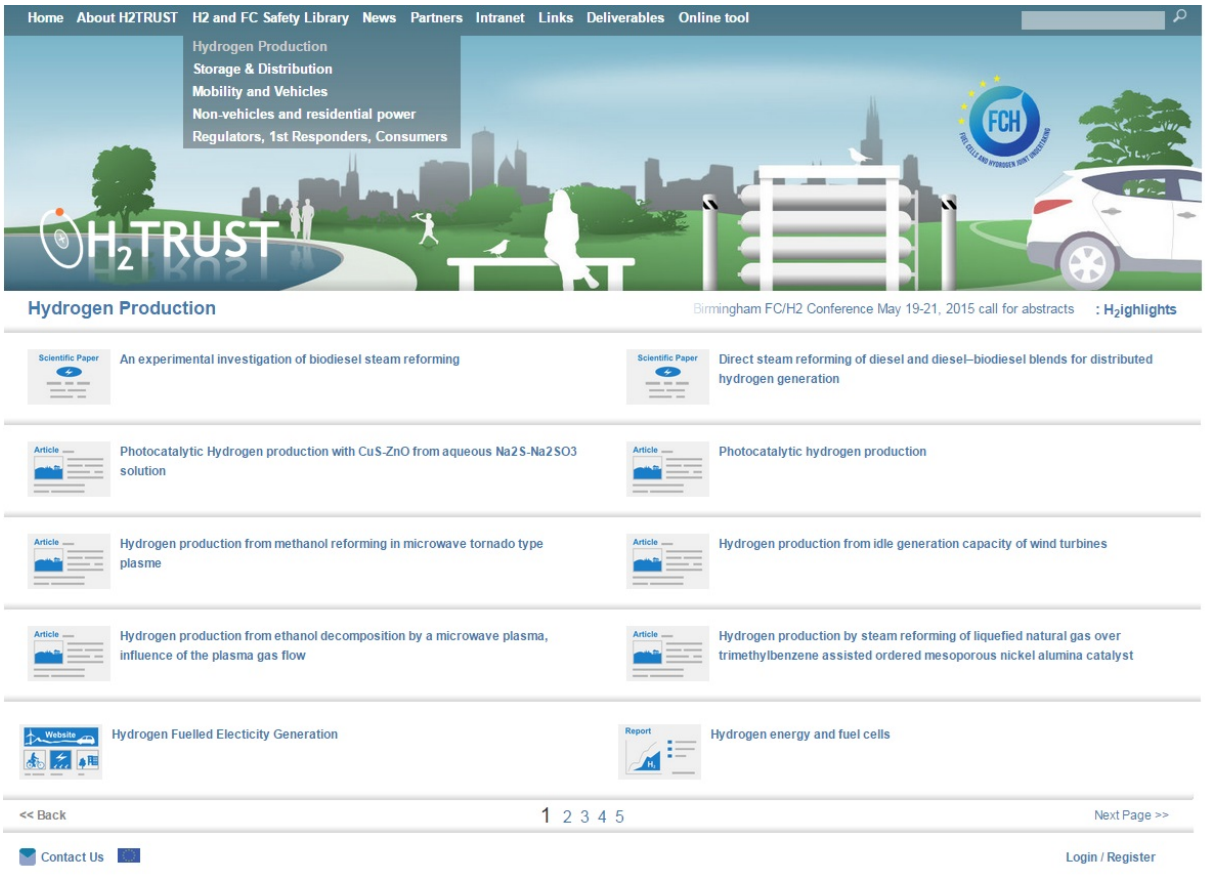


Figure 6. Library - section Hydrogen Production

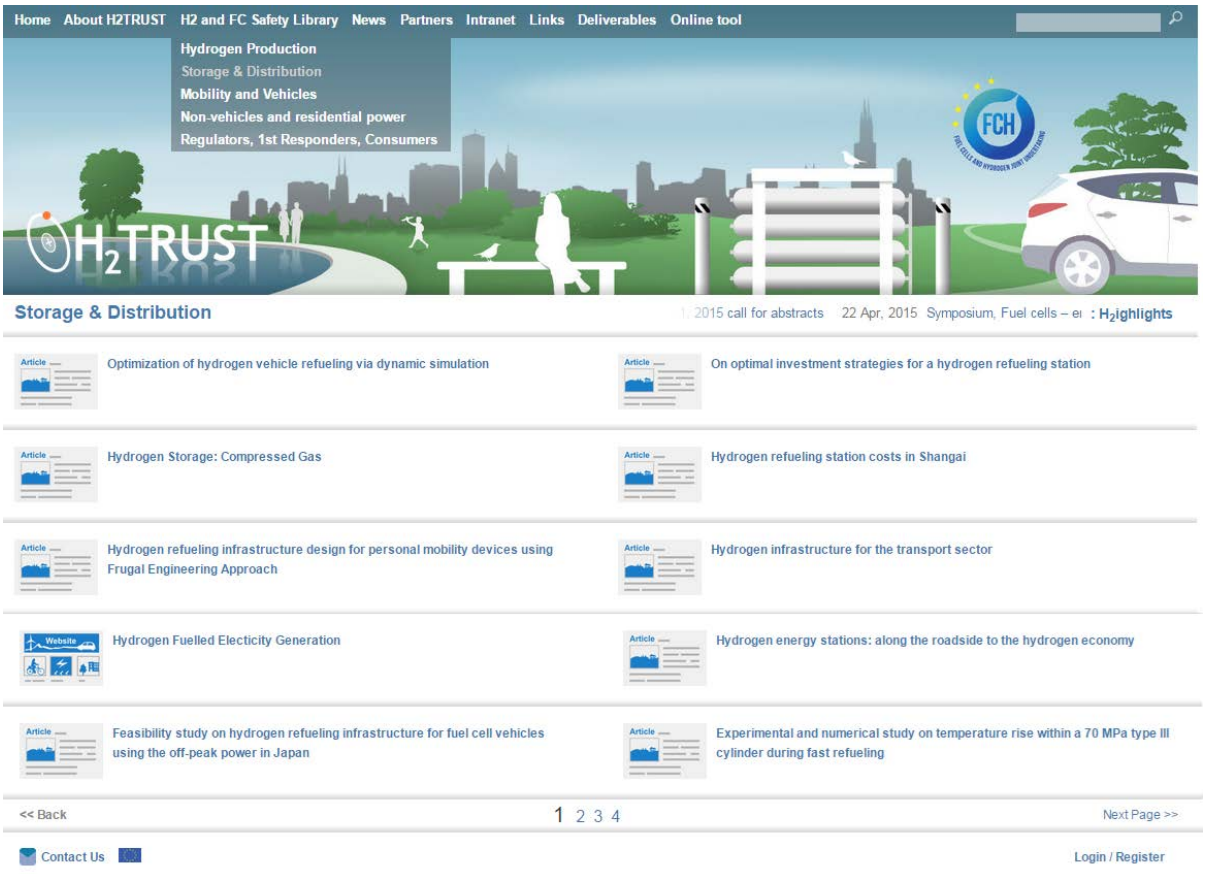


Figure 7. Library - section Storage & Distribution

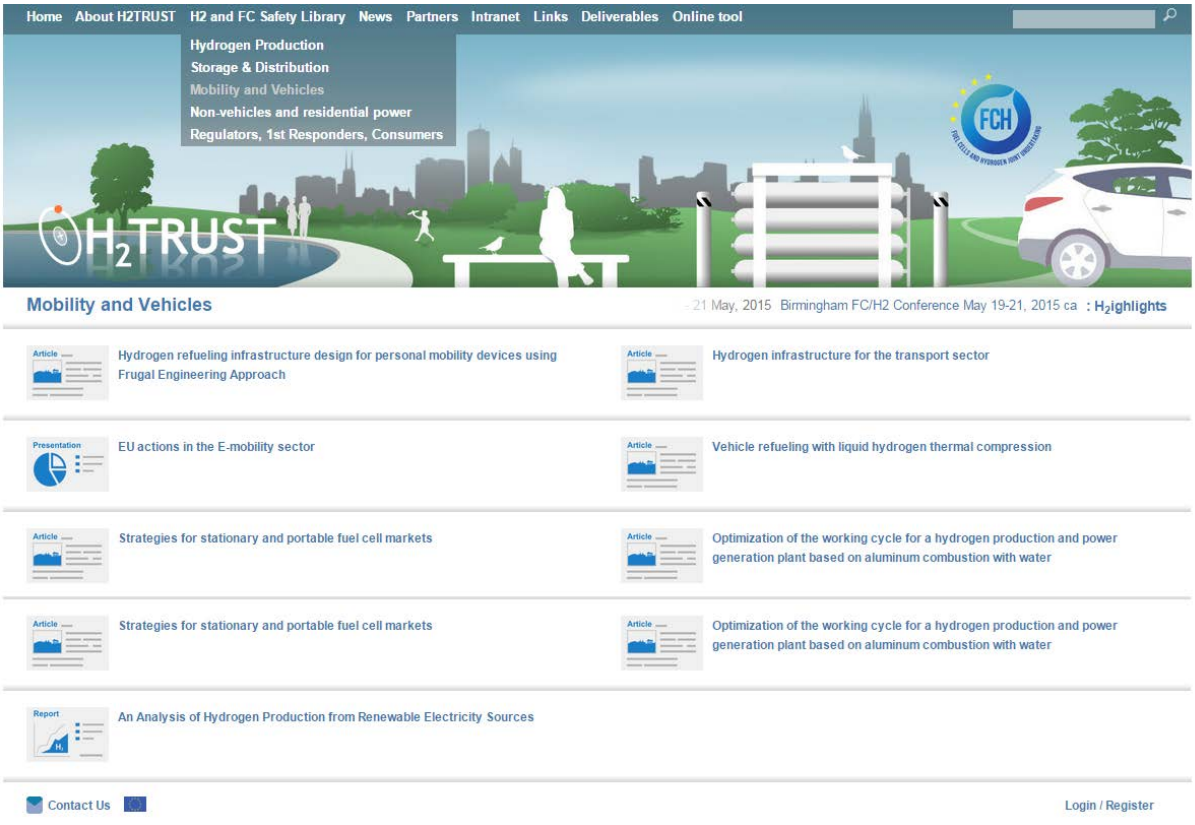


Figure 8. Library - Section Mobility and Vehicles

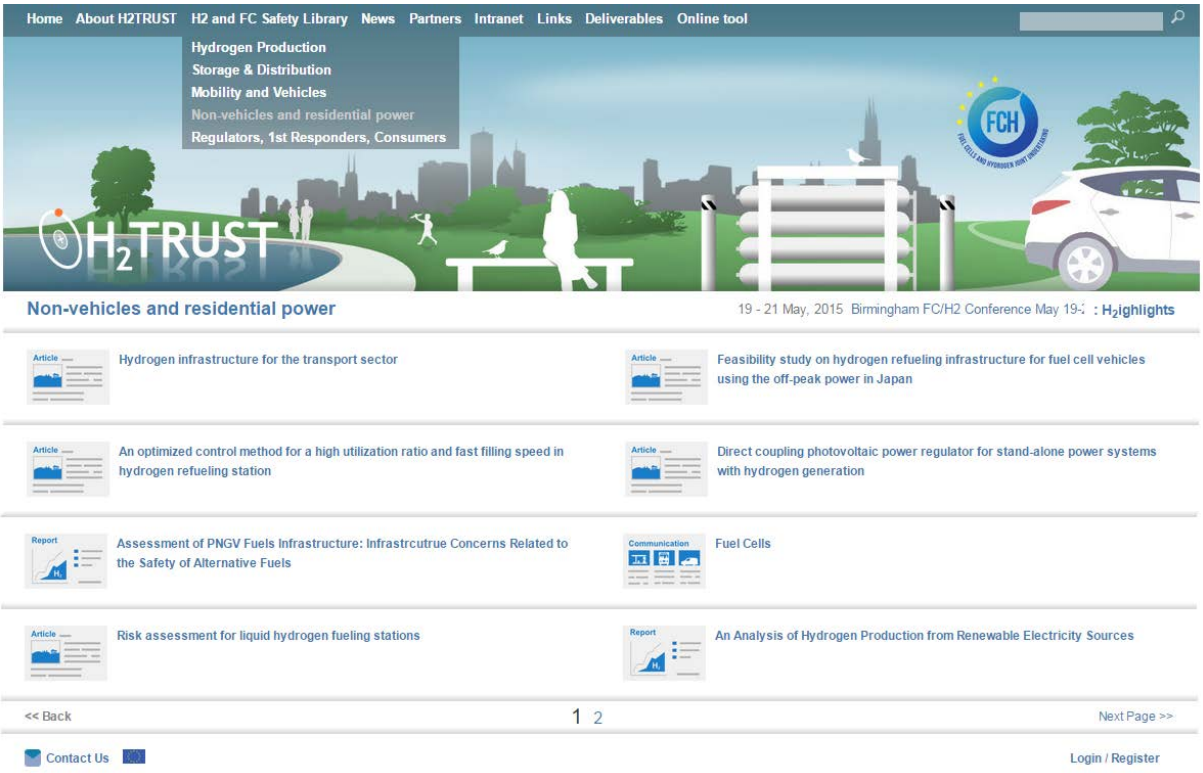


Figure 9. Library - Section Non Vehicles and Residential Power

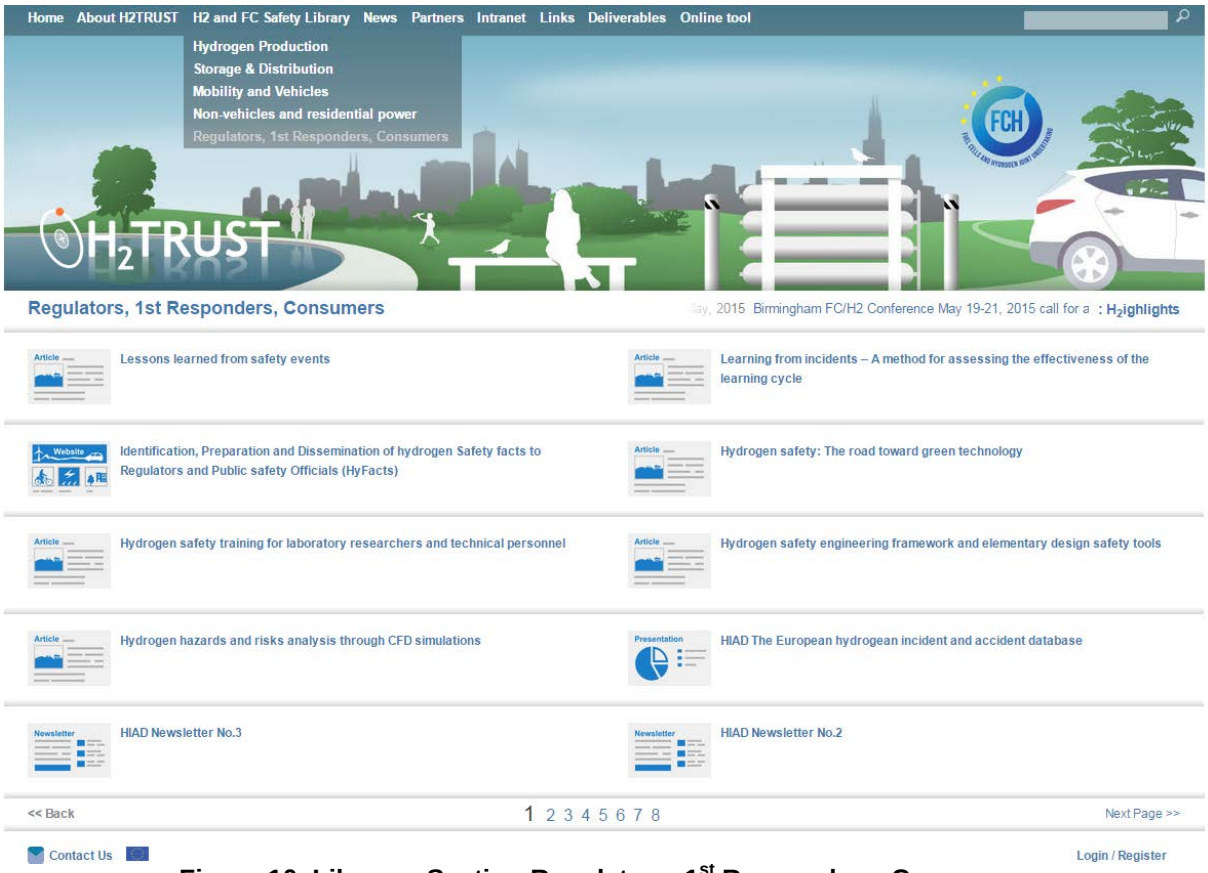


Figure 10. Library - Section Regulators, 1st Responders, Consumers

Finally, by clicking in the title of the document you want to consult, you can see all the related information (Authors, Language, Link -where the document can be found-, Reference, Type of document, Year of publication and Keywords).

Figure 11. Detail on the Article

2.2.3 Section “News”

The News and event sections are updated sections with the latest news on Hydrogen and Fuel Cells and the upcoming related events. The News section is to report news of interest to the website visitors focusing on what is happening in fuel cell and hydrogen world on the academic level, industrial level and political level. As part of the “News” section on the H_2TRUST website, a specific page is dedicated to News related to safety of Hydrogen and FCH technologies. (Fig. 12-15).

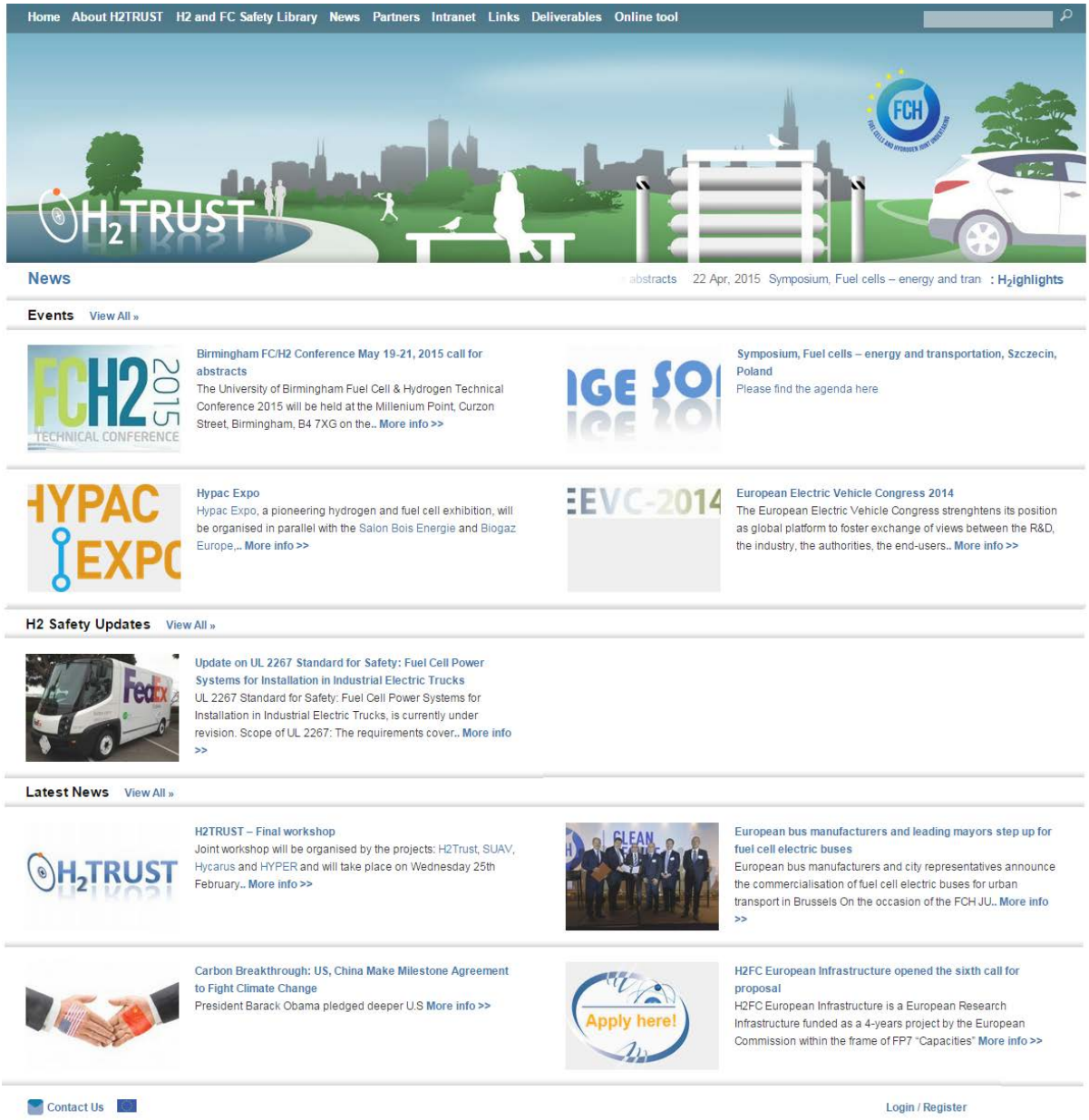


Figure 12. News

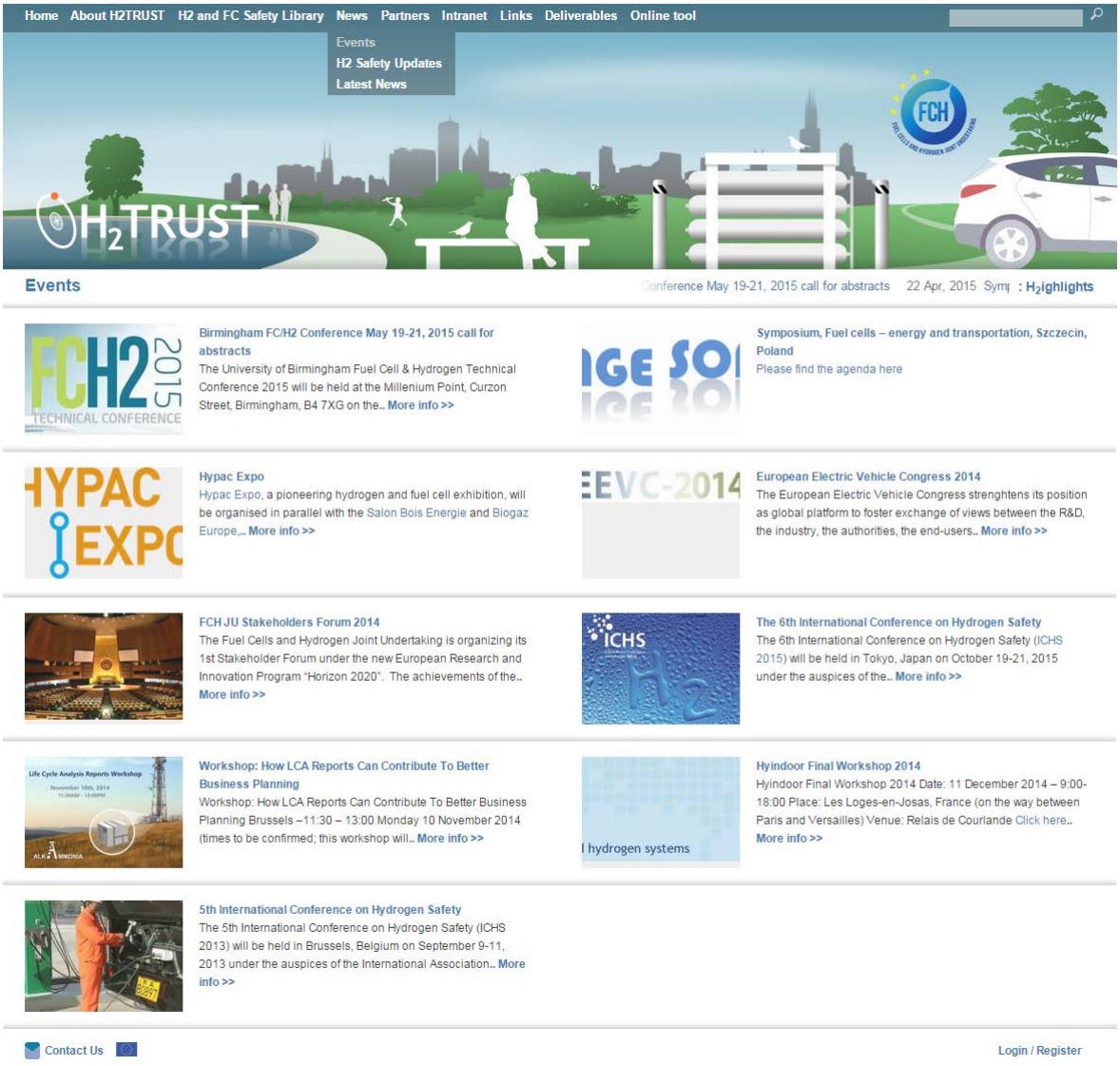


Figure 13. News - Events

Figure 14. News - H_2 Safety Updates

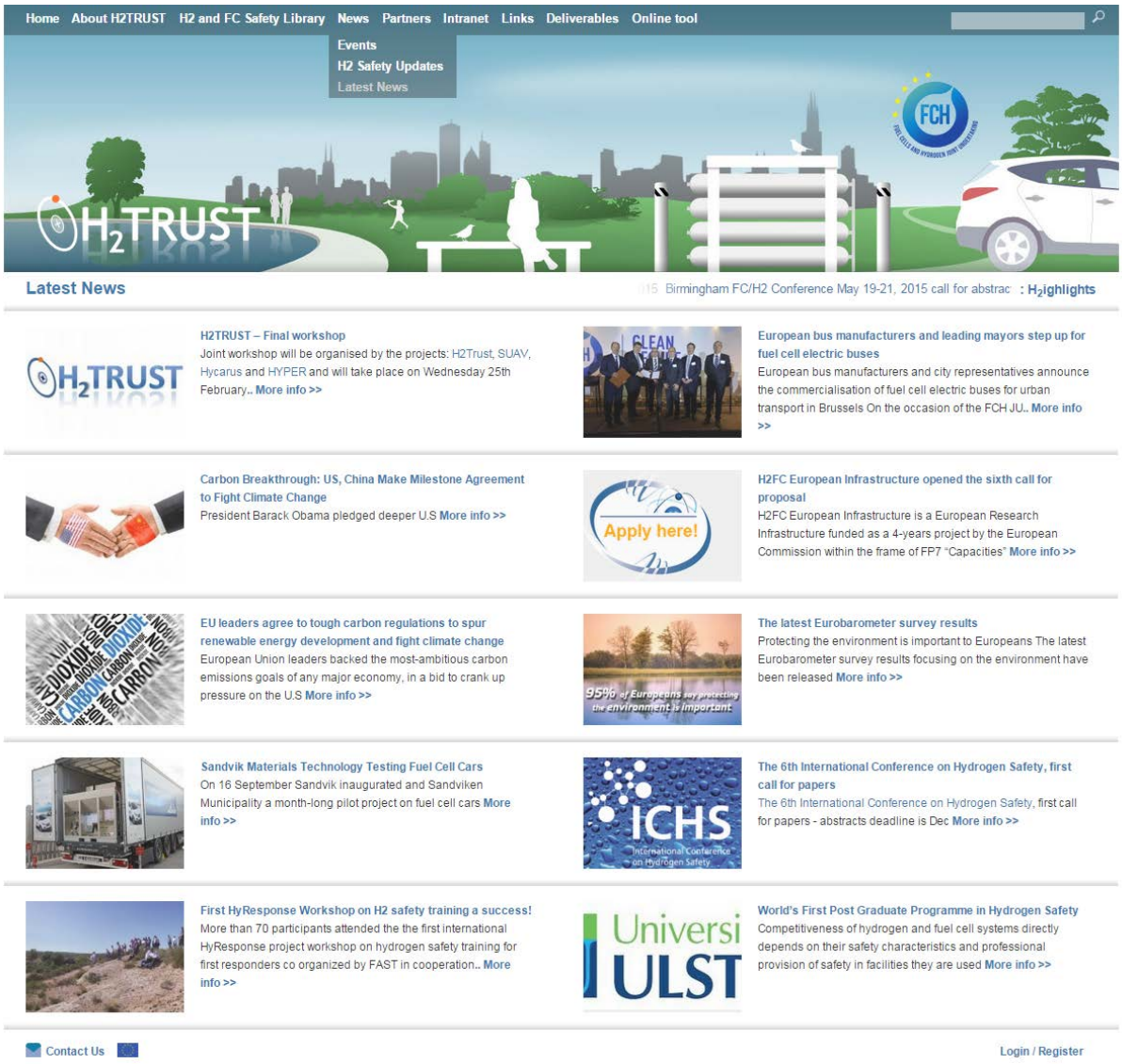


Figure 15. News - Latest News

2.2.4 Section "Intranet"

This section of the portal ("back-end") has the main purpose of creating an area of sharing of information and documents among project partners, EC officials and relevant accredited stakeholders.

A specific "Registration Form" has been developed as part of the H_2TRUST portal, in order to allow encrypted access to this area by project partners and accepted users.

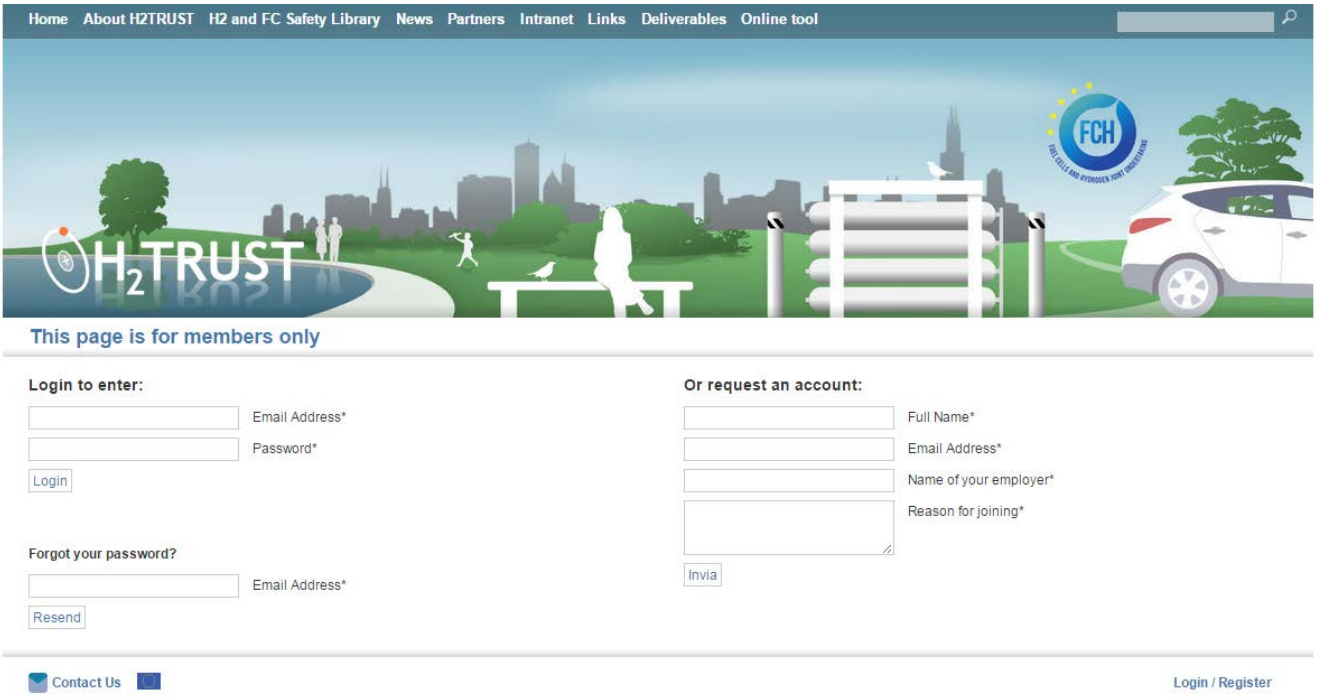
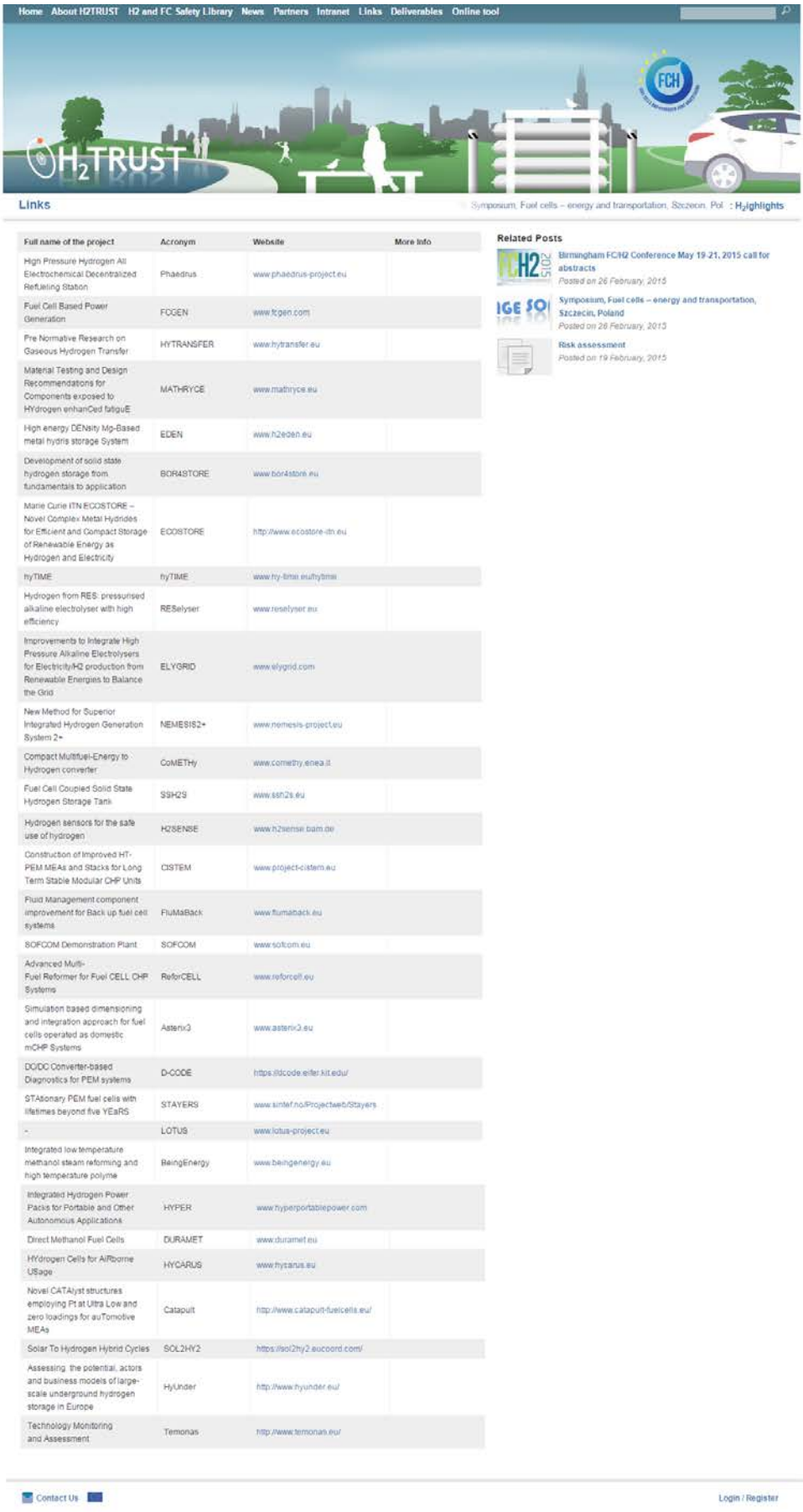


Figure 16. Intranet

2.2.5 Section “Links”

The Links section is including hydrogen and fuel cells third parties websites and blogs, where H_2TRUST website link is published.



Full name of the project	Acronym	Website	More info
High Pressure Hydrogen All Electrochemical Decentralized Refueling Station	Phaedrus	www.phaedrus-project.eu	
Fuel Cell Based Power Generation	FCGEN	www.fcgen.com	
Pre Normative Research on Gaseous Hydrogen Transfer	HYTRANSFER	www.hytransfer.eu	
Material Testing and Design Recommendations for Components exposed to HYdrogen enhanCed fatigue	MATHRYCE	www.mathryce.eu	
High energy DENsity Mg-Based metal hydris storage System	EDEN	www.h2eden.eu	
Development of solid state hydrogen storage from fundamentals to application	BOR4STORE	www.bor4store.eu	
Marie Curie ITN ECOSTORE – Novel Complex Metal Hydrides for Efficient and Compact Storage of Renewable Energy as Hydrogen and Electricity	ECOSTORE	http://www.ecostore-itn.eu	
hyTIME	hyTIME	www.hy-time.eu/hytime	
Hydrogen from RES: pressurised alkaline electrolyser with high efficiency	RESelyser	www.reselyser.eu	
Improvements to Integrate High Pressure Alkaline Electrolysers for Electricity/H2 production from Renewable Energies to Balance the Grid	ELYGRID	www.elygrid.com	
New Method for Superior Integrated Hydrogen Generation System 2+	NEMESIS2+	www.nemesis-project.eu	
Compact Multifuel-Energy to Hydrogen converter	CoMETHy	www.comethy.enea.it	
Fuel Cell Coupled Solid State Hydrogen Storage Tank	SSH2S	www.ssh2s.eu	
Hydrogen sensors for the safe use of hydrogen	H2SENSE	www.h2sense.bam.de	
Construction of Improved HT-PEM MEAs and Stacks for Long Term Stable Modular CHP Units	CISTEM	www.project-cistem.eu	
Fluid Management component improvement for Back up fuel cell systems	FluMaBack	www.flumaback.eu	
SOFCOM Demonstration Plant	SOFCOM	www.softcom.eu	
Advanced Multi-Fuel Reformer for Fuel CELL CHP Systems	ReforCELL	www.reforcell.eu	
Simulation based dimensioning and integration approach for fuel cells operated as domestic mCHP Systems	Asterix3	www.asterix3.eu	
DC/DC Converter-based Diagnostics for PEM systems	D-CODE	https://dcode.eifer.kit.edu/	
STAtionary PEM fuel cells with lifetimes beyond five YEaRS	STAYERS	www.sintef.no/Projectweb/Stayers	
-	LOTUS	www.lotus-project.eu	
Integrated low temperature methanol steam reforming and high temperature polyme	BeingEnergy	www.beingenergy.eu	
Integrated Hydrogen Power Packs for Portable and Other Autonomous Applications	HYPER	www.hyperportablepower.com	
Direct Methanol Fuel Cells	DURAMET	www.durametl.eu	
HYdrogen Cells for AiRborne USage	HYCARUS	www.hycarus.eu	
Novel CATAlyst structures employing Pt at Ultra Low and zero loadings for auTomotive MEAs	Catapult	http://www.catapult-fuelcells.eu/	
Solar To Hydrogen Hybrid Cycles	SOL2HY2	https://sol2hy2.eucoord.com/	
Assessing the potential, actors and business models of large-scale underground hydrogen storage in Europe	HyUnder	http://www.hyunder.eu/	
Technology Monitoring and Assessment	Temonas	http://www.temonas.eu/	

Figure 17. Links

2.2.6 Section “Deliverables”

In this section, all the public deliverables resulting from the H_2TRUST project, will be uploaded in order to be disseminated not only for experts but also for the public in general.

These documents will be available once the FCH JU has approved them.

These deliverables are:

- D2.1 Framework and methodology
- D2.2 Reference Benchmark for H_2 production-storage-distribution technologies
- D2.3 Literature and Knowledge Base
- D2.4 Mirror groups organisation chart and Data gathering procedures
- D3.1 State of play H_2 issues (5 Chapters)
- D4.1 FCH Safety Issues, Industry Best Practices, and Recommendations
- D4.2 Safety Risk Assessment
- D4.3 Public Safety Assessment
- D5.1 Online portal
- D5.2 Assessment and Due-Diligence Tool
- D5.3 Demo, conference and trade fair kit.
- D5.4 Dissemination implementation measures checklist.

2.2.7 Section “Online Tool”

Beyond project deliverables, in order to contribute in a practical manner to safety and trust among FCH stakeholders and the general public, under this section the portal features the following relevant building blocks:

1. **Advanced Search engine**: It uses modern semantic web techniques and tools based on a series of funded EU projects (TechITeasy, InSearch) to continuously crawl the web to find relevant safety related literature to be structured within categories and a continuously updated searchable H_2 safety document repository. Pages crawled are indexed and processed so that the results displayed are ordered on the basis of their relevance.

2. **Hazard and consequences Tables**: These Tables have been structured in Task 4.2 as a result of the development of the methodology for risk assessment performed by TU/e (see deliverable D4.2 for more information).

These tables are based on the identification of all passible hazard types related to the hydrogen process considered. Based on the list of hazard types, the suitable hazard identification method (e.g. HAZID + FTA, etc) can be applied for each type of hazard.

The final tables report the list of Hazard Type, Hazardous Event, Initiating Cause, Prevention Controls, Consequences, and Mitigation Controls.

The user can either scan the tables to identify the hazard type or navigate the tables by applying filters on the hazard type and hazardous event. These tables are also the starting point for the risk assessment tool (see also D 5.2).

3. **H_2 due diligence safety risk assessment tool:** Based on the H_2TRUST FCH stakeholders and analyses model as well as the reference benchmark for production-storage-distribution technologies, a specific on-line tool (result from Task 5.2) is made available for whoever wants to use it to assess its safety readiness/adequacy.

It has to be noted that the tool is not intended to be an exhaustive tool for risk assessment, but more a “guiding instrument” in the hands of users to help them understand the steps needed to perform a solid risk assessment. To this end, the main parameters involved, the mathematical and physical models that regulate the different hazard situation and potential consequences, have been studied for several case studies, as well as how these are calculated and treated to evaluate the risk associated to a certain technology, process, plant, involving hydrogen.

The tool makes some assumptions in order to be user-friendly and shows them as well as the formulas used for the calculation, in a step-by-step flavour that should be very handy for users.

In the following Figures we show the screenshots of the “Online Tool” section Menu and the single building blocks. For a more detailed description of the H_2 due diligence safety risk assessment tool please refer to Deliverable 5.2.

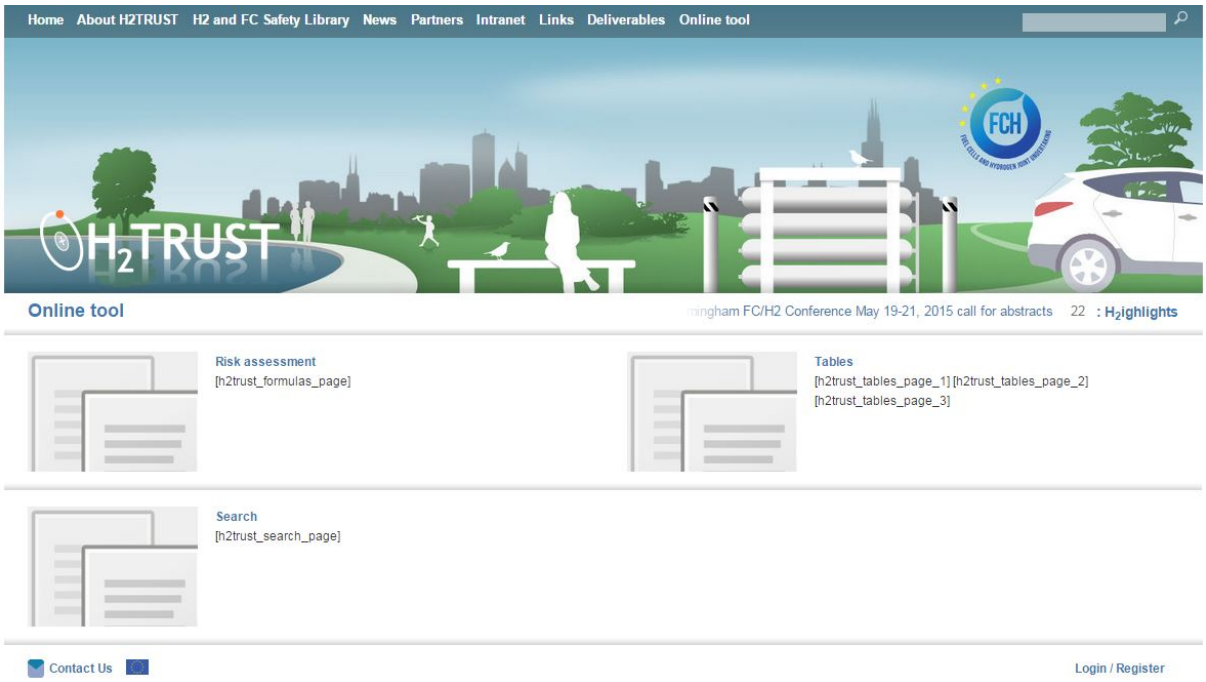


Figure 18. Online tool – main page

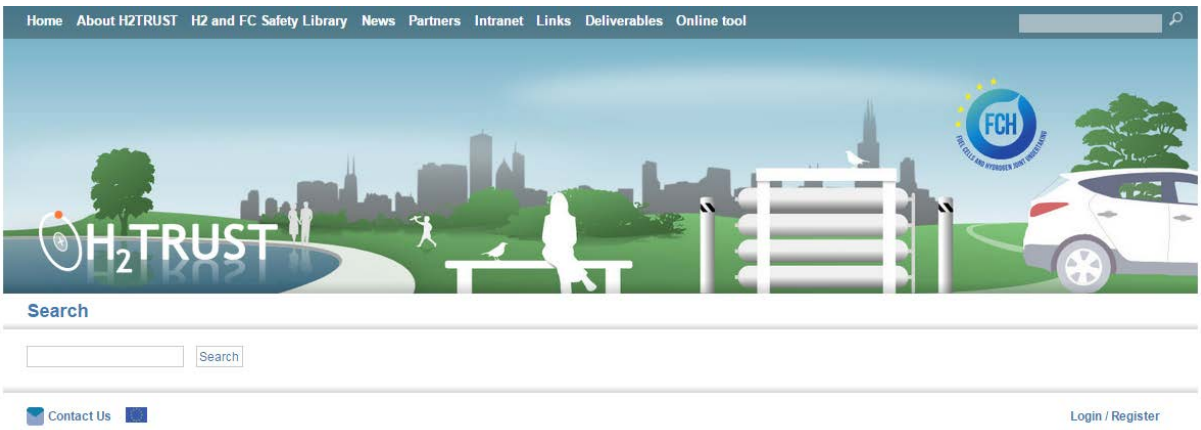


Figure 19. Online Tool – Search engine

Tables

Table D- 1: HAZID analysis table - Large scale SR of NG.

-- Filter hazard type -- -- Filter hazardous event --

No	Hazard Type	Hazardous Event	Initiating Cause	Prevention Controls	Consequences	Mitigation Controls
1	Hydrocarbons under pressure	Loss of containment	①Tube rupture inside the reformer ②Heavier H/C (C2+) presence in NG due to varying quality of natural gas. ③Coke formation ④Hotspots development on reformer tubes ⑤Deactivation of reformer catalyst	①Pre-reforming ②High S/C (steam/carbon) ratio ③Safety valves ④Design with low inlet temperature to reformer, short connecting lines to reformer	①Flammable gas release ②Flammable mixture fire/explosion	①Gas quality requirements to NG supplier. ②Regular inspection and maintenance ③Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system ④Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.
2	Hydrocarbons under pressure	Loss of containment	①Tube rupture ②NG leak inside reformer ③Metal dusting (Disintegration of the affected metal into a powdery mixture of graphite and metal particles) ④Lower oxygen partial pressures and higher carbon activities.	①High S/C (steam/carbon) ratio ②Protective coating (Aluminide coatings, alloying with copper) ③Safety valves ④Appropriate material selection (Alloys such as INCONEL® alloy 600 and INCOLOY alloy 800H.)	①Flammable gas fire/explosion ②Flammable gas ignition	①Regular inspection and maintenance ②Explosion relief panels ③Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system. ④Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.
3	Hydrocarbons under pressure	Loss of containment	①Large leak of flammable gas (NG/H2/CO) mixture inside container. ②Wear and tear ③Mechanical aggression/fatigue ④Failure of gaskets/joints ⑤Human failure ⑥Insufficient safety measures	①Explosion relief of containment ②Gas detection which activates: d) Emergency ventilation, e) Opening of ceiling and/or walls f) Closure of segmentation valves ③Safety valves	①Flammable gas mixture fire/explosion ②Flammable gas ignition ③Lost time injury	①Segmentation valves, located outside the container in an area with good natural ventilation ②Regular inspection and maintenance ③Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system . ④Explosion relief panels ⑤Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.
4	Hydrocarbons under pressure	Loss of containment	①Leakage of NG feed line ②Wear and tear ③Mechanical aggression/fatigue ④Failure of gaskets/joints ⑤Stress corrosion cracking (SSC) ⑥Insufficient safety measures	①Gas detection which activates: d) Emergency ventilation, e) Opening of ceiling and/or walls f) Closure of segmentation valves ②Ventilation system ③Adequate inspection ④Protective coating ⑤Safety valves ⑥Appropriate material selection (Alloys such as INCONEL® alloy 600 and INCOLOY alloy 800H.)	①Flammable gas mixture fire/explosion ②Hydrogen ignition ③Lost time injury	①Segmentation valves, located outside the container in an area with good natural ventilation ②Regular inspection and maintenance ③Explosion relief panels ④Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system . ⑤Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.
5	Toxic/flammable substances	Loss of containment	①Pipe failure ②Stress corrosion cracking (SSC) ③The presence of incompatible materials (KOH as promoter present in the SMR catalyst) ④Hydrogen embrittlement	①Protective coating ②Cathodic protection ③Piping specifications (Replacement of the SS 24-inch with 1-1/4 Cr 1/2 Mo alloy pipe that is corrosion-resistant to SCC) ④Adequate inspection ⑤Safety valves ⑥Adequate Hydrogen detection equipment	①Flammable mixture release ②Flammable mixture fire/explosion ③Ignition ④Damage of equipment near the event	①Detailed hazard review and evaluation of all of the materials of construction in the hydrogen plant process to prevent changing several pieces of piping and equipment items in the SMR process. ②Regular inspection and maintenance ③Refresh and re-enforce personnel training on fire and gas identification and interpretation. ④Explosion relief panels

6	Toxic/flammable substances	Loss of containment	①Tube rupture inside reformer ②Sulphur poisoning ③Deactivation of reformer catalyst ④Hotspots development on reformer tubes	①Cu-catalyst as sulphur guard in the bottom of ZnO bed (Protective coating) ②Pre-reforming upstream reformer ③Safety valves	①Flammable gas release ②Flammable mixture fire/explosion	①Gas quality requirements to NG supplier. ②Regular inspection and maintenance ③Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system . ④Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation. ⑤Re-enforce personnel training on their roles to ensure that non-essential personnel are cleared from the area during startup.
7	Gases under high pressure	Loss of containment	①Pipe rupture ②Failure of structure after startup. ③Hydrogen embrittlement ④Localized deterioration and hotspots ⑤High pressure ⑥High temperature	①Adequate inspection ②Careful change in Procedures, equipment, or Materials ③Comply with correct Standard Operating Protocol (SOP) ④Safety valves	①Flammable mixture release ②Flammable mixture fire/explosion ③Ignitimitigation_controlson	①Regular inspection and maintenance ②Refresh and re-enforce personnel training on fire and gas identification and interpretation. ③Operation and management of the Steam/methane reformer unit should be strengthened to account for local corrosion. ④Explosion relief panels
8	Hot or Cryogenic fluids	Loss of containment	①Rupture of H2 pipe ②Hydrogen embrittlement ③Excessive temperature ④Excessive pressure ⑤Failure of gaskets/joints	①Safety valves ②Adequate inspection ③Gas detection which activates: d) Emergency ventilation, e) Opening of ceiling and/or walls f) Closure of segmentation valves ④Causes shutdown when exceeding max operation temperature ⑤Protective coating ⑥Appropriate material selection (Alloys such as INCONEL® alloy 600 and INCOLOY alloy 800H.)	①Leakage of H2 pipeline before or after cooling ②Flammable gas mixture fire/explosion	①Regular inspection and maintenance ②Detailed hazard review andevaluation of all of the procedures in the hydrogen plant process gas system . ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation. ④Explosion relief panels.
9	Utility facilities	Loss of function	①Tube rupture ②NG leak in heat exchanger ③Metal dusting (Disintegration of the affected metal into a powdery mixture of graphite and metal particles) ④Lower oxygen partial pressures and higher carbon activities.	①High S/C (steam/carbon) ratio ②Protective coating (Aluminide coatings, alloying with copper andaddition of steam) ③Improve design(use of boiling water and steam for cooling) ④Appropriate material selection (Alloys such as INCONEL® alloy 600 and INCOLOY alloy 800H.)	①Flammable gas fire/explosion ②Hydrogen ignition	①Regular inspection and maintenance ②Explosion relief panels ③Detailed hazard review andevaluation of all of the procedures in the hydrogen plant process gas system . ④Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation
10	Safety systems	Loss of function	①Tube rupture during startup ②Steam flow picking up water and carrying it into the furnace ③Entrained water impinges on hot catalyst and pipe wall and instantaneously flashes ④Winter shutdown operation (external impact) ⑤Operating error ⑥Hotspot development ⑦Extreme internal pressure	①Comply with Standard Operating Procedures ②Adequate management of change ③Efficient decision making ④Provide adequate draining system to facilitate water removal ⑤Safety valves	①Flammable mixture fire/explosion ②Shock wave development ③Lost Time Injury ④Generation of shrapnel and brittle fracture	①Regular inspection and maintenance ②Detailed guidance for verifying that the feed system is dry, and a formal sign-off by both operations and engineering personnel. ③A separate cold-eyes review by external experts is recommended as part of the pre-startup safety review. Refresh and re-enforce personnel training on their roles to ensure that non-essential personnel are cleared from the area during startup activities.
11	Safety systems	Loss of function	①Rupture of vent line ②Mechanical aggression ③Corrosion ④Overpressure	①Safety valves ②Adequate inspection ③Gas detection which activates: d) Emergency ventilation, e) Opening of ceiling and/or walls f) Closure of segmentation valves ④Protective coating ⑤Appropriate material selection (Alloys such as INCONEL® alloy 600 and INCOLOY alloy 800H.)	①Flammable gas mixture standing flame/explosion ②Hydrogen ignition	①Regular inspection and maintenance ②Detailed hazard review andevaluation of all of the procedures in the hydrogen plant process gas system . ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation. ④Explosion relief panels.
12	Safety systems	Loss of function	①No proper purge system after removing and installing a vent valve ②Maintenance error	①Safety valves ②Adequate inspection ③Gas detection which activates: d) Emergency ventilation, e) Opening of ceiling and/or walls f) Closure of segmentation valves	①H2 vent line explosion ②H2-Air mixture ignition from flare stack or static charge	①Regular inspection and maintenance ②Detailed hazard review andevaluation of all of the procedures in the hydrogen plant process gas system . ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation. ④Explosion relief panels. ⑤Fenced site

						⑤Fenced site
13	Instrumentation and Control systems	Loss of control	①Pipe rupture ②Valve failure ③Operating error ④Extremely high pressure (pressure explosion)	①Regularity requirements to suppliers of control system (PLC and valve operation). ②Adequate system monitoring/inspection. ③Ventilation system.	①Flammable gas fire/explosion ②Ignition ③Lost time injury	①Remote operated process will reduce the probability of human failure. ②Industry guidance on the type of pressure relief device materials in terms of their metallurgical makeup. ③Regular inspection and maintenance ④Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system . ⑤Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.
14	Instrumentation and Control systems	Loss of control	①Pressure disk failure in the regulator ②Improper installation of check valves (backward installation) ③Deficiency in procedures ④Human error	①Proper installation of check valves ②Adequate system monitoring/inspection. ③Visual inspection of check valves and equipment prior to pressurization ④Ventilation system.	①H2 release ②H2 ignition ③Flammable gas fire/explosion	①Regular inspection and maintenance ②Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system to prevent abnormal phenomena. ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.
15	Dangerous equipment	Loss of function	①Rotary PSA safety valve failure ②Fatigue ③Wear and tear ④Failure of gaskets/joints	①Safety valves ②Adequate inspection ③Gas detection which activates: d) Emergency ventilation, e) Opening of ceiling and/or walls f) Closure of segmentation valves	①Flammable gas leakage ②Flammable gas mixture standing flame/explosion ③Injury	①Regular inspection and maintenance ②Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system . ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation. ④Explosion relief panels.
16	Dangerous equipment	Loss of function	①Burst of the PSA ②Overpressure (external fire) ③Excessive pressure at reformer outlet ④Hydrogen embrittlement ⑤Mechanical aggression	①Safety valves ②Adequate inspection ③Gas detection which activates: d) Emergency ventilation, e) Opening of ceiling and/or walls f) Closure of segmentation valves ④Protective coating ⑤Use sensors to identify the presence of oxygen or air ingress upstream and actuate alarms/emergency stop when concentrations exceed predetermined set point ⑥Purge the adsorber bed with an inert gas to reduce the risk of ignition if high oxygen concentrations are present. ⑦Appropriate material selection (Alloys such as INCONEL® alloy 600 and INCOLOY alloy 800H.)	①Toxic gas dispersion ②Missiles ③Fireball	①Regular inspection and maintenance ②Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system to prevent abnormal phenomena. ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation. ④Explosion relief panels. ⑤Fenced site ⑥Pull a vacuum on the adsorber to remove any adsorbed oxygen before the adsorber is put back online
17	Dangerous equipment	Loss of function	①Leakage or burst of the H2 line to the compressor ②Operating error ③Wear and tear ④Technical defect ⑤Errors in process controlling	①Safety valves ②Adequate inspection ③Gas detection which activates: d) Emergency ventilation, e) Opening of ceiling and/or walls f) Closure of segmentation valves ④Protective coating ⑤Causes shutdown when exceeding max operation temperature	①Jet fire ②Explosion	①Regular inspection and maintenance ②Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system to prevent abnormal phenomena. ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.
18	Dangerous equipment	Loss of function	①Blow off of cylinder head ②H2 compressor repair ③Error at assembly ④Discharge valve installed in intake position of compressor	①Safety valves ②Adequate inspection ③Gas detection which activates: d) Emergency ventilation, e) Opening of ceiling and/or walls f) Closure of segmentation valve	①H2 release ②Fire/explosion	①Regular inspection and maintenance ②Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system to prevent abnormal phenomena. ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.
19	Dangerous equipment	Loss of function	①Constant vibration of the process equipment (compressor) ②Design flaw	①Hydrogen distribution lines should be designed and carefully inspected to ensure process equipment in the area is correctly and safely installed.	①The bolt rubbed a hole in the high-pressure suction piping, resulting in the release of make-up hydrogen.	①Regular inspection and maintenance ②Equipment subject to vibration should not be placed in contact with hydrogen lines or with other equipment. ③If equipment is moved or rearranged, the hydrogen system should be re-inspected as per the above.
20	Dangerous equipment	Loss of function	①Incorrect installation of sized gasket at the suction line of a hydrogen compressor ②Inadequate Venting Design ③Flammable Mixture in Confined Area ④Design Flaw	①Adequate inspection ②Adequate System Monitoring/Oversight ③Adequate Hydrogen Detection Equipment ④Ventilation system	①H2 leak ②Fire/explosion ③Human life	①Regular inspection and maintenance ②Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system . ③Carefully revise the risk assessment process to evaluate any confined areas where hydrogen is handled. ④Separate the fire and gas detection alarm system from the process information to provide easy and clear identification. ⑤Retrain personnel on emergency procedures andenhance their understanding and awareness of risky, flammable, explosive,and/or toxic substances.
21	Ignition source	Failure of safety systems	①Tube rupture ②Heat release ③Burn wires ④Short circuit in the electrical junction box in the vicinity of a H2 line	①Install circuit protection devices (e.g. Fuses, circuit breakers, ground-fault circuit interrupters)	①H2 release ②Fire/explosion ③Hydrogen ignition	①Regular inspection and maintenance ②Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.

22	General radiation, not ionized	External impact (welding)	① Holes burned through the hydrogen tubing ②Improper hot work performance in the vicinity of a charged flammable gas line. ③A short during welding caused the pinholes in the tubing containing the gaseous H2. ④Failure to follow Standard Operating Procedures ⑤Human error/Individual action	①Perform hot work only after the gas supply is verified closed (along with a lock and tag). ②The system should be checked for leaks prior to turning the gas back on.	①H2 leak ②H2 ignition ③Minor injury	①Regular inspection and maintenance ②Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system. ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.
23	Surrounding-Related hazards	General facility damages (severe weather)	①Usually calm weather ②Cold H2 gas vented through the stack into atmosphere ③Gas accumulation around the vent stack	①Check for weather conditions and adjust procedures	①H2 release ②H2 ignition	①Regular inspection and maintenance ②Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system . ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.

Table D- 2: HAZID analysis table - Alkaline electrolyzer.

-- Filter hazard type -- ▾ -- Filter hazardous event -- ▾

No.	Hazard Type	Hazardous Event	Initiating Cause	Prevention Controls	Consequences	Mitigation Controls
1	Toxic/Flammable substances Hazardous Materials	Leakage / Loss of containment	①Lye leak through cells ②Overpressure (External fire) ③Failure of gaskets/joints/fittings ④Excessive temperature	①Safety valves ②Proper purging system ③H2 detection system with shutdown ④Isolation valves closure	①Explosion ②Jet flame	①Regular inspection and maintenance ②Adequate venting design ③Exceeding max operation temperature causes shutdown
2	Toxic/Flammable substances Hazardous Materials	Leakage / Loss of containment	①Leakage from lye pipes ②Hydrogen embrittlement (hydrogen corrosion) ③Overpressure ④Failure of gaskets/joints	①H2 detection system with shutdown (Limit leak time) ②Safety valves ③Isolation valves closure	①Explosion ②Jet flame ③Injury	①Regular inspection and maintenance ②Forced and emergency ventilation ③Proper purging system
3	Toxic/Flammable substances Hazardous Materials	Leakage / Loss of containment	①Lye discharge through vent line ②Overpressure in hydrogen separator ③Low level in break tank	①H2 detection system with shutdown (Limit leak time) ②Expand vent line with water trap.(Vent stack kept frost free by heating elements) ③Safety valves ④Isolation valves closure	①Explosion ②Jet flame ③Injury	①Regular inspection and maintenance ②Forced and emergency ventilation
4	Toxic/Flammable substances Hazardous Materials	Leakage / Loss of containment	①Lye pipe rupture ②Hydrogen embrittlement (hydrogen corrosion) ③Excessive pressure ④Excessive temperature ⑤Welds and connections failure	①H2 detection system with shutdown (Limit leak time) ②Safety valves ③Exceeding max operation temperature causes shutdown	①Explosion ②Jet flame ③Injury	①Regular inspection and maintenance ②Forced and emergency ventilation ③Proper purging system
5	Toxic/Flammable substances Hazardous Materials	Leakage / Loss of containment	①Sludge deposits in the electrolyte passages ②Inadequate flush water system to remove Sludge formation ③Electrolyte flow rate reduce caused by sludge blockage ④High temperature ⑤High electrolyte concentration ⑥Severe corrosion/erosion of cell electrodes and separator(Hydrogen embrittlement)	①Periodical flush the system with water to remove sludge formation. ②Adequate Hydrogen Detection Equipment ③Continuous gas analyzer test of oxygen and hydrogen product purity. ④Supply supervision alarming.	①Physical breakdown of cell separators ②H2 andO2 mixture ③Flammable mixture ignition ④Explosion ⑤Separator drum rupture	①Regular inspection and maintenance ②Check on a routine basis the individual cell purity levels to monitor the deterioration of performance of individual cells. ③Carry out a risk assessment of the current LP purity analyzers to determine the level of risk associated with a loss of sample flow.
6	Safety systems	Loss of functions	①Technical defect ②Operating error ③Discharge form safety relief valve to an unsafe location	①H2 detection system with shutdown (Limit leak time) ②Adequate venting design ③Location selection according to local regulatory authority	①Explosion ②Jet fire	①Regular inspection and maintenance. ②Detailed hazard review of all procedures in the hydrogen plant process gas system to prevent abnormal phenomena. ③Location away from residence area

7	Instrumentation and Control System.	Loss of control	①Bursting disc ruptured ②Air ingress in the system ③LP filter and LP dryer failure allowing air in the line. ④LP Pipe low point drain at LP gasholder blocked ⑤LP gasholder failure(sticking bell or mal-operation) ⑥Design flaw on inlet and outlet of gasholder ⑦Oxygen ingress form cells ⑧Low electrolyte level due to built-up of magnetite and other contaminants at the inlets leading to blocked water inlet pipes at the affected cells . (Blocked drain valves) ⑨Failure of welds and connections at the storage banks allowing hydrogen gas to be released in large quantities	①LP purity analyzer ②Isolation transformer ③Supply supervision alarming	①Hydrogen release ②Ignition ③Explosion in the hydrogen HP feed pipes ④Hydrogen self-ignited resulting in an explosion and fire in storage tanks.	①Regular inspection and maintenance. ②Check on a routine basis the individual cell purity levels to monitor the deterioration of performance of individual cells. ③Replace the drain valves with open port ball valves to improve the drain operation and to allow effective cleaning of the cells. ④Replace the existing LP purity analyzer with a fail-safe model that ensures the vent valve is opened under the conditions described above. ⑤Carry out a risk assessment of the current LP purity analyzers to determine the level of risk associated with a loss of sample flow. ⑥Fit hydrogen purity analyzers that fail safe either between the stages of the compressor or immediately after the compressor. ⑦Fit pot type water seals with open trough water makeup as a replacement for the U tube and pot type seals. ⑧Remove the end sheeting from the building to increase ventilation ⑨An investigation be carried out into the feasibility of establishing a gas up station away from the hydrogen generation plant possibly near the CO2 plant to allow the units to be gassed from transportable pallets in an emergency

Table D- 3: HAZID analysis table - GH2 storage system.

-- Filter hazard type -- ▾ -- Filter hazardous event -- ▾

No	Hazard Type	Hazardous Event	Initiating Cause	Prevention Controls	Consequences	Mitigation Controls
1	Liquids and Gases under high pressure	Leakages / Loss of containment	①Massive GH2 leak due to pipe rupture ②A pneumatically operated GH2 isolation gate valve failed in open position (overpressure) ③Absence of coating at the leak point ④Galvanic corrosion ⑤Pipe rupture when high-pressure gas was applied to the thin pipe membrane. ⑥GH2 was trapped in large quantities in sand and gravel under the apron surface (a 1-foot-thick concrete pad about 160 x 140 ft). ⑦GH2 entrance in the basement of the electrical control and instrumentation terminal building, located immediately adjacent to the facility, through penetrations in the basement wall, including cable ducts, cable pulls, and two 24-inch-diameterair conditioning ducts. GH2 was transported through the air conditioning ducts to a support building about 90 feet from the terminal building. ⑧The possible ignition source in the terminal building was considered to be an electrical arc froma sump pump.	①Active GH2 sensors should be installed and continuously monitored in all enclosed buildings near GH2 sources. All buildings near areas where hydrogen is used should be designed to preclude GH2 entrapment (e.g., sloping roof with ventilationat the highest point). ②Underground carbon steel lines beneath concrete pad areas should not be used for GH2 transmission. All GH2 lines are now stainless steel and above ground. ③Any GH2 transmission lines buried underground should be proof-tested and leak-checked on a periodic basis. ④Any below-grade piping installation should be in open trenches covered by grating. ⑤Facilities should be protected from GH2, at a safe distance, by manual isolation valves. If remote-operated valves (ROVs) are required for operational isolation purposes, the ROVs should be in series with and downstream of the manual isolationvalve. ⑥Valves repaired in the field should be subjected to functional and leak checks, including actuator and valve seals at simulated operating conditions. A written procedure should be prepared and used. ⑦Valves utilizing pneumatic actuators should have actuator piston and piston nut staked (or locked by other positive means) in the installed condition.	①H2 release ②H2 ignition (an electrical arc from a sump pump) ③Flamable gas explosion	①Regular inspection and maintenance ②The pressure between isolation valves and stand shut-off valves should be routinely monitored on a daily basis. ③Field repair of mechanically severable valves in high-pressure systems should be eliminated. ④All high-pressure gas lines scheduled to be inactive for periods greater than 6 months should be physically isolated by blind flanges from active systems. ⑤Supply system status of pressure vessels and lines (pressure and/or quantity) should be recorded at the start and completion of operations each day. All reservoirs should be isolated at close of business each day, and before weekends andholidays. ⑥Corrosion protection systems for underground lines should be reviewed and tested to confirm the adequacy of the systems. ⑦Operational and support buildings at hazardous sites should be isolated (i.e., interconnecting air conditioning systems should be avoided). Buildings connected to hazardous sites by tunnels and/or conduits should be physically isolated byseals. If physical isolation is not practical, then positive air flow should be maintained in tunnels and conduits. ⑧Explosive gas detection meters should be included in the equipment carried by firefighters and emergency medical personnel. ⑨Fire alarm transmitters should be located at all hazardous locations. ⑩Emergency instructions for isolating GH2 and utilities for hazardous locations should be permanently posted with names and telephone numbers of key individuals to be contacted.
2	Liquids and Gases under high pressure	Leakages / Loss of containment	①Rupture of the H2 storage output line ②Mechanical aggression(digger) ③Hydrogen embrittlement (hydrogen corrosion) ④External fire or overpressure (excessive temperature)	①Fenced site ②Regular monitoring system ③Safety valve at the storage output (released by a fuse) ④Pressure reducer as close as possible to the high pressure source ⑤H2 gas detection system with shutdown if in confined ventilated space ⑥Flame detection	①H2 release ②H2 ignition ③Flamable gas explosion or jet fire	①Work permit/Trained employees ②Regular inspection and maintenance
3	Liquids and Gases under high pressure	Leakages / Loss of containment	①Release of of hydrogen through the pressure relief valve (PRV) line ②External fire or overpressure/excessive pressure input	①Adequate gas detection system with shudown ②Pressure reducer as close as possible to the high pressure source	①H2 release ②H2 ignition ③Flamable gas explosion or jet fire	①Regular inspection and maintenance ②PRV vent in a safe location

	pressure					
4	Liquids and Gases under high pressure	Leakages / Loss of containment	①Burst of hydrogen tank ②External fire ③Jet flame/impingement ④Overpressure (input line) ⑤Loss of mechanical properties (ageing, mechanical aggression, material defect) ⑥Chemical aggression	①Adequate gas detection system with shudown ②Avoid combustible materials used in design-housekeeping ③Location of vent outlet (open air, no congestion) ④Fenced site ⑤Compatible material use	①H2 release ②H2 ignition ③Pressure wave+missiles+fireball	①Regular inspection and maintenance ②Periodic control ③Work permit/trained employees ④Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system to prevent abnormal phenomena.
5	Liquids and Gases under high pressure	Leakages / Loss of containment	①Release of hydrogen through the vent line due to voluntary action / human error (maintenance) ②voluntary emergency release (fire)	①Design: release hydrogen in a safe location ②Adequate gas detection system with shudown ③Refresh and re-enforce personnel training on abnormal phenomena identification and interpretation.	①H2 release ②H2 ignition ③Explosion or jet fire	①Regular inspection and maintenance ②Periodic control ③Work permit/trained employees ④Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system to prevent abnormal phenomena.
6	Liquids and Gases under high pressure	Leakages / Loss of containment	①Rupture of the H2 bundle manifold or of the manifold feed line due to mechanical aggression (drop of a heavy equipment, displacement of cylinders) ②hydrogen embritlement (hydrogen corrosion) ③external fire	①Detect / Limit the flow / quantity of H2 that can leak at the H2 bundle manifold or at the manifold feed line with isolation through fail safe valve ②Limit manifold material to those that can withstand an ignited leak	①H2 release ②H2 ignition ③Explosion or jet fire	①Regular inspection and maintenance ②Periodic control ③Work permit/trained employees ④Detailed hazard review and evaluation of all of the procedures in the hydrogen plant process gas system to prevent abnormal phenomena.
7	Liquids and Gases under high pressure	Leakages / Loss of containment	①A pressure relief device (PRD) valve failed on a high-pressure storage tube at a hydrogen fueling station ②the use of incompatible materials in the manufacturing of the PRD valve, ③improper assembly resulting in over-torquing of the inner assembly ④over-hardening of the inner assembly materials by the valve manufacturer ⑤Gas ignition at the exit of the vent pipe	①adequate quality assurance/quality control procedures during the design and safety reviews. ②it is likely that the vent stacks adjacent to the canopy would have been raised in order to avoid any damage in the event of a fire.	①H2 release ②H2 ignition (Either static electricity or spark from escaping particle) ③Fire or Jet flame ④Property Damage ⑤Facility closure	①new and modified procedures were instituted to improve the timely communication of station status during emergency events. ②Additional training of personnel focused on improving the response time and effective communication between employees, first responders, and the hydrogen equipment supplier.

Contact Us

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Figure 20. Online Tool – Hazard Tables

3 Online Forum Form

Based on the H_2TRUST mirrors groups the Consortium has established and facilitates access to a permanent set of H_2 expert groups that may be consulted by public or private organisations for the purpose of develop adequate and informed public responses to H_2 safety issues. The users of the forum will have to register first before posting or participating in the forum.

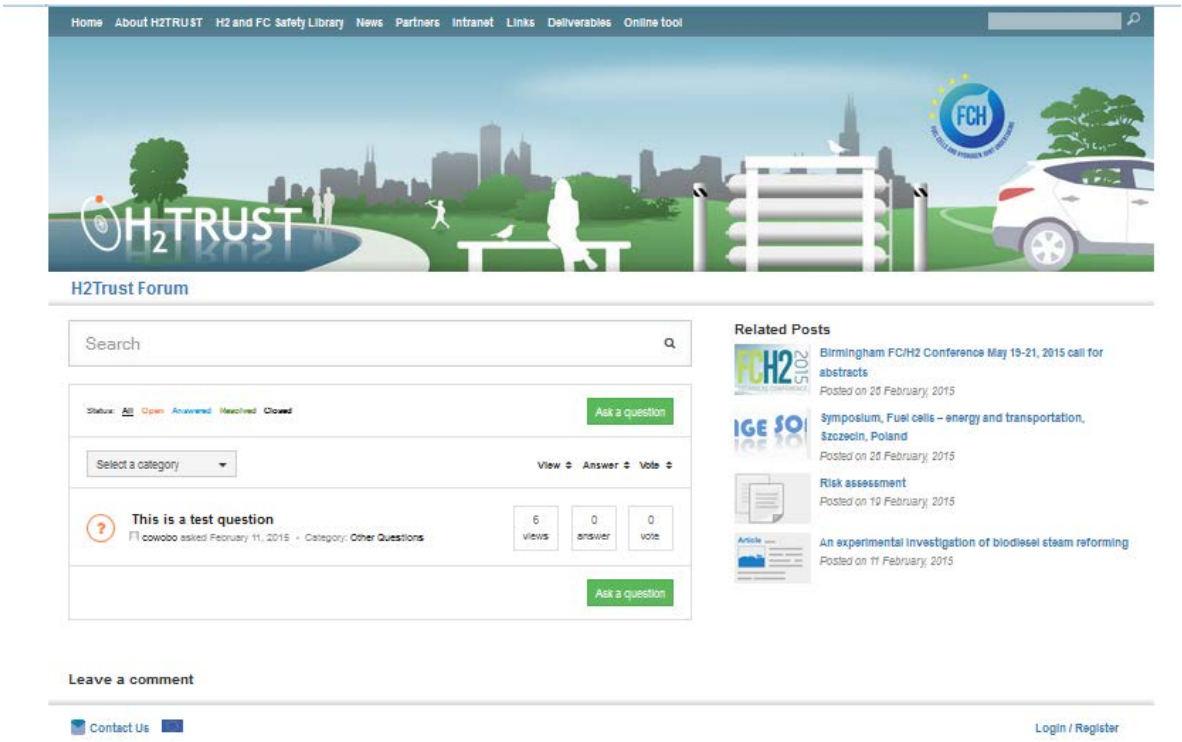

Figure 21. H_2TRUST online forum form

4 H_2ighlights

H_2ighlights is a news bar under the main menu and the banner of H_2TRUST website. H_2ighlights is a fixed bar in all website pages and its objective is to highlight the important news or events in a visible way to the website visitors.