Increasing Reliability and Safety of Hydrogen Components - Reliability Data Collection

William Buttner (NREL), Christine Watson (DOE HFTO), Genevieve Saur (NREL), Dr. Katrina Groth (UMD), Ahmad Al-Douri (UMD), Olivia Robinson (NREL)

Virtual Technical Webinar
March 13, 2024

Welcome to the joint NREL-UMD Technical Seminar

Increasing Reliability and Safety of Hydrogen Components - Reliability Data Collection

March 13, 2024

Today's Agenda

EDT (MDT)	Day 1 (Monday Dec 11, 2023)	
Start Time	Topic	Presenter
11:00 AM (9:00 AM)	Introduction	William Buttner, NREL Christine Watson, DOE/HFTO
11:05 AM	What is the hydrogen component reliability database (HyCReD)?	Genevieve Saur, NREL
11:20 AM	Analysis to support reliability and safety at hydrogen refueling stations	Katrina Groth, University of Maryland
11:35 AM	Using the database and evolution	Ahmad Al-Douri, University of Maryland Olivia Robinson, NREL
11:50 AM	Ways to collaborate; support the project, support the industry	Genevieve Saur, NREL
11:55 AM	Open Discussion: - Feasibility of implementation - Industry needs - Feedback	All
12:15 PM	End (Presenters available for continued discussion)	

Special acknowledgement to U.S. Department of Energy's Hydrogen and Fuel Cell Technologies Office

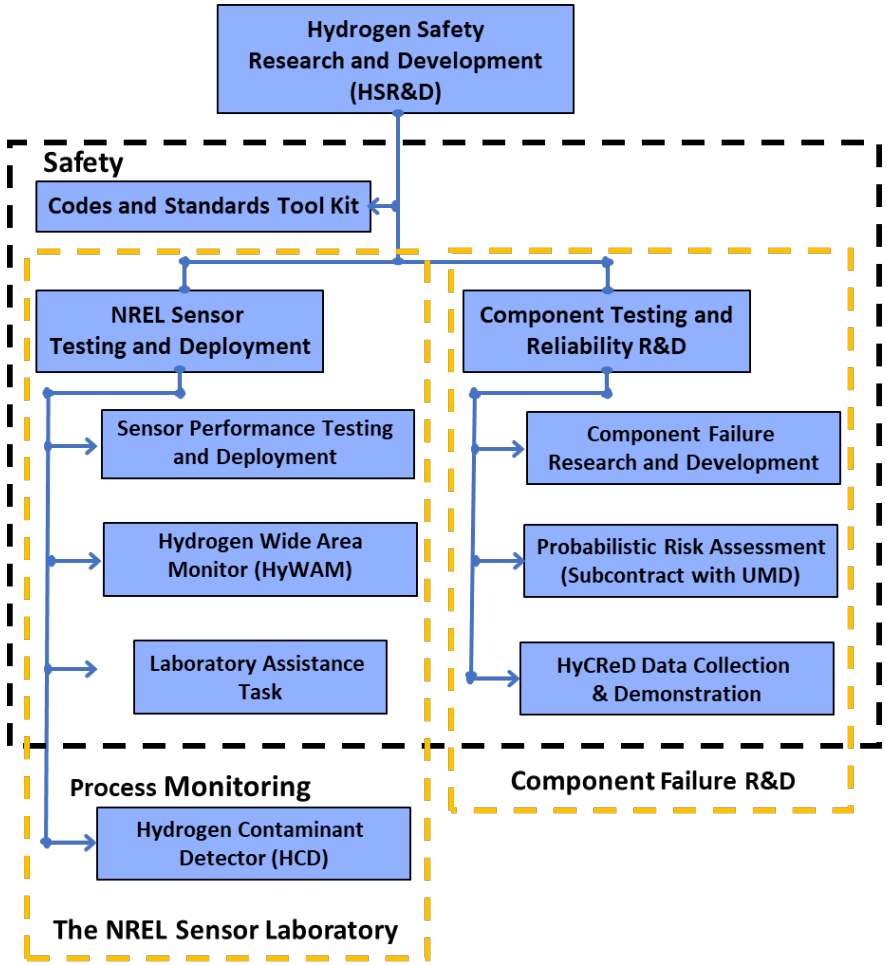
Technical Seminar

Increasing Reliability and Safety of Hydrogen Components - Reliability Data Collection

NREL HSR&D Program

- The NREL Sensor Laboratory
- Component Testing and Reliability
- Support of Hydrogen Codes and Standards

Detection and Mitigation of the Impacts of Unintentional Hydrogen Releases



Support for the NREL HSR&D Program is through the DOE HFTO Safety, Codes & Standards (Laura Hill, Technology Manager and Christine Watson, Technology Manager)

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What is the hydrogen component reliability database (HyCReD)?

Genevieve Saur

HyCReD Virtual Technical Seminar

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Why is this important for YOU (H_2 stakeholders)?

HyCReD addresses a gap in H2 infrastructure deployments

- **Design and safety of projects (codes and standards development)**
- **Infrastructure reliability and O&M cost (component failure rates, maintenance)**
- **Component R&D needs (robust supply chain)**

The **Hy**drogen **C**omponent **Re**liability **D**atabase is a collaborative project between NREL's Hydrogen Safety R&D team and National Fuel Cell Technology Evaluation Center (NFCTEC), University of Maryland and hydrogen stakeholders.

NREL Transforming ENERGY

Hydrogen Safety R&D Team

UNIVERSITY OF MARYLAND

SYRRA

NREL's National Fuel Cell Technology Evaluation Center

Component Reliability

Approach brings together expertise in three areas of mosaic importance with industry as the key

NREL Transforming ENERGY

UNIVERSITY OF MARYLAND

SYRRA

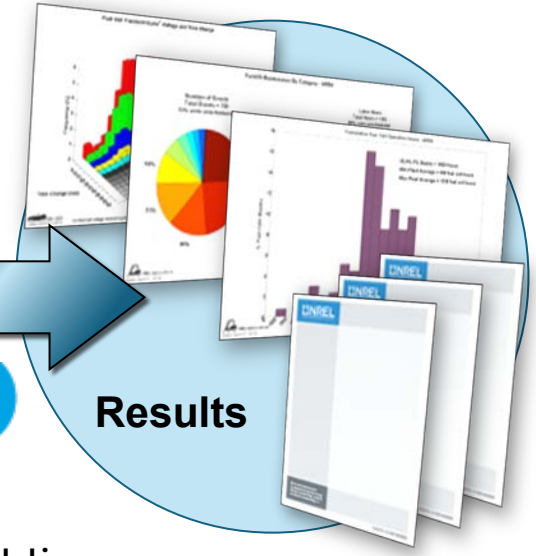
NREL's National Fuel Cell Technology Evaluation Center (NFCTEC)

Bundled data (operation and maintenance/safety)

DDPs

Internal analysis

NREL's National Fuel Cell Technology Evaluation Center



Confidential

Public

CDPs

Project and Authorized Access List:
List of Projects and Authorized Individuals for the
NREL National Fuel Cell Technology Evaluation Center
National Renewable Energy Laboratory
Revision E, May 28, 2019

Table 1: NFCTEC Projects

Project	Fund	Name
FC Vehicle	DOE	FCEV
FC Bus	DOE/DOT	FCB
FC Stationary	DOE	FCS
Component Validation	DOE	CMP
Infrastructure	DOE	INFR
FC Material Handling	DOE/ARRA/DLA	FCMHE
FC Backup Power	Completed - DOE/ARRA	FCBU
FC Technology Status	DOE	FCTech
FC Ground Support Equipment	DOE	FCGSE
TIGGER	DOT	TIGGER
Lo/No Bus	DOT	LONOB

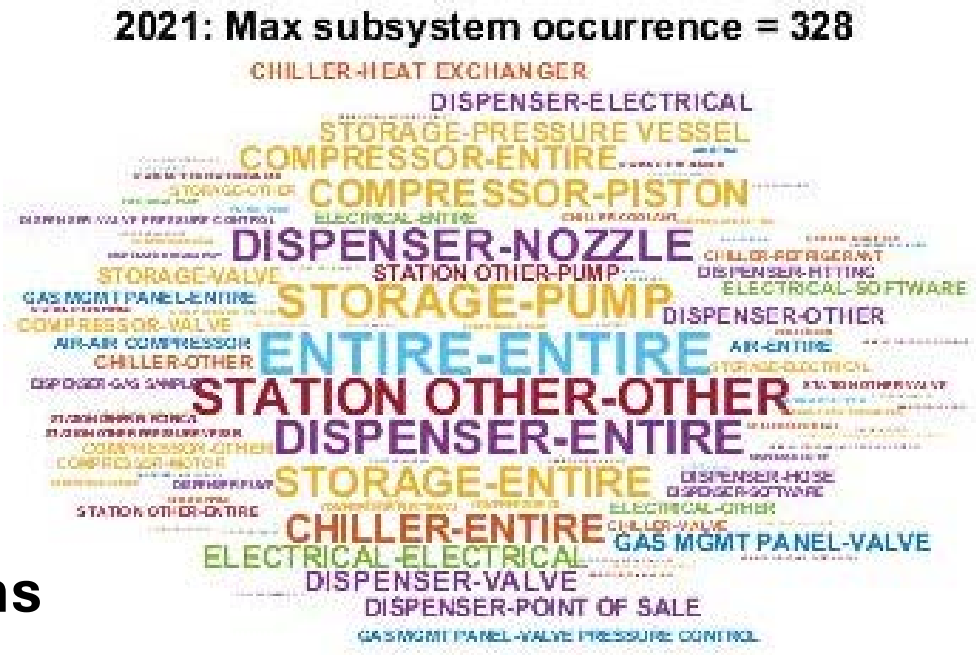
Table 2: Authorized Individuals

Individual	Organization	Project (Scope)	Badge Access
Sunita Satyapal	DOE HQ, DC	DOE funded projects	N

- NFCTEC – data collection, analysis, and security
  - Drawing upon reputation and security doctrines established during 19 years of field evaluation work
  - Utilizing existing relationships and establishing new ones to enable high quality data collection
  - Developing online platform for continuous real-time data collection, hycred.nrel.gov (in development)

An historical perspective: Light duty stations

- NREL's NFCTEC has been collecting data on California's retail H2 refueling stations since 2015 [1]
- What have we collected (snapshot)
  - ❖2021 1.2M kg H2 dispensed from ~40 stations [2]
  - ❖~1,700 maintenance events reported in 2021Q1
  - ❖2020 O&M costs were $12k/quarter/station [3]
  - ❖Top categories of equipment failures: Dispenser, compressor, chiller, storage, and other [4]
- **In retrospect data template had limitations (lessons learned)**
  - ❖**Data quality issues**
  - ❖**Some drop downs were confusing**
  - ❖**Long lists to navigate**



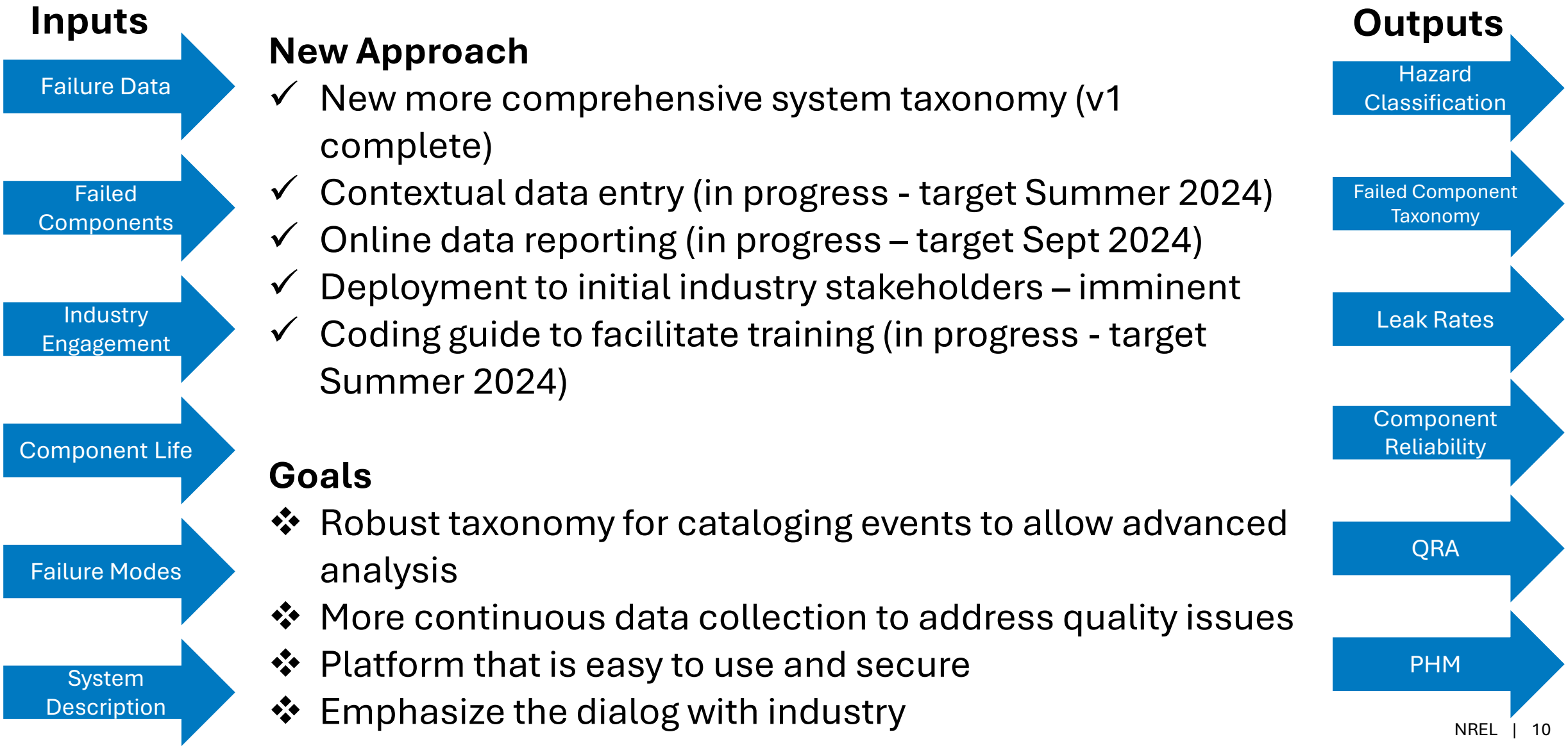
Excerpt NREL NFCTEC cdpRetail_infr_98, 2 quarters of data

Saur, Genevieve, Spencer Gilleon, and Sam Sprik. 2022. Next Generation Hydrogen Station Composite Data Products: Retail Stations – Summer 2021: Data Through Quarter 2 of 2021. https://www.nrel.gov/docs/fy22osti/83036.pdf

[1] https://www.nrel.gov/hydrogen/hydrogen-infrastructure-analysis.html
[2] # of reporting stations varies by quarter, averaged
[3] Data no longer reported in CEC template
[4] Other may refer to either unidentified events or multiple repairs reported in single event

NREL's National Fuel Cell Technology Evaluation Center

Component Reliability Strategy: New approach will address limitations and expand analysis focus



HyCReD Partnership Motivation

- Station uptime makes your customers happy
- Station reliability increases profitability
- Component reliability analysis -> robust supply chain -> deployment and adoption
- Avoid overregulation through proactive treatment of safety and reliability

- **Working together** → **More Impact**

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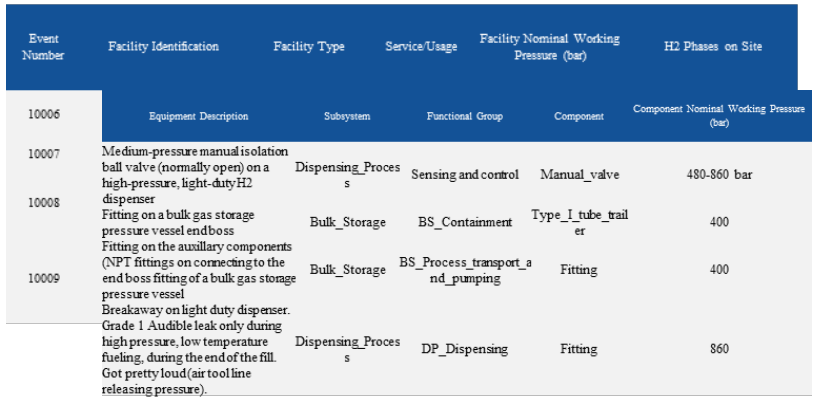


Event Number	Facility Identification	Facility Type	Service/Usage	Facility Nominal Working Pressure (bar)	H2 Phases on Site
10006	Equipment Description	Subsystem	Functional Group	Component	Component Nominal Working Pressure (bar)
10007	Medium-pressure manual isolation ball valve (normally open) on a high-pressure, light-duty H2 dispenser	Dispensing_Process	Sensing and control	Manual_valve	480-860 bar
10008	Fitting on a bulk gas storage pressure vessel end boss	Bulk_Storage	BS_Containment	Type_I_tube_trailer	400
10009	Fitting on the auxillary components (NPT fittings on connecting to the end boss fitting of a bulk gas storage pressure vessel	Bulk_Storage	BS_Process_transport_and_pumping	Fitting	400
	Breakaway on light duty dispenser. Grade 1 Audible leak only during high pressure, low temperature fueling, during the end of the fill. Got pretty loud (air tool line releasing pressure).	Dispensing_Process	DP_Dispensing	Fitting	860

Date & Time of Event	Phase of Operation	ailure Mode	Failure Mechanism	Failure Root Cause Description	Failure Severity
12/20/2021; 11:45	Op				
08/13/2021; XX:XX	Recor				
6/8/2022	Recor				
Tuesday (fueling day for Hyundai ~8/4/2023 ~3 PM (discovery)	Op				

H2 release?	H2 release size	Accumulation?	Detection?	Detection notes	Ignition? (yes/no)	Consequences
Yes	Small (1-2 kg)	No, outside	Yes	Audible	No	downtime for replacement of the valve
Yes	Medium (~10 kgs), 0.2kgs/min	No, outside	No	Audible	No	Downtime and event investigation
Yes	Small (~5 kgs) over a long duration, 0.17 g/min	No, outside	Yes	Audible (barely)	No	
Yes	Small (check data)	No, outside	Dispenser shutdown (leak check) not CG	Audible	No	

Hydrogen Component Reliability Database (HyCReD)

Ahmad Al-Douri[1], Katrina M. Groth[1],

Kevin Hartmann[2], Olivia Robinson[2], Genevieve Saur[2], William Buttner[2]

[1]Systems Risk and Reliability Analysis (SyRRA) Lab,

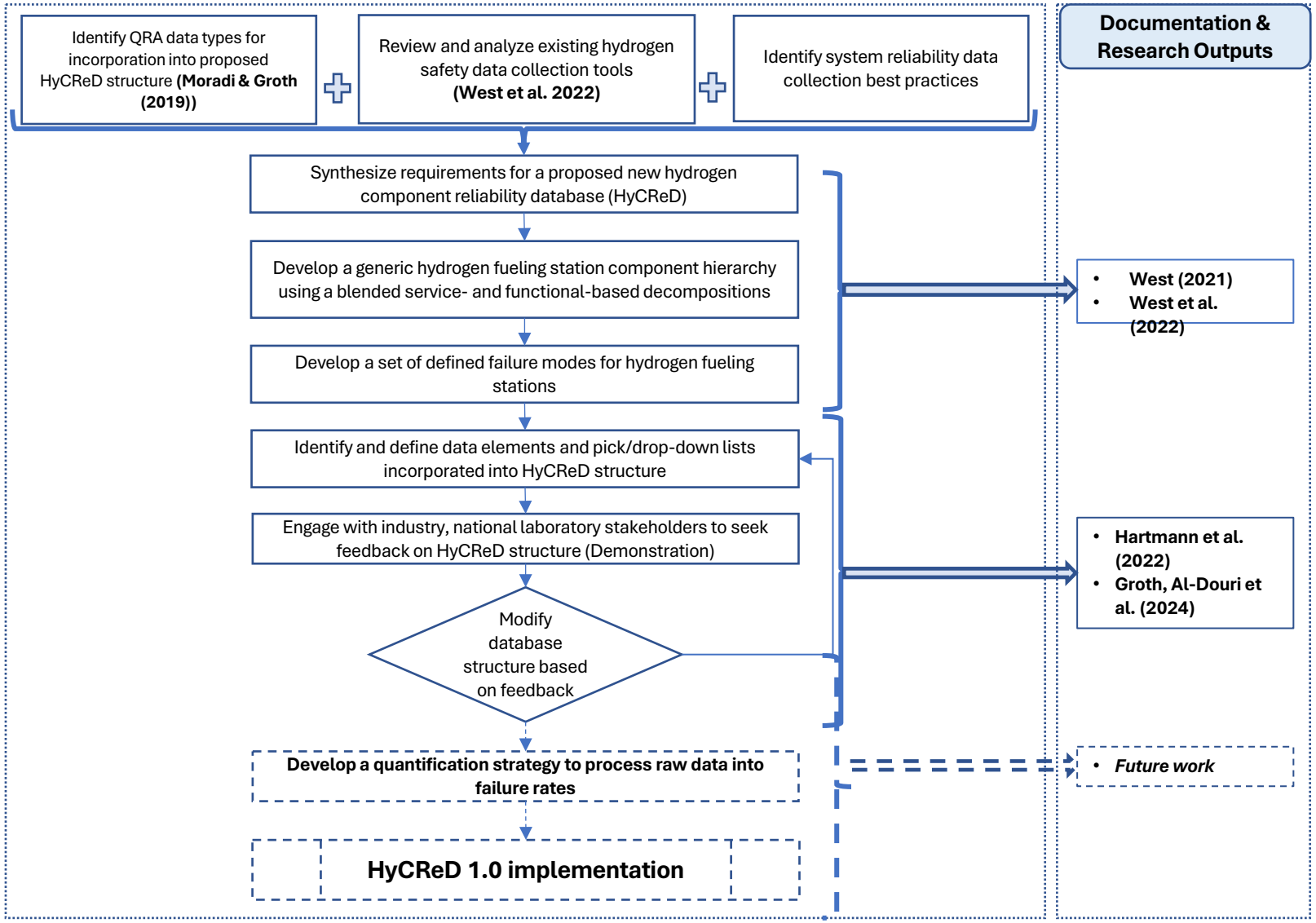
Center for Risk and Reliability,

University of Maryland

[2] National Renewable Energy Laboratory, Golden, CO, USA

This work was supported by the NREL, operated by Alliance for Sustainable Energy, LLC, for the U.S. DOE under Contract No. DE-AC36-08GO28308. Funding provided by U.S. DOE-EERE Hydrogen and Fuel Cell Technologies Office. The views expressed do not necessarily represent the views of the DOE or the U.S. Government.

Approach: Development and refinement of HyCReD

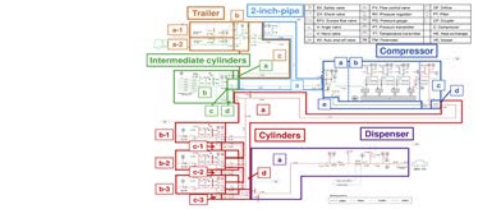


HyCReD Summary

Evaluating existing hydrogen safety data collection tools

	Data Type	H2Tools	NREL CDPs	HIAD	CHS Failure Rate Data
Event and failure characterization	Initiating event (description)	✓	✓	✓	×
	Location within system	×	✓	○	×
	Failure mode	×	×	×	×
	Failure mechanism	×	×	×	×
	Failure root cause	✓	✓	✓	×
	Release size	×	○	✓	✓
	Incident severity	✓	✓	✓	✓
	Consequences	○	✓	✓	○
	System response (Mitigation)	×	×	×	○
	H2 accumulation	×	×	×	×
	H2 detection	×	×	×	○
Life/usage	Component life	×	×	×	×
	Operations	×	✓	×	○
	Maintenance	×	✓	×	○
	Site inventory	×	✓	×	○
Data scope	Public access to data	✓	×	✓	?
	Scope includes any H2 incident	✓	×	✓	✓
	Regular reporting	×	✓	×	✓
	Anonymous data presentation	✓	✓	✓	✓
	Data quality checks	×	✓	×	?
	Process documentation	×	×	○	×

Developing system-specific hydrogen fueling station decomposition



Developing & validating HyCReD structure

- **Static data fields**

Event Number	Station/Facility Identification	Facility Type	Service/Usage	Nominal Working Pressure	H2 phases on site
25	A	Commercial, public	Heavy-duty	700 bar	Gas
26	B	Research, limited-access	Both heavy- and light-duty	350 bar	Gas

Event Number	Equipment Description	Subsystem	Functional Group	Component	Component Nominal Working Pressure	Component Population	P&ID Part Number
25		Bulk storage	Containment	Type III tank	250-300 bar	18	TK-103
26		Compression process	Compression	Compressor	400-680 bar	2	CO-E-19A

- **Failure event data fields**

Event Number	Time & Date of Failure	Failure Mode	Failure Severity	Failure Mechanism	Failure Root Cause Description	Hydrogen Release (Yes/No)	Release Size (Small/ Medium/La rge)	Ignition (Yes/No)
25	07/17/2021 08:32	External leakage-Process medium	Critical	Leakage		Yes	Medium	No
26	10/17/2021 15:33	Parameter deviation	Degraded	Overheating		No	Small	No

- **Maintenance event data fields**

Date & Time Repair Started	Date & Time Repair Completed	Date & Time Station Restarted	Action Performed	Maintenance Description
07/18/2021 09:55	07/28/2021 10:00	07/29/2021 09:30	Replacement	
10/17/2021 17:30	10/20/2021 13:30	10/20/2021 15:30	Repair	

Defining a set of 24 requirements for a HyCReD

Characteristics	Static data	Failure event data	Maintenance event data
• Design for usability • Publicly available • Regular reporting • Anonymity • Quality assurance • Regular updating • Process documentation	• Component location • Operating condition • Component life • Number of like components	• Narrative event description • Failure mode • Failure mechanism • Root cause • Release location & size • Hydrogen accumulation • Detection • Isolation • Consequence • Severity	• Type of maintenance • Maintenance action performed • Active repair time • Manhours

Defining hydrogen-specific component failure modes

Failure Mode	Definition
Abnormal output-high	Above normal output indicates potential failure(s)
Abnormal output-low	Below normal output indicates potential failure(s)
Bent/warped/damaged	Visible damage
Contamination	Component allows foreign material to contaminate product
Drift	Erroneous reading due to lack of calibration
Erratic output	Inconsistent output
External leak hydrogen	Hydrogen leak from within system to environment
External leak utility medium	Utility medium leak from the system to the environment
External rupture hydrogen	Complete loss of containment, hydrogen exhausts to the environment
External rupture utility medium	Complete loss of utility medium to the environment
Fail closed	Component stops working in the closed position
Fail open	Component stops working in the open position
Fail to close	Component does not close on demand
Fail to disconnect	Components meant to disconnect does not do so on demand
Fail to evaporate	Hydrogen remains in liquid form after passing through evaporator
Fail to operate	Component does not function on demand
Fail to stop	Component does not stop on demand
Freezing	Component is frozen and becomes inoperable/requires maintenance
Insufficient heat transfer	Target parameters for temperature are not met in a heat exchanger
Internal leak hydrogen	Hydrogen leak within system boundary (e.g. across a closed valve)
Internal leak utility medium	Utility medium leak within system boundary (e.g. across a closed valve)
Internal rupture hydrogen	Complete loss of containment, hydrogen stays within the system boundary
Internal rupture utility medium	Complete loss of containment, utility medium stays within the system boundary
Open circuit	Electrical circuit that is not complete
Overheating	Component is exposed to temperatures above design specifications
Overspeed	Component operates above desired/specified speed
Plugging	Buildup of material restricting flow
Restrict flow	Component is restricting flow when not intended to do so
Short circuit	Diversions of current
Spurious operation	Activation without specified demand (components normally idle)
Spurious stop	Stop without specified demand (components normally active)
Stuck connection	Component is stuck at point of contact (nozzle)
Underspeed	Component operates below desired/specified speed

HyCReD system event fields

Event Number	Facility Identification	Facility Type	Service/Usage	Facility Nominal Working Pressure (bar)	H2 Phases on Site
10025	A	Commercial, public	Heavy-duty	700 bar	Gas
10026	B	Research, limited-access	Both heavy- and light-duty	350 bar	Gas

Event Number	Equipment Description	Subsystem	Functional Group	Component	Component Nominal Working Pressure (bar)	Component Maximum Allowable Working Pressure (bar)	Component Population	Installation Date	P&ID Part Number
10025	*Narrative truncated for space*	Bulk storage	Containment	Type III tank	300	400	18	03/2016	TK-103
10026		Compression process	Compression	Compressor	700	820	2	11/2012	CO-E-49A

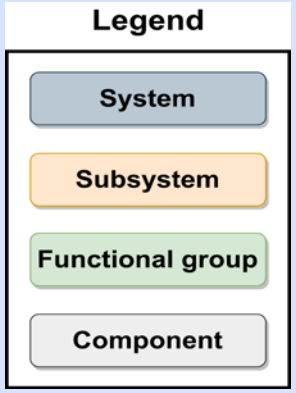
- Recorded system information including **station name, type, subsystems and components** involved.
- Equipment description is a narrative field to help fill in next columns.

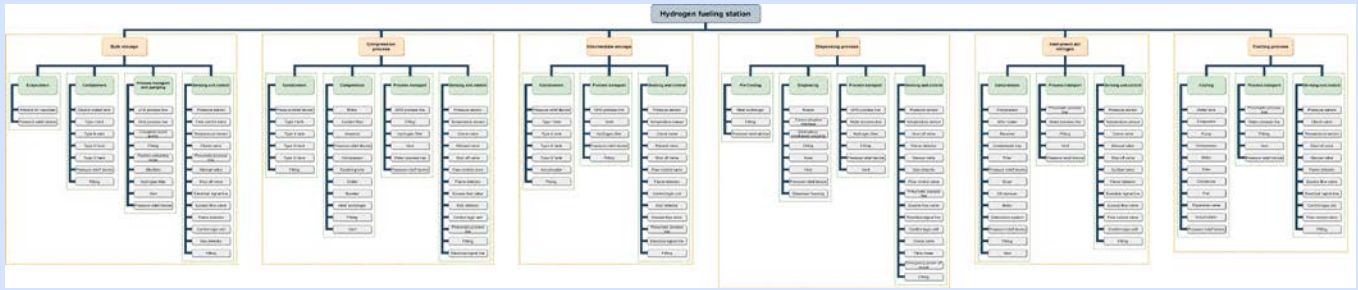
Groth, Katrina M., Ahmad Al-Douri, Madison West, Kevin Hartmann, Genevieve Saur, and William Buttner. "Design and requirements of a hydrogen component reliability database (HyCReD)." *International Journal of Hydrogen Energy* 51 (2024): 1023-1037.

Data: Sample system information fields

Event Number	Equipment Description	Subsystem	Functional Group	Component	Component Nominal Working Pressure (bar)	Component Maximum Allowable Working Pressure (bar)	Component Population	Installat-ion Date	P&ID Part Number
10025		Bulk storage	Containment	Type III tank	300	400	18	03/2016	TK-103
10026	*Narrative truncated for space*	Compression process	Compression	Compressor	700	820	2	11/2012	CO-E-49A

- Full system taxonomy developed for H2 fueling stations by West (2021)
- Six subsystems, 21 functional groups, and major components identified
- Taxonomy becomes drop-down menu for easy user input





West, M. (2021). Development of a Reliability Data Collection Framework for Hydrogen Fueling Station QRA (M.S. Thesis, University of Maryland, College Park).

HyCReD failure event fields

Event Number	Time & Date of Failure	Phase of Operation	Failure Mode	Failure Severity	Failure Mechanism	Failure Root Cause Description
10025	07/17/2021 08:32	Normal operations	External leakage-Process medium	Critical	Leakage	*Narrative truncated for space*
10026	10/17/2021 15:33	Maintenance	Parameter deviation	Degraded	Overheating	

Event Number	Hydrogen Release?	Hydrogen Release Size	Detection?	Detection Notes	Ignition?	Consequences
10025	Yes	Medium	Yes	*Narrative truncated for space*	No	*Narrative truncated for space*
10026	No	Small	No		No	

- All fields and their potential pick lists are defined in Groth et al. (2024) IJHE paper and the data coding guide.

Groth, Katrina M., Ahmad Al-Douri, Madison West, Kevin Hartmann, Genevieve Saur, and William Buttner. "Design and requirements of a hydrogen component reliability database (HyCReD)." *International Journal of Hydrogen Energy* 51 (2024): 1023-1037.
Data Coding Guide Draft

Data: Sample failure event fields

Event Number	Time & Date of Failure	Phase of Operation	Failure Mode	Failure Severity	Failure Mechanism	Failure Root Cause Description
10025	07/17/2021 08:32	Normal operations	External leakage-Process medium	Critical	Leakage	*Narrative truncated for space*
10026	10/17/2021 15:33	Maintenance	Parameter deviation	Degraded	Overheating	

- Total of 44 defined failure modes developed for components of H2 fueling stations by **West (2021)**
- Failure mode taxonomy for each functional group identified
- Taxonomy becomes drop-down menu for easy user input

Failure Mode	Definition
Abnormal output-high	Above normal output indicates potential failure(s)
Abnormal output-low	Below normal output indicates potential failure(s)
Bent/warped/damaged	Visible damage
Contamination	Component allows foreign material to contaminate product
Drift	Erroneous reading due to lack of calibration
Erratic output	Inconsistent output
External leak hydrogen	Hydrogen leak from within system

West, M. (2021). Development of a Reliability Data Collection Framework for Hydrogen Fueling Station QRA (M.S. Thesis, University of Maryland, College Park).

Data: Hydrogen fueling station failures

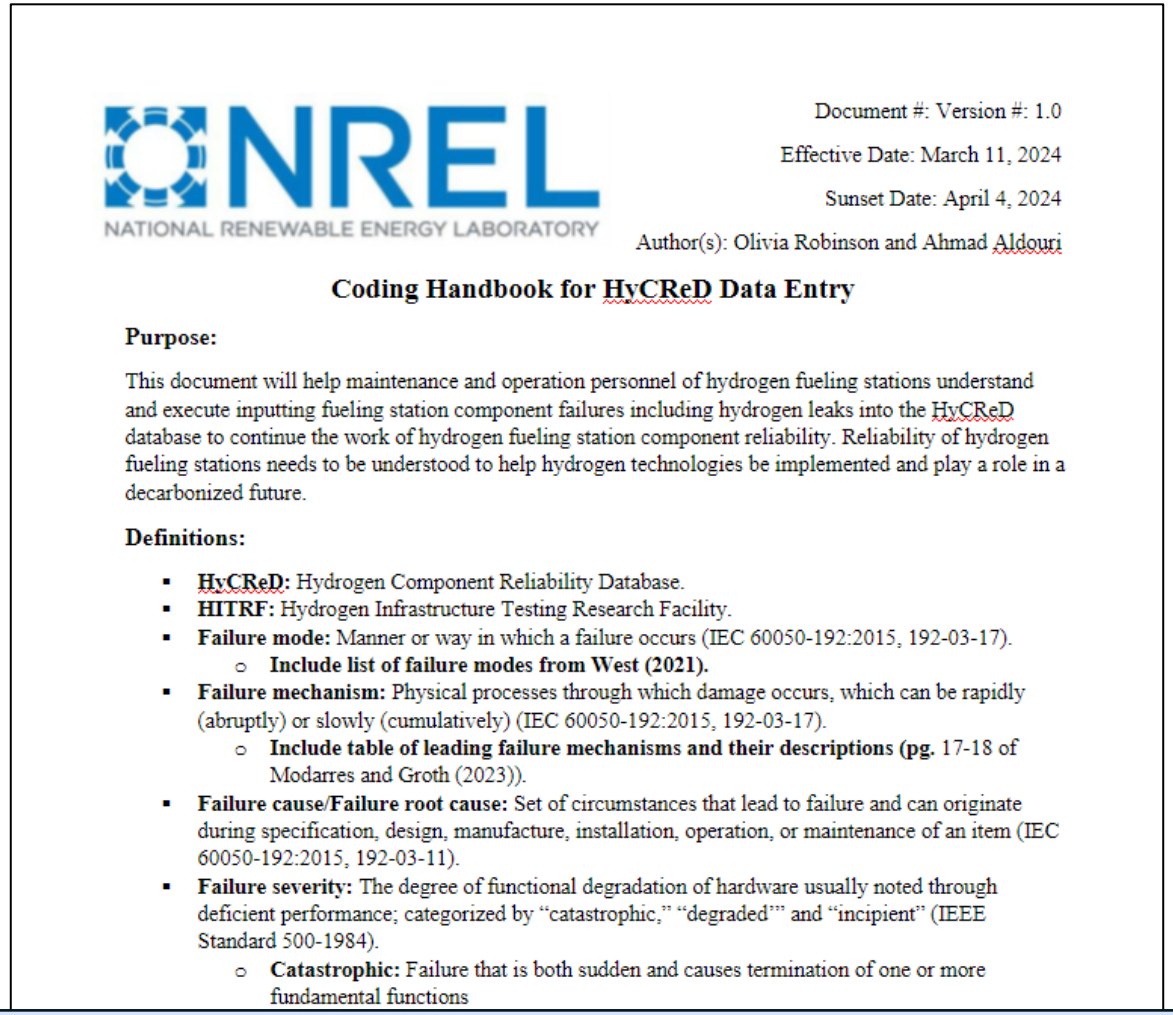
- **Hydrogen Infrastructure Testing and Research Facility (HITRF)**
  - National Renewable Energy Laboratory

- **KHK Database (Japan)**
  - High Pressure Gas Safety Institute of Japan
  - Collecting information on incidents involving high pressure gases, including hydrogen

- **HIAD**
  - European Joint Research Commission, since 2004
  - Public H2 incident reporting and lessons learned database

- **H2Tools Lessons Learned**
  - Pacific Northwest National Lab, since 2006
  - Public H2 incident reporting and lessons learned database

HyCReD Data Coding Handbook



NATIONAL RENEWABLE ENERGY LABORATORY

Document #: Version #: 1.0

Effective Date: March 11, 2024

Sunset Date: April 4, 2024

Author(s): Olivia Robinson and Ahmad Aldouri

Coding Handbook for HyCReD Data Entry

Purpose:

This document will help maintenance and operation personnel of hydrogen fueling stations understand and execute inputting fueling station component failures including hydrogen leaks into the HyCReD database to continue the work of hydrogen fueling station component reliability. Reliability of hydrogen fueling stations needs to be understood to help hydrogen technologies be implemented and play a role in a decarbonized future.

Definitions:

- **HyCReD:** Hydrogen Component Reliability Database.
- **HITRF:** Hydrogen Infrastructure Testing Research Facility.
- **Failure mode:** Manner or way in which a failure occurs (IEC 60050-192:2015, 192-03-17).
  - **Include list of failure modes from West (2021).**
- **Failure mechanism:** Physical processes through which damage occurs, which can be rapidly (abruptly) or slowly (cumulatively) (IEC 60050-192:2015, 192-03-17).
  - **Include table of leading failure mechanisms and their descriptions (pg.** 17-18 of Modarres and Groth (2023)).
- **Failure cause/Failure root cause:** Set of circumstances that lead to failure and can originate during specification, design, manufacture, installation, operation, or maintenance of an item (IEC 60050-192:2015, 192-03-11).
- **Failure severity:** The degree of functional degradation of hardware usually noted through deficient performance; categorized by "catastrophic," "degraded"" and "incipient" (IEEE Standard 500-1984).
  - **Catastrophic:** Failure that is both sudden and causes termination of one or more fundamental functions

- If you are not already on the email list, please contact HyCReD@nrel.gov to be added to email list for when handbook becomes available.

Results: System event data fields for 5 incidents

Event Number	Facility Identification	Facility Type	Service/Usage	Facility Nominal Working Pressure (bar)	H2 Phases on Site
10006	HITRF	Research-limited access	Both heavy- and light-duty	700	Gas
10022	White Plains, NY	Pre-commercial, limited-access	Light-duty	700	Unknown
10031	DS, Netherlands	Commercial, public	Heavy-duty	Unknown	Gas
10035	Aichi Prefecture, Japan	Commercial, public	Light-duty	700	Both
10036	United Kingdom	Unknown	Unknown	700	Gas

- Using existing databases, we were able to **extract and code system information into** the proposed database **structure**.
- HITRF incident was obtained through discussions, which shows information can be obtained readily.

Results: Equipment hierarchy data for 5 incidents

Event Number	Equipment Description	Subsystem	Functional Group	Component	Component NWP (bar)	Component MAWP (bar)	Component Population	Install. Date	P&ID Part No.
10006	Medium-pressure manual isolation ball valve (normally open) on a high-pressure, light-duty H2 dispenser	Dispensing Process	Sensing and control	Manual valve	700	1378	5	Jan-19	HV-120A*
10022	Pressure switch	Cooling Process	Sensing and control	Pressure sensor	700	Unknown	-	-	-
10031	Hydrogen storage tank	Bulk Storage	Containment	Type IV tank	Unknown	Unknown	-	-	-
10035	Relief valve (back pressure valve) on a liquid hydrogen storage tank	Bulk Storage	Containment	Pressure relief device	700	Unknown	-	-	-
10036	Hydrogen fuel dispenser	Dispensing Process	Dispensing	Pressure relief device	700	Unknown	2	-	-

- **Using mostly narrative descriptions, we were able to extract and code failed component information into the proposed HyCReD structure.**

Results: Failure event data fields for 5 dispensing-related incidents

Event Number	Date & Time of Event	Failure Mode	Failure Mechanism	Failure Root Cause Description	Failure Severity	H2 release ?	H2 release size	Accumulation?	Detection ?	Detect-ion notes	Ignition?
10006	12/20/2021; 11:45	External leak hydrogen	Mechanical failure	Appears to be O-ring extrusion/failure (sent to NREL for LRQA testing)	Incipient	Yes	Small (1-2 kg)	No	Yes	Audible	No
10022	8/21/2008	External leak hydrogen	Leakage	Hydrogen was released from a failed weld on a pressure switch causing the initial fire. This cascaded down to 3 stainless steel line failures, release of glycol coolant, and release/combustion of compressor oil. Non-metallic seals and hoses containing hydraulic fluid and coolant melted/burned and caused leakage of the fluid, which was mostly consumed by the fire. The compressor skid was consumed by the fire and was a total loss. Other equipment were also moderately damaged.	Critical	Yes	Unknown	Unknown	No	-	Yes
10031	07/21/2023; 2:39 PM	External leak hydrogen	-	-	Incipient	Yes	Unknown	No	Yes	Audible	No
10035	7/9/2021	Spurious operation	Leakage or Control failure	The pressure relief valve operated and ignited a fire at the outlet of the discharge pipe during an automatic discharge of hydrogen gas.	Incipient	Yes	Unknown	No	Yes	Visible	Yes
10036	7/19/2013	External leak hydrogen	Leakage	The event description only mentioned that the dispenser was shut down and fueling operations switched to the second dispenser. There is not enough detail on the mechanism and root cause of this event.	Incipient	Yes	Unknown	No	Yes	Pressure drop	No

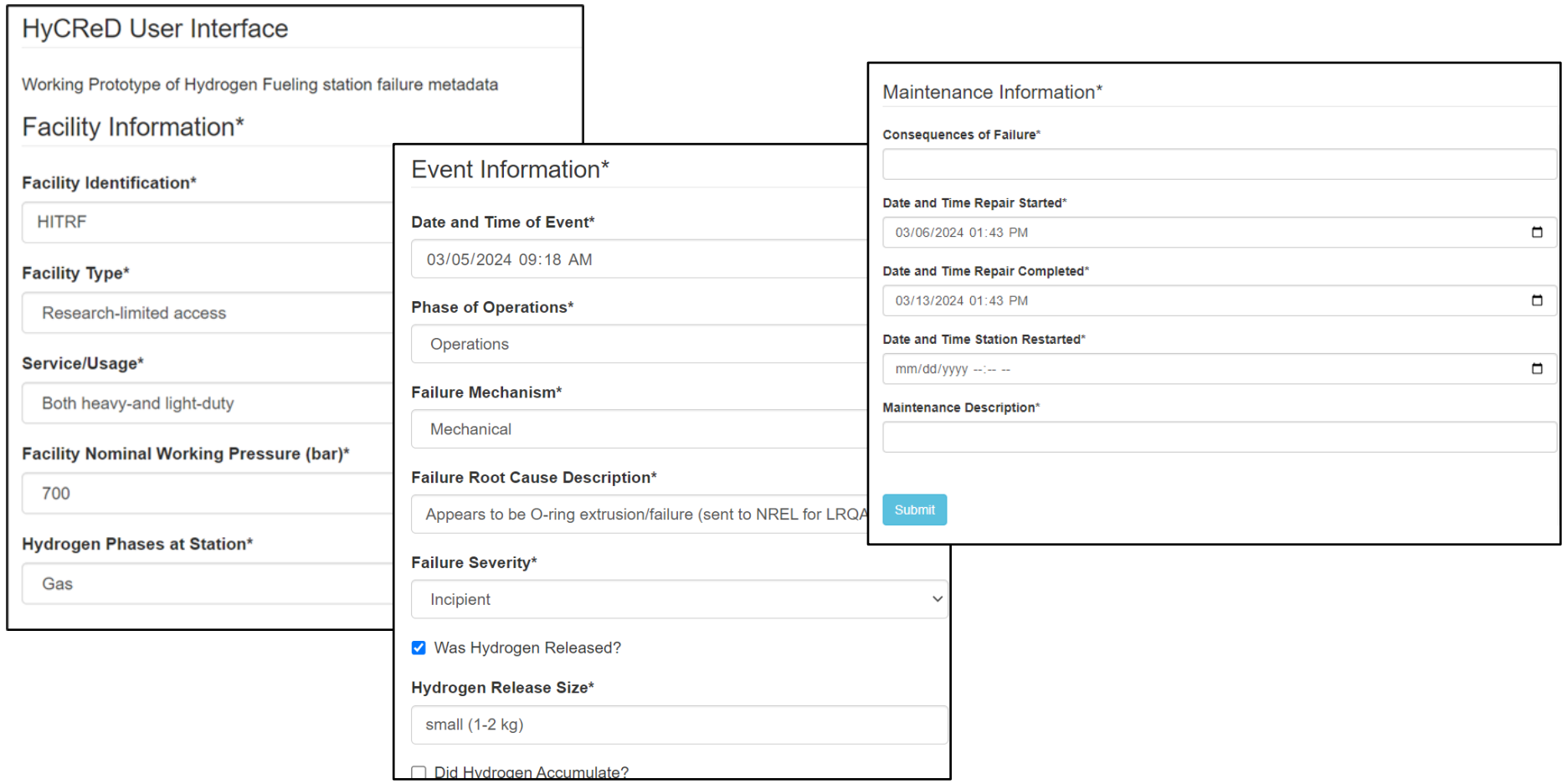
- **Failure event data** was mostly **deduced from narrative** descriptions.
- Availability of **HyCReD** as a reporting structure **would enhance data quality**, leading to more accurate failure rate estimates.

HyCReD fields: Maintenance event data for 5 dispensing incidents

Event Number	Date & Time Repair Started	Date & Time Repair Completed	Date & Time Station Restarted	Maintenance Description
10006	-	-	-	-
10022	-	-	-	The fire department responded and shut off the power supply to the station as well as water spray the surrounding equipment which caught on fire. **The compressor skid had to be replaced as it was a total loss. The pressure switch component was replaced with a better design.** Additional lessons considered by the team include shutoff valve location and/or redundant shutoff valves at storage vessels to prevent escalation.
10031	-	-	-	-
10035	-	-	-	Immediately after the event, the site safety supervisor closed the relief valve and confirmed the fire was extinguished. Later, maintenance personnel installed additional fire extinguishing equipment.
10036	25/07/2013	25/07/2013	-	The leaking valve caused Dispenser A to be down until a replacement was ordered. The replacement valve was scheduled to be installed on 25/07/2013. The station continued operating as normal using Dispenser B.

- **Maintenance event data is sparse**, with only narrative descriptions being available.
- Repair start, end, and station restart times are vital to determining ***duration*** **and** ***economic impact*** **of station downtime**.

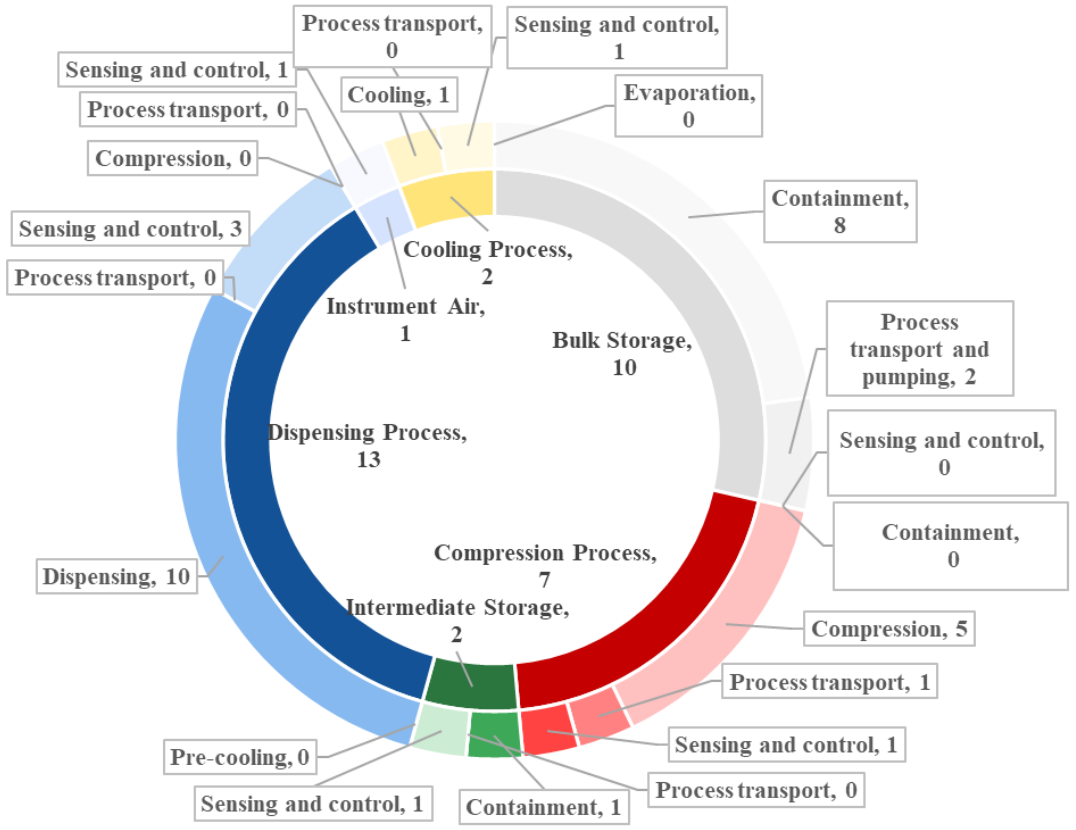
Future User Interface Input Screen



- Easy to use with formatted cells and dependent drop downs for indicating the failed component.
- Remember past inputs for facility information to remove duplicate work and a potential for QR codes on parts of the station to allow for quick failed component identification.

Breakdown of initial results

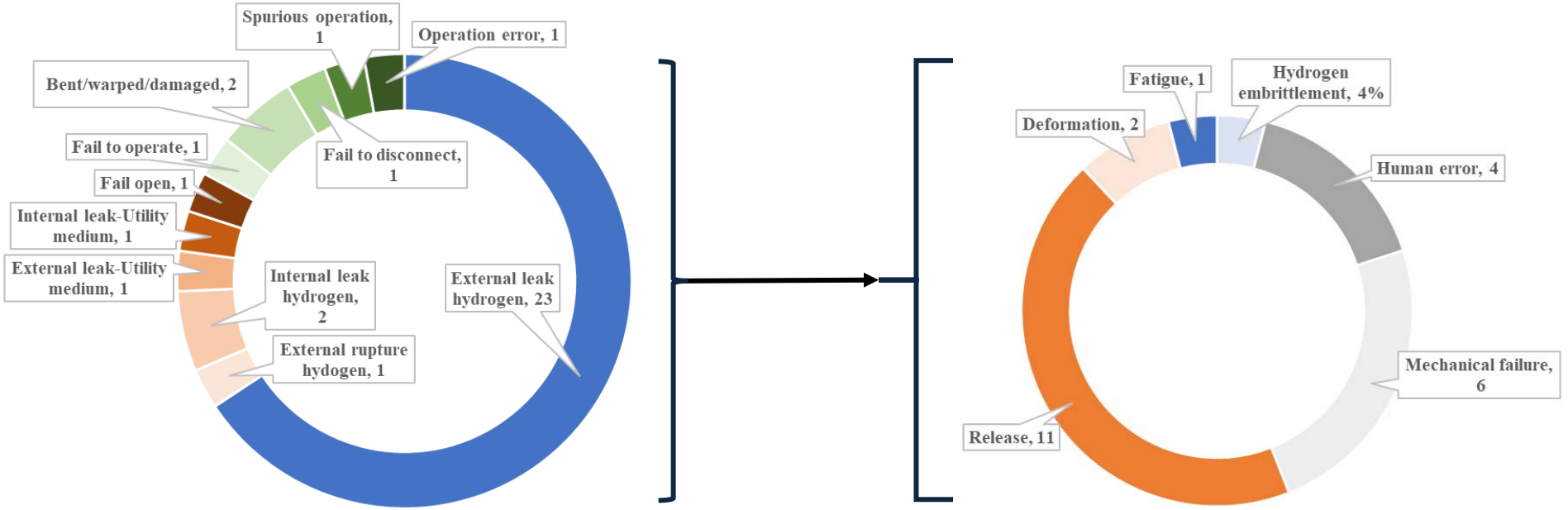
Based on 35 incidents as of March 2024. We expect ~10 more to be in by June 2024.



- Initial results identify *dispensing process* subsystem as the source of most failures in a hydrogen fueling station.
- The dispensing functional group is the leading contributor to dispensing process failures.

Breakdown of initial results

Based on 35 incidents as of March 2024. We expect ~10 more to be in by June 2024.



Breakdown of current HyCReD events by failure mode

Breakdown of "external leak-hydrogen" events by failure mechanism

- Based on initial results, *external leak of hydrogen* is the dominant failure mode observed. For this mode, release and mechanical failure are primary failure mechanisms.
- These results indicate the **importance of leak prevention and mechanical integrity** in hydrogen fueling stations.

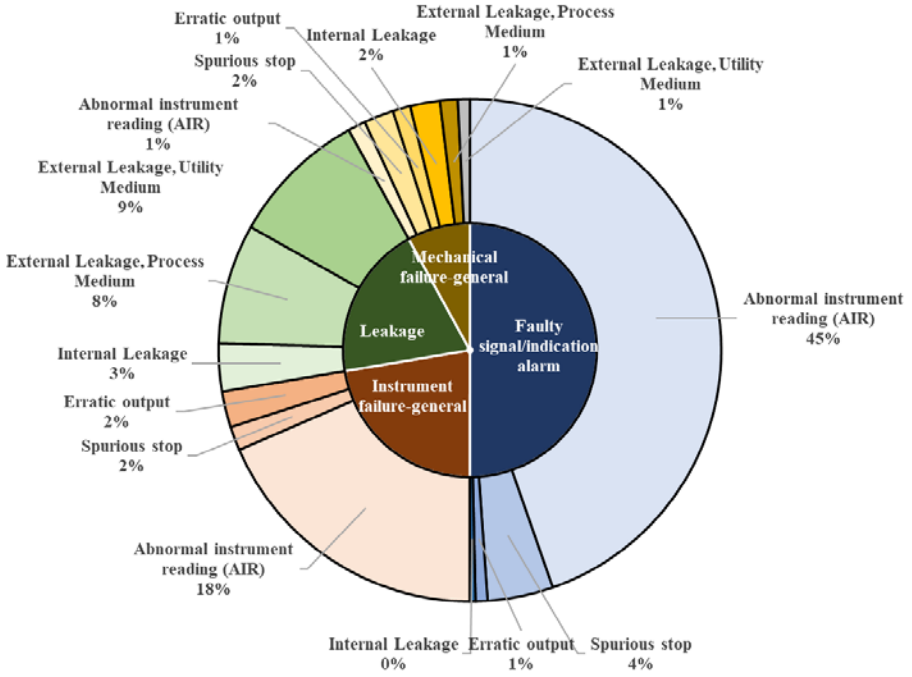
Result we anticipate creating: Example of a component reliability data chart

Population	Installations	Aggregated time in service (10^6 hours)		
17	8	Calendar time		Operational time
		0.7057		0.6296
Failure mode	**No. of failures**	**Failure rate (per 10^6 hours)**		
		Mean	**Std. Dev.**	**# of failures/service time**
Critical	128	220.34	273.35	181.39
	128	306.39	395.68	203.3
Degraded	149	242.6	216.05	211.15
	149	315.83	300.78	236.65
Incipient	132	132.29	309.17	187.06
	132	152.71	324.45	209.65
Unknown	2	2.78	2.93	2.83
	2	3.22	3.77	3.18
All modes	411	604.72	543.73	582.42
	411	777.05	742.96	652.78

- **Calculated failure rates per failure mode and severity class.**
- **Enables identification of components with highest failure frequencies and most impactful consequences (downtime).**

Result we anticipate creating: Failure modes and mechanisms

- Relative contribution of each failure mechanism to total failure rate.
- Percentage of occurrence of each combination of failure mechanism a



- Information can be **vital in reliability-centered maintenance (RCM)** analysis.
- Useful in **identifying candidate components for** scheduled **replacement** and/or **maintenance**.

Welcome to the joint NREL-UMD Technical Seminar

Increasing Reliability and Safety of Hydrogen Components - Reliability Data Collection

March 13, 2024

Today's Agenda

EDT (MDT)	Day 1 (Monday Dec 11, 2023)	
Start Time	Topic	Presenter
11:00 AM (9:00 AM)	Introduction	William Buttner, NREL Christine Watson, DOE/HFTO
11:05 AM	What is the hydrogen component reliability database (HyCReD)?	Genevieve Saur, NREL
11:20 AM	Analysis to support reliability and safety at hydrogen refueling stations	Katrina Groth, University of Maryland
11:35 AM	Using the database and evolution	Ahmad Al-Douri, University of Maryland Olivia Robinson, NREL
11:50 AM	Ways to collaborate; support the project, support the industry	Genevieve Saur, NREL
11:55 AM	Open Discussion: - Feasibility of implementation - Industry needs - Feedback	All
12:15 PM	End (Presenters available for continued discussion)	

Call to Action: How to engage with HyCReD

- ❑ 3-way NDAs with NREL, UMD, <company> for data sharing
  - ✓ Initial standardized version developed, can be modified
- ❑ Develop CRADA language that allows industry support of analysis and feature build-out
  - ✓ Requirement is that developed features/analysis can be used across data sets

- ✓ **Current status of partnerships**
  - ✓ 2 NDAs executed
  - ✓ 4 NDAs in progress

Email Genevieve Saur
hycred@nrel.gov

Thanks to the team (and many others for auxiliary support)
(NREL) William Buttner, Kevin Hartmann, Olivia Robinson, Genevieve Saur
(UMD) Katrina Groth, Ahmad Al-Douri

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Thank You

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