Hydrogen Innovation Initiative

Photonics-Based Hydrogen Sensing: Demonstrator Development and Industry Validation

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About the Hydrogen Innovation Initiative

The Hydrogen Innovation Initiative (HII) brings together UK industry, government, and academia to create an investible, globally competitive hydrogen technology and services sector. Our vision is for UK technology to power the global hydrogen economy, while transforming UK industry into a net zero powerhouse.

Set up with support from Innovate UK and the Industrial Advisory Board, the HII mission is to help build robust and resilient hydrogen technology supply chains. By accelerating the development of critical technologies and supply chains for the fast-growing hydrogen economy, we will support UK industry to anchor high-value jobs, boost resilience and drive decarbonisation.

HII's partners include the Catapult Network, the Advanced Propulsion Centre, the Aerospace Technology Institute, the Net Zero Technology Centre and the National Physical Laboratory.

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HII partners

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Introduction

Hydrogen is widely recognised as a critical enabler of net zero targets across sectors including energy, transport, aerospace, and industrial manufacturing. However, the safe and reliable deployment of hydrogen at scale depends on robust sensing and monitoring infrastructure that is capable of detecting hydrogen leaks accurately across diverse operational environments, including electrolysis production facilities and high-pressure storage systems, distribution pipelines, and on-board vehicle and aircraft applications.

Conventional hydrogen-sensing technologies – including catalytic bead, electrochemical cell, thermal conductivity, and metal oxide semiconductor sensors – each carry inherent operational constraints that limit their suitability in safety-critical or extreme environments. In particular, oxygen dependency, electrolyte degradation, susceptibility to cross-contamination, and the requirement for electrical power at the sensing point present persistent challenges in hazardous area classifications such as ATEX Zone 0. Photonics-based hydrogen sensing, based on the interaction of hydrogen with palladium-coated optical fibres, offers a promising alternative by enabling passive, intrinsically safe detection with no electrical energy required at the sensing tip.

This report documents the work undertaken by Digital Catapult in collaboration with the Photonics & Nanotechnology group at King's College London (KCL), to build a digital stack for a photonics-based hydrogen detection demonstrator and validate the concept with industry experts.

The project was structured around two principal workstreams:

- Research and market analysis, including use case selection and validation through structured engagement with hydrogen industry experts
- Technology selection, system design, hardware procurement, demonstrator build, testing, and laboratory validation

Project objectives

The objectives of the project were to:

- Conduct a structured analysis of existing hydrogen-sensing technologies and their deployment across the hydrogen value chain (production, storage, distribution and transportation)
- Engage with hydrogen industry operators to validate market findings, identify priority use cases, and define a value proposition for photonics-based hydrogen sensing
- Design and build a photonics-based hydrogen detection demonstrator, integrating hardware and a full software stack for real-time data acquisition, processing, and visualisation

The outcomes of this project contribute directly to HII's broader mission of enabling UK industry to lead in hydrogen technology development, and provide a foundation for future innovation, commercialisation, and supply chain development in photonics-based hydrogen sensing.

This project was funded by Innovate UK as part of the Hydrogen Innovation Initiative.

Research and market analysis

The first workstream was focused on researching and analysing sensing requirements across the hydrogen value chain in order to and developing recommendations for the demonstrator project. Through engagement with hydrogen industry experts from **Steamology** and **ZeroAvia**, we identified specific opportunities where the sensor could improve hydrogen processes, together with priority use cases. These interactions helped define clear value propositions and competitive advantage over current sensing solutions for each use-case.

Hydrogen properties

Our market analysis began with an examination of the properties of hydrogen that influence installation and detection principles.

Properties of hydrogen-influencing detection methodologies		
Property	**Hydrogen**	**Inputs for sensor installation and detection methodologies**
Density	0.0898 kg/m^3 (lower than air density of 1.204 kg/m^3)	Travels along the underside of the ceiling or roof and accumulates in apex points, ridges, and high dead zones
Explosive limit	4.0%-75% volume in air	Wide range explosive limit Standard industry practice sets warning alarm limit to 0.4% volume of hydrogen
Diffusivity (molecular weight)	2.016 g/mol (lower than air diffusivity of 29 g/mol)	High diffusivity; escapes through microscopic defects
Atomic radius	53pm	Diffuses into interstitial spaces within crystal lattices of metals such as palladium (Pd)

Figure 1: Typical hydrogen leak detection sensor installation in storage tanks.
Source: ***Fuel Cell Works***

Market analysis: existing sensor solutions

Working principles, installation practices, advantages and limitations

We conducted market analysis through a structured review of five main hydrogen sensing principles, including evaluation of a commercially deployed sensor for each one. This study assessed deployment suitability across the hydrogen value chain and identified the key operational challenges associated with each sensing technology. Our findings formed the basis for targeted industry engagement, enabling us to validate the challenges identified against real-world operational experience, and infer the potential market need and use case for photonics-based hydrogen detection sensors.

Catalytic bead sensors

The active bead is resistively heated to approximately 500–550°C. When hydrogen contacts the catalytic surface, exothermic combustion occurs at temperatures well below the hydrogen auto ignition point. The localised heat release increases the active bead's resistance relative to the reference bead, generating an imbalance voltage that is proportional to gas concentration. Output is expressed as percentage of lower explosive level (%LEL).

Commercially deployed sensor evaluated: ***Honeywell CMP200-D***

Electrochemical sensors

Hydrogen diffuses through a polytetrafluoroethylene (PTFE) membrane to a platinum (Pt) or palladium (Pd) electrode, where it is oxidised. The resulting current at the working electrode, measured against a counter electrode across a liquid or polymer solid electrolyte, is proportional to hydrogen partial pressure. Output ranges from sub-ppm to approx. 2–4% volume, depending on membrane diffusion characteristics and cell design.

Commercially deployed sensor evaluated: ***Honeywell 4HYT CiTiceL***

Thermal conductivity sensors

A sensing element (Pt filament, thermistor) is maintained at a constant temperature or at a constant current. Heat dissipation to the surrounding gas varies with the gas's thermal conductivity.

A Wheatstone bridge compares the sensing element to an identical reference element in a sealed reference gas chamber (typically air or nitrogen). The bridge imbalance voltage is proportional to the thermal conductivity difference, which correlates to the concentration of hydrogen.

Commercially deployed sensor evaluated: ***XENSIV™ TCI H2 gas sensor***

Metal oxide semiconductor sensors

A thin film or sintered bead of n-type metal oxide (most commonly tin dioxide) is heated to 300–400°C. At this temperature, oxygen adsorbs on the surface, creating a depletion layer of high resistance.

When hydrogen (or any reducing gas) is present, it reacts with the adsorbed oxygen, releasing electrons back to the conduction band and dramatically reducing resistance. The resistance change is logarithmically related to hydrogen concentration.

Commercially deployed sensor evaluated: ***Figaro TGS2616-C00***

Palladium-based optical fibre sensors

Hydrogen dissolves into the Pd crystal lattice to form palladium hydride, which changes the material's optical reflectivity and refractive index.

The shift is measured via fibre-optic interferometry or surface plasmon resonance (SPR). The sensor does not require a power supply, which means it can be used in explosion-safe environments.

Commercially deployed sensor evaluated: ***Technica T910/FBG Hydrogen Detection Sensor***

Typical sensor installations in the hydrogen value chain				
Sensor technology	**Production**	**Storage**	**Distribution**	**Transport**
Catalytic bead	Electrolyser rooms, compressor stations, small module reactors	Cylinder bays, buffer vessel rooms where oxygen is present	Pipeline stations, hydrogen refuelling station (HRS) dispenser cabinets	Vehicle engine bays
Electrochemical cell	Area monitoring in production facilities (ppm monitoring)	Battery rooms/ enclosures Sealed vessel spaces	HRS forecourts, dispenser cabinets	Fuel cell electric vehicle (FCEV) cabins, bus underfloor, fuel cell stack inlet
Thermal conductivity	Process stream analysis at electrolyser outlet	Oxygen deficient storage vaults	Remote compressor stations; long service interval	Enclosed tube trailer cargo holds
Metal oxide semiconductor	General area surveillance monitoring for hydrogen	Perimeter monitoring at storage yards; low precision	Pipeline nodes	Maritime engine rooms; compact and low cost
Optical fibre	Zone 0 electrolyser internals	Vessel wall permeation monitoring*	Distributed pipeline monitoring through fibre runs*	Onboard tank structural health and permeation sensing*

**Low commercial maturity*

Summary of key advantanges and constraints by sensor type			
Sensor technology	**Key advantages**	**Key constraints**	**Impact on deployment**
Catalytic bead	Linear output across 0–100% LEL Proven sensors with ATEX Zone 1 and Zone 2 certification	Oxygen dependency and catalytic poisoning	Complete sensor failure in oxygen-depleted environment
Electrochemical cell	No external bias voltage required, very low standby power consumption Suitable for battery-powered portable instruments and integrated vehicle safety systems	Electrolyte degradation; limited to 1–3 years life; cross-sensitivity in mixed gas streams	High replacement frequency
Thermal conductivity	Operates entirely independently of oxygen concentration No consumables, leading to longer lifetime (over 5 years)	Poor selectivity in mixed gas environments	False readings in mixed gas environments
Metal oxide Semiconductor	Low cost compared to other technologies, so widely used for high-density deployment use cases	Responds to all reducing gases, output sensitive to ambient temperature and humidity variation	Elevated false alarm rate; unreliable quantitative measurement
Optical fibre	Sensing element power supply at the measurement point	Limited commercial deployment, performance degradation in high humidity conditions	Technology readiness constraint for safety-critical deployment

Engagement with UK industries

Once market research was complete, we conducted targeted industry engagement to validate our findings against real-world experience of implementation, to support the definition of application-specific requirements for a photonics-based hydrogen detection sensor. This engagement took the form of structured interviews with two companies, Steamology and ZeroAvia, based on a guiding framework of questions (detailed in Appendix 1).

- Our engagement with Steamology centred on the comparative assessment of photonics-based sensor performance against an MOS-based sensing technology.
- Our engagement with ZeroAvia focused on the identification and characterisation of deployment use cases for photonics-based hydrogen sensing in the aerospace sector.

We used insights derived from these structured interviews to inform the development of a market-fit framework for photonics-based hydrogen detection sensors, identifying use cases for commercial deployment.

Learnings from engagement with Steamology

Steamology develops zero-emission steam engine technology utilising hydrogen storage and combustion systems, operating within the production and utilisation segments of the hydrogen value chain. Their team was able to provide insights into sensor installation constraints, performance requirements, and safety considerations within the context of propulsion systems.

Steamology currently deploys the **MQ-8** metal oxide semiconductor (MOS) sensor for onboard hydrogen detection, installing it in equipment cabinets near ventilation points where hydrogen and steam may escape.

Operational parameter insights, Steamology sensor deployment	
Parameter	**MQ-8 sensor-based solution**
Detection threshold	1% vol. of hydrogen (4% vol of hydrogen is LEL)
Response time	<1 second
Sensor life	12–18 months Low cost (approx £20-25) means replacement is not a major challenge
Hazardous area zone	Zone 1 or Zone 2 (Zone 0 is not a current requirement)
Operating environment	High humidity (steam)
Power availability	Not a constraint/non-critical (supplementary instrumentation, including transducers and thermocouples, is already powered within the same installation)
Digital stack	Arduino-based data acquisition

The next table shows the operational requirements for hydrogen sensing in the propulsion industry, together with the capability differentiators and technical parameters that require validation before deployment of a photonics-based hydrogen sensor.

Hydrogen sensor operational requirements, propulsion industry		
Parameter	**Current operational requirements/ scenarios**	**Implications for photonics-based hydrogen sensor development**
Ambient temperature	Operating environment may exceed 90°C	To be tested and confirmed
Detection trigger point	1% volume of hydrogen	Currently >0.4%
Response time	Must be formally quantified and demonstrated	To be tested for warm-up/stabilisation time
Sensor life	Currently replaced every 12–18 months; longer life strongly preferred	Extended operational lifetime is a differentiator
Humidity performance	High-humidity environment with steam co-present	Currently 0-98% ambient humidity
Sensor redundancy	Minimum three sensors per installation; system must remain operational with at least one sensor active	Redundancy architecture with hardware, signal, and voting logic could be designed into the system
Hazardous area	Zone 1/Zone 2 as minimum	Competitive advantage, as passive sensing element enables Zone 0 deployment Passive sensing element in Zone 0/Zone 1 with light source and electronics in a less hazardous zone confirmed as a compelling distributed architecture use case

We identified the following testing and validation requirements for demonstrating technical readiness and performance compliance against defined operational specifications, prior to commercial deployment of the photonics-based hydrogen sensor:

- The system must actively demonstrate that the light source is operational
- Warm-up time must be characterised and formally specified, like the preheat period of the MOS sensor

We also identified potential commercial deployment strategies and use cases for the photonics-based hydrogen sensor:

- Distributed sensor architecture
- Body-worn hydrogen detection
- Multi-redundancy voting architecture, using two-out-of-three (2oo3) configuration with hardware, signal, and logic-level redundancy layers, aligned with safety integrity level (SIL) and other safety system requirements

Learnings from engagement with ZeroAvia

ZeroAvia develops hydrogen-electric propulsion and fuel cell powertrain systems for commercial aerospace applications. Engagement with ZeroAvia helped us to identify validation use cases and certification requirements governing hydrogen sensor adoption in aerospace applications.

Interview insights from ZeroAvia sensor deployment	
Technology particulars	**Differentiators**
Contamination resistance of photonics-based sensor	The non-contact nature of the photonics-based sensor, with no catalytic surface or liquid electrolyte, was identified as a significant differentiator for commercial deployment in aviation industry
Humidity performance	Sensor must operate stably across a range of humidity conditions; the fact that the photonics-based sensor is not susceptible to contamination in humid conditions was identified as a positive differentiator
Certification requirements	**Implication for photonics-based hydrogen sensor**
Civil Aviation Authority (CAA) regulatory and certification framework	Aviation-specific safety regulations governing hydrogen use at airports and during refuelling operations define the certification baseline; compliance with CAA requirements must be established in addition to standard ATEX (Atmospheres EXplosibles) certification for airborne and airport installations respectively
Hangar environment classification	Airport hangars are classified as industrial hazardous environments for sensor certification purposes: standard industrial ATEX certification is applicable to hangar-based installations, while airborne installations require aerospace-grade qualification to additional standards
Testing/validation Use cases	**Implication for photonics-based hydrogen sensor**
Operating temperature range	Sensor must perform reliably across a wide ambient temperature range, including low-temperature high-altitude conditions. -55°C to 150°C inferred from sensor requirements in aerospace industry (Source: **Honeywell**).
Dynamic environmental cycling	Combined and simultaneous fluctuation of temperature, humidity and pressure during ascent, cruise, and descent cycles represents the critical real-world test condition
Testing under pressure variation	Testing under varying pressure conditions was identified as a key validation lesson: pressure fluctuation affects gas diffusion rates and optical path characteristics and must be incorporated as an independent variable in the validation test programme
Safety demonstration and sensor health monitoring	For flight-safety-critical applications, active demonstration that the light source is functioning is as important as the detection measurement itself

We identified the following potential commercial deployment strategy and use cases for the photonics-based sensor:

- Sensor deployment for on-board hydrogen storage.
  "The ability to continuously and demonstrably prove that onboard hydrogen storage is safe is a firm operational requirement" (source: ZeroAvia interview)
- Multi-sensor voting architecture (aligned to SIL and other safety system requirements) is applicable for aviation industry as for other industries

Summary of industry engagement findings

Major wins	Sensor design considerations	Test cases
Extended life Humidity range 0-98% RH Electrically passive sensing is Zone 0- capable	Light source health monitoring Multi-redundancy architecture	Warm-up/stabilisation time must be characterised Temperature range -55°C to +150 °C Dynamic environmental cycling Pressure variation testing

Photonics-based hydrogen sensor deployment requirements

Multi-redundancy voting architectures

A multi-redundancy voting architecture deploys three independent sensor channels, each with its own dedicated power supply, to monitor the same measurement point.

A 2oo3 voting logic unit compares all channel outputs in real-time, triggering an alarm only when at least two of the three sensors agree, eliminating single-sensor false alarms. The architecture maintains system integrity even upon failure of one channel, in compliance with IEC 61508 Safety Instrumented System (SIS) requirements for safety-critical hydrogen detection, as shown in Figure 2.

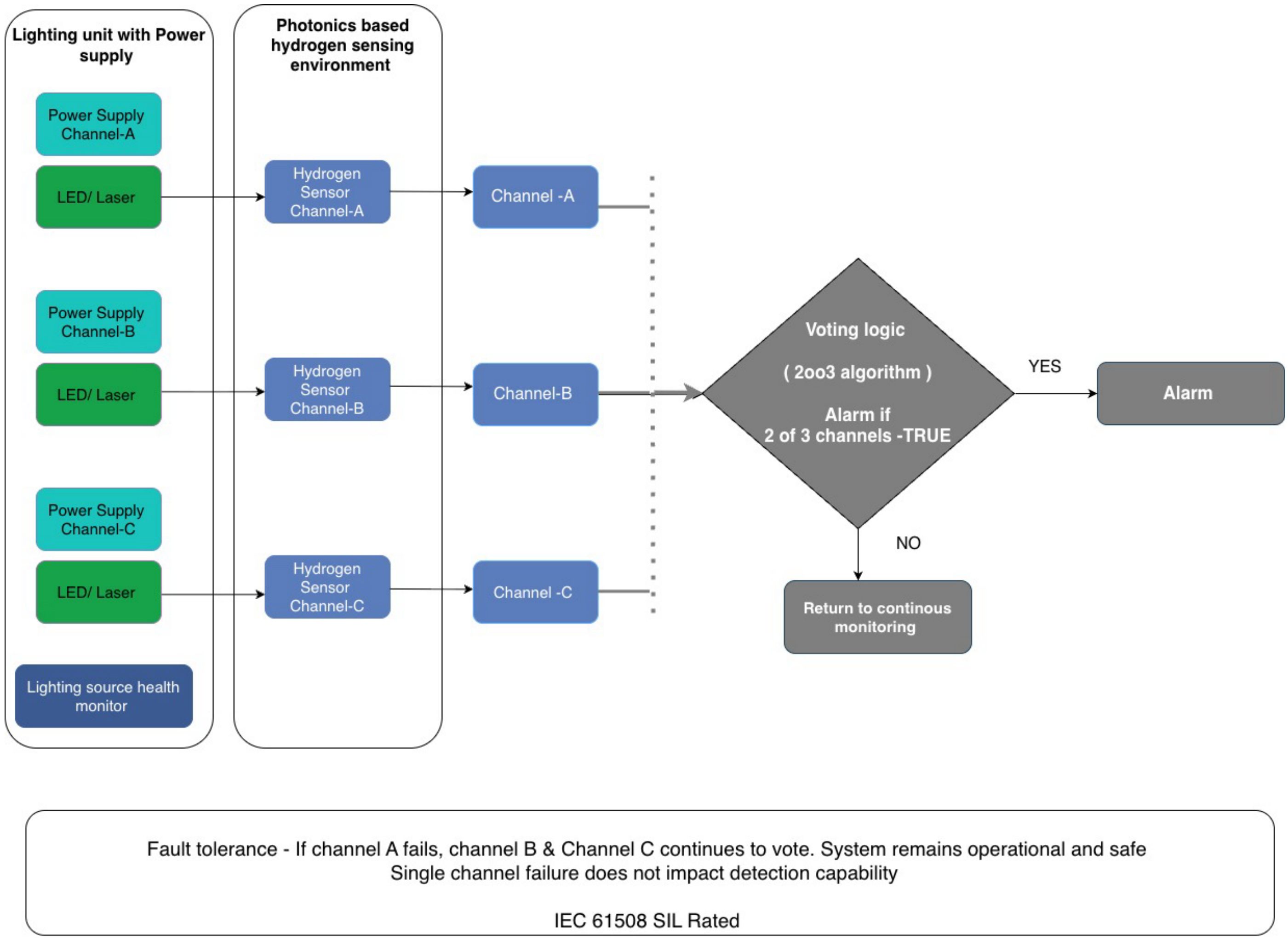

Figure 2: Conventional sensor, SIL architecture.

Unlike conventional sensors, photonics-based hydrogen sensors introduce an additional failure mode, the failure of the light source or of the photodiode. A failed LED or photodiode produces a zero output that is indistinguishable from a functioning sensor operating in a hydrogen-free environment, rendering the channel inactive without triggering an alarm. This has direct implications for functional safety compliance, as undetected failures constitute dangerous hidden faults under IEC 61508 SIL-related requirements.

The photonics-based hydrogen sensor architecture should be organised into two distinct zones: one with the lightning unit with the power supply, and the photonics-based sensing environment. Three independent channels should be deployed, each served by a dedicated power supply and LED or laser light source located outside the sensing environment. The three channel outputs converge at a 2oo3 voting logic unit, which raises an alarm only when at least two of the three channels detect hydrogen.

A dedicated lighting source health monitor should be incorporated within the lighting unit to continuously verify that each LED/laser source is active. The resulting architecture diagram for the 2oo3 voting logic implementation for the photonics-based hydrogen sensor is shown in Figure 3.

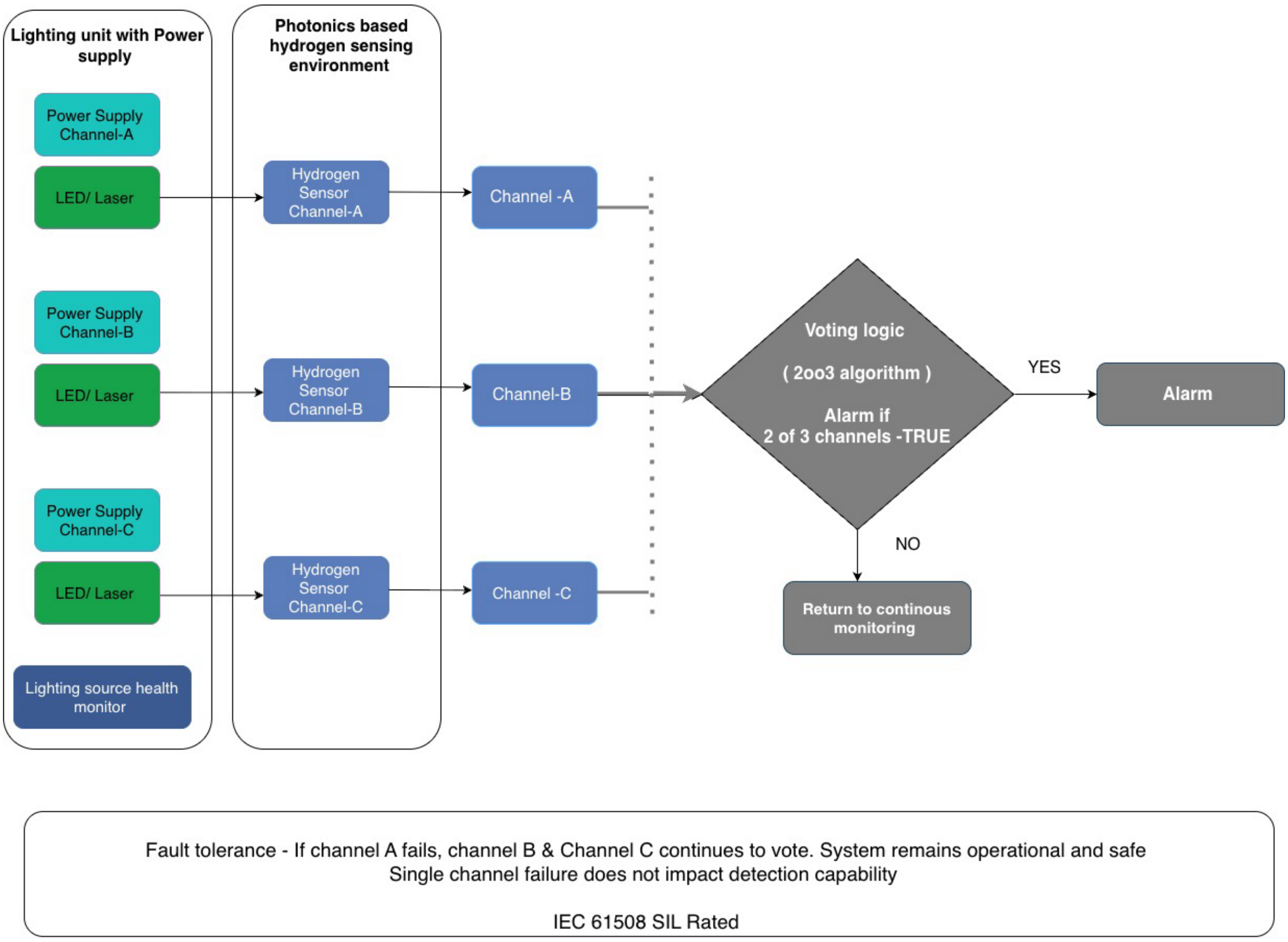

Figure 3: Photonics-based hydrogen sensor sensor, SIL-compliant architecture.

Body-worn hydrogen detectors

Body-worn hydrogen detectors are a growing area in the hydrogen industry. To assess the viability of the photonics-based hydrogen sensing for body-worn personal safety applications, specification analysis was carried out using the Honeywell RAE Systems **ToxiRAE Pro H_2 sensor** as a commercially deployed reference, representing the current state-of-the-art in personal hydrogen detection.

Technical parameters requiring validation are identified as prerequisite for commercial deployment (such as optical unit miniaturisation and warm-up time characterisation).

Body-worn hydrogen sensor findings		
Technical parameter	**ToxiRAE Pro H_2**	**Implication for photonics hydrogen sensor**
Sensing technology	Electrochemical cell (3-electrode)	Photonics-based passive sensor
Detection range	0-1,000 ppm H_2	>0.4 Vol. of hydrogen
Resolution	1 ppm	10% accuracy
Response time	<90 seconds	In seconds (to be quantified)
Warm-up / stabilisation	<60 seconds (EC cell typical)	To be validated
Operating temperature	−20°C to +50°C	To be validated
Humidity range	0-95% RH, non-condensing	0-98% RH
Contamination resistance	Low: electrolyte evaporation; cross-sensitivity to other reducing gases	High, no catalytic surface; no electrolyte
Form factor	Single clip-on unit	Design aspect: light source and photodiode miniaturisation required
Battery/runtime	>30 hours in non-wireless mode	Design aspect: depends on light source and photodiode
Power at sensing point	Electrical power required, not Zone 0 rated standalone	No electrical energy at sensing tip
Sensor life	1 year (consumable electrochemical cell, annual replacement required)	More than 5 years, to be quantified by use case
Data logging	Up to 3 months with one-minute data interval	Design aspect for building digital stack
Wireless connectivity	IEEE 802.15.4 sub-1 GHz ISM, real-time remote alarm	Design aspect for building digital stack

Hydrogen sensing demonstrator build

The second project workstream was dedicated to building the demonstrator. Hardware selection was guided by the technical requirements and practical considerations of real-world deployments, and components for both collocated and distributed configurations were selected and specified in collaboration with members of the Photonics & Nanotechnology group in the Department of Physics at King's College London (KCL). The defined technical specifications for all system components were used as a reference for procurement, build, and validation activities.

Following system design and technical specification, Digital Catapult procured hardware components for the demonstrator supporting equipment for laboratory validation.

Construction took place at Digital Catapult's Digital Futures Laboratory, where a data acquisition, storage and data visualisation stack was created to support the real-time monitoring of hydrogen and light sensors, and the recording of sensing data for subsequent visualisation and analysis. We also developed control interfaces to enable the light sensor calibration.

The demonstrator's functionalities and interfaces were tested under controlled laboratory conditions at Digital Catapult and validated using hydrogen injection systems in the Photonics & Nanotechnology group laboratories at KCL's Department of Physics.

Demonstrator scope

The scope of this demonstrator was threefold.

Integration and extension

To design and build a solution that would be compatible with the existing hardware provided by KCL, while extending its original functionality.

Optimisation and portability

To design and build a solution that will:

- Minimise the footprint of the original KCL demonstrator
- Enable the integration of additional environmental sensors such as temperature and humidity
- Be compact and portable enough to be transported to events and showcases

Full-stack implementation

To design and implement a software stack which will be able to:

- Sample real-time data coming from the hardware sensors
- Transform incoming data in real time
- Store incoming data
- Replicate the calibration mechanism of sampled photodiode values that had already been built by KCL, and which was triggered by a hardware button
- Configure the sampling rate of the hardware sensors
- Analyse incoming data and detect hydrogen presence
- Present real-time sensor/hydrogen events data in a dashboard
- Present historical sensor/hydrogen events data in a dashboard

Hardware selection

The hardware selection for the hydrogen demonstrator took place in two phases, enabling transition from a modular architecture to fully-integrated, high-precision architecture.

For the first phase, the primary objective was to preserve the existing infrastructure developed by KCL while adding value in the form of a software stack. To achieve this without altering the original sensor logic and its accompanying electronics, we used a Raspberry Pi (RPi) as a host. By connecting the existing prototype to the RPi, the Arduino Uno microcontroller board (part of the original hardware) could serve as a peripheral instead of being a stand-alone controller. The system could maintain its original 10-bit sampling and analogue filtering while leveraging on the RPI's ability to run a powerful software stack.

Once the software stack was validated, the project moved into its second phase, targeting advanced sensing and a refined footprint and packaging. We replaced Arduino Uno with a high-precision 32-bit analogue-to-digital converter (ADC) as hardware attached on top (HAT). This ADC HAT provides significantly greater resolution that the Arduino UNO's original 10-bit onboard converter, and the HAT architecture markedly reduces the hardware's physical footprint. The Raspberry Pi and HAT are housed inside a specialised standing case equipped with a touchscreen, shown in Figure 5. This configuration has proved to be valuable at events, as it allows users to interact with the demonstrator without any need for external monitors or personal computers.

Figure 4: Standing case for Raspberry Pi and touch screen. (Source: thepihut.com)

Summary of hardware iterations for the demonstrator			
Feature	**Phase 1**	**Phase 2**	**Advantage**
ADC resolution	10-bit (Arduino)	32-bit (HAT)	4,000,000 x increased sensitivity
Communication	External USB cable	Direct GPIO	Reduced footprint and noise
Cooling	Passive	Active coller	Augmented reliability
User interface	External screen, mouse, keyboard	Touchscreen	Portability, ease of use

Demonstrator components

The architecture of the demonstrator evolved through two phases as illustrated in Figures 5 and 6Figure . These diagrams present the transition from a modular system that is incorporating all the original hardware from KCL, to an integrated and high-precision architecture. A breakdown of the components is presented below:

- **Arduino Uno** is now directly powered by a Raspberry Pi, through a Type A to Type B USB cable. A sketch written in C++ was implemented to enable the following mechanisms:
  - Powering one LED, one photodiode and one LCD screen
  - Continuous sampling of photodiode
  - Receiving calibration button clicks
  - Smoothing photodiode samples
  - Serial bilateral communication with Raspberry Pi over USB
  - On-the-fly photodiode sampling interval configuration over Serial
  - Pushing JSON payload with photodiode measurements over Serial
  - Calibration (establishing baseline photodiode value) when triggered by button click

- **Raspberry Pi** is physically connected to the Arduino UNO or directly to any external hardware to supply power and exchange data. It runs Raspberry Pi OS (64-bit) and allows remote management via SSH. It has the Docker virtualisation platform installed to allow the building and deployment of containerised applications.

- **High precision ADC HAT** is mounted directly on the Raspberry Pi's general-purpose input/output (GPIO) header. It features a 32-bit analogue-to-digital converter and minimises external wiring and the latency during data acquisition.

- **Portainer** serves as the Docker management tool. It exposes a web-based graphical interface that provides information about the health status of Docker and the remaining deployed containers.

- **Node-RED** is the flow-based open-source programming tool at the centre of the demonstrator's logic. In the Arduino-based architecture, it monitors the USB port for incoming messages and parses them. In a similar manner, it can transmit commands over serial to emulate a button click (calibration mechanism) or to change the sampling frequency of the photodiode. All incoming sensor data are formatted and pushed to the InfluxDB database, where they are stored.

  Meanwhile, another programming flow is assessing whether the incoming values are the results of a hydrogen leak event. If so, information about the event (such as timestamp and measurement values that triggered the detection) is calculated and also stored in the database.

Finally, Node-RED exposes a user interface (UI) that displays real-time and historical data.

- **InfluxDB** is the open-source time-series database deployed as a Docker container inside Raspberry Pi. It stores sensor measurements with their associated timestamp. Hydrogen leak events are also hosted there.

- **Grafana** is the open-source data visualisation and monitoring platform deployed as a Docker container inside Raspberry Pi. It queries the InfluxDB directly to capture historic and real-time photodiode values and hydrogen detection events.

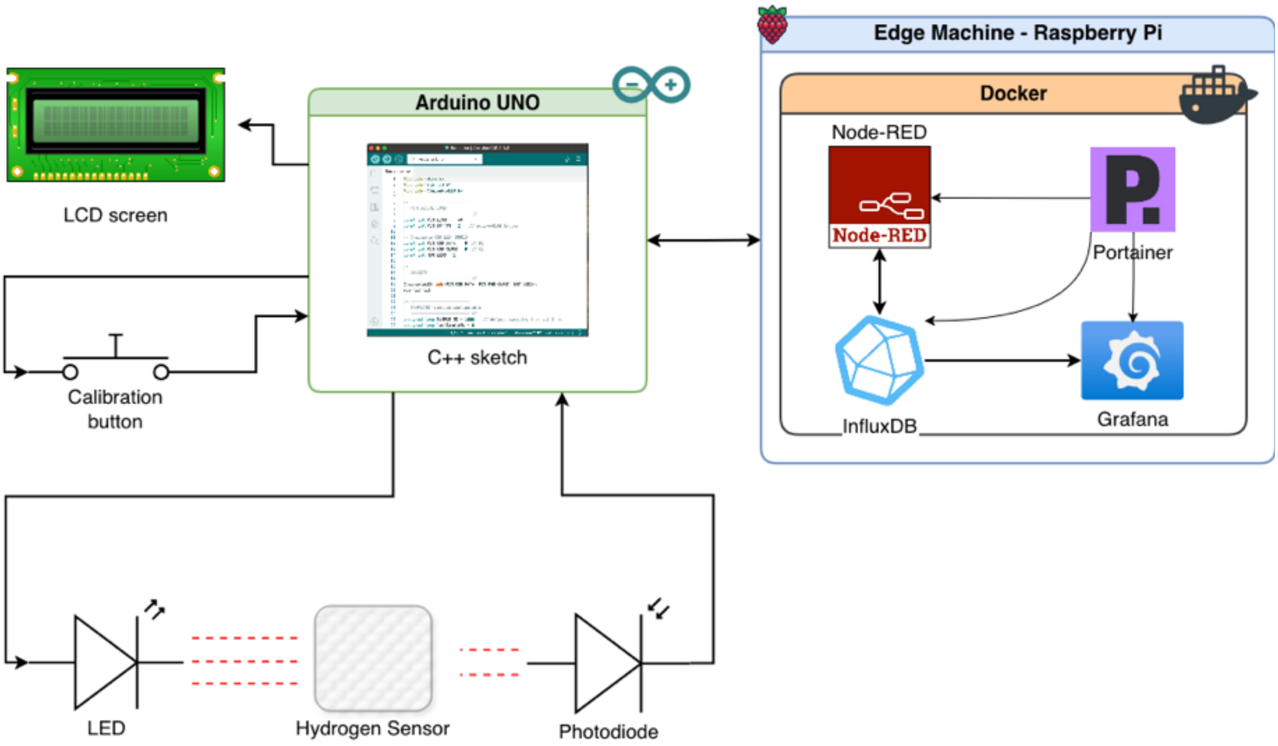

Figure 5: Architecture of the demonstrator's first phase (modular).

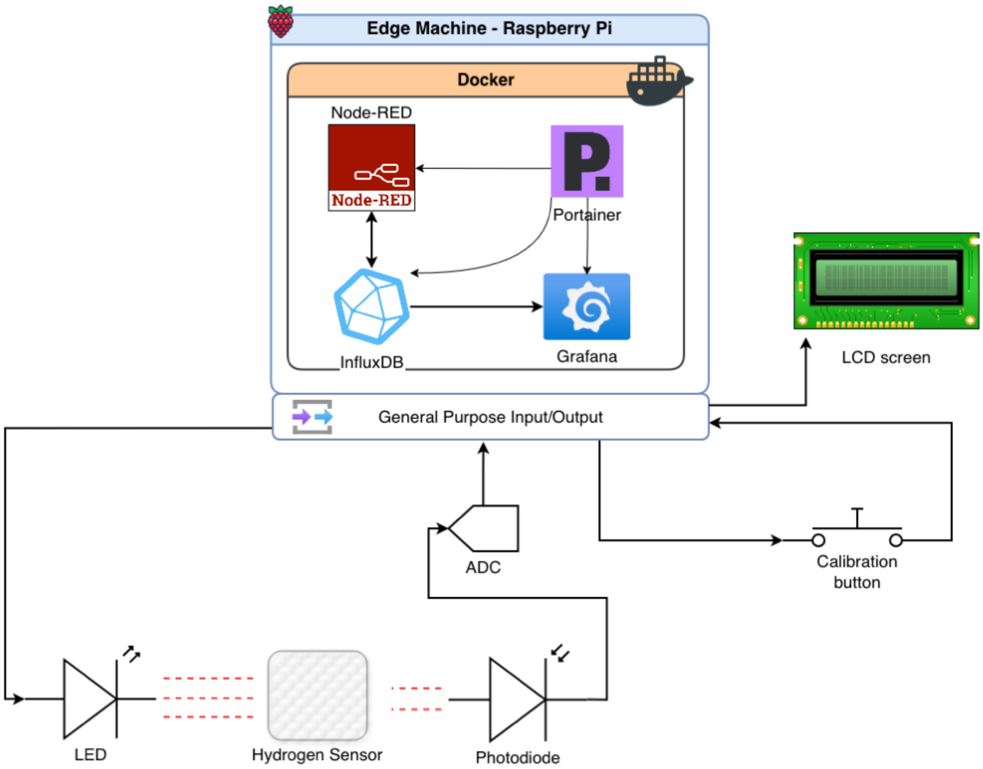

Figure 6: Architecture of the demonstrator's second phase (integrated).

Figure 7: Demonstrator dashboard.

Demonstrator dashboard

Real-time information

The demonstrator dashboard we developed using Grafana is shown in Figure 7.

- The top of the screen displays the light intensity values sampled from the photodiode, with the 'raw' gauge showing the absolute light value, and the 'calibrated' gauge showing the delta from the set baseline, after a system calibration.
- The two figures on the upper right-hand side how how many times hydrogen has been detected during that day, and also during any selected time window (this can be changed in the dashboard settings).
- The green and purple charts provide a high-resolution view of the raw and calibrated light intensity values observed during the selected time window. They provide an at-a-glance visualisation that shows whether an event was triggered by a single sharp drop or a continuous drop.
- The 'Calibrate Sensor' button triggers a Node-RED flow that sends a Serial command to the hardware to reset the light intensity baseline to the current raw light level, removing the need to use the physical button.

Hydrogen detection history

The bottom section of the dashboard shows when and how often hydrogen events have been detected.

- The 'Hydrogen Detection Events vs Time' scatter plot indicates the precise moment a hydrogen leak is detected and maps it against the timeline. This enables users to easily correlate any spikes or events with external factors, such as a specific time of day or a change in gas flow.
- The 'Daily Hydrogen Detections' bar chart acts as a week-long audit log, combining data by day and enabling users to see trends over the previous seven days. The big spike visible in Figure 7 is the result of high activity and testing.
- 'Hydrogen Detection History' provides a different representation of the detected events, showing a counter and a timestamp for events logged during the selected time window.

Conclusions and next steps

This project has successfully delivered a photonics-based hydrogen detection demonstrator and established clear evidence for the technology's potential competitive advantage over current sensing solutions. The project met its core objectives across both its workstreams, producing actionable market intelligence, validated use cases, and a fully functional, portable demonstrator with an integrated real-time data acquisition and visualisation stack.

Market analysis findings

The market analysis confirmed that no single conventional sensing technology is capable of meeting the full range of operational requirements across the hydrogen value chain without meaningful compromise. Each established technology – catalytic bead, electrochemical cell, thermal conductivity, metal oxide semiconductor, and existing fibre-optic sensors – presents specific constraints in areas such as oxygen dependency, cross-gas sensitivity, electrolyte lifespan, and hazardous area classification.

The photonics-based approach, by virtue of its passive sensing element that requires no electrical power at the measurement point, is uniquely positioned to address Zone 0 deployment requirements, while offering extended operational life and a reduced maintenance burden.

Industry engagement findings

Our work with Steamology and ZeroAvia validated our market analysis findings through real-world deployment experience, and we identified concrete priority use cases, including distributed multi-redundancy voting architectures, body-worn personal detection devices, and onboard aerospace hydrogen storage monitoring.

Both organisations highlighted the passive sensing element's compatibility with Zone 0 hazardous area classification and its resistance to contamination in high-humidity environments as compelling differentiators when compared to incumbent technologies.

Demonstrator success

The demonstrator build successfully transitioned from the modular architecture that incorporated KCL's original hardware to an integrated, high-precision system featuring a 32-bit analogue-to-digital converter HAT and a compact touchscreen-equipped enclosure, suitable for use at public events and industry showcases.

The full software stack – Node-RED, InfluxDB and Grafana – enables real-time sampling, calibration, hydrogen event detection, and both live and historical data visualisation. Laboratory validation at Digital Catapult and hydrogen injection testing at KCL confirmed the demonstrator's functional performance across its intended operational parameters.

Next steps

Although the HII demonstrator project has established strong proof-of-concept performance, through the industry engagement process we have identified several technical parameters that require further validation before the photonics-based hydrogen sensor can be considered ready for commercial deployment in safety-critical applications. These include the formal characterisation of warm-up and stabilisation time, performance verification across the full operating temperature range (including high-temperature propulsion and low-temperature aerospace conditions), and validated performance under combined environmental stresses, such as simultaneous temperature, humidity, and pressure cycling.

We have identified the following actions as priorities for advancing the technology towards commercial deployment.

Real-world environment testing

The demonstrator should be deployed and validated in operational hydrogen environments, including propulsion test facilities and hydrogen refuelling station infrastructure, in collaboration with industry partners such as Steamology and ZeroAvia. Real-world testing will generate the empirical performance data required to demonstrate technical readiness and build operator confidence ahead of commercial adoption.

ATEX certification

Progression through ATEX hazardous area certification is a prerequisite for deployment in Zone 0, Zone 1, and Zone 2 environments across the hydrogen value chain. The passive nature of the photonics-based sensing element provides a strong technical basis for Zone 0 certification (which is unachievable for electrically-powered incumbent technologies) and this represents a significant competitive differentiator that should be formally demonstrated through the certification process. Engagement with an approved certification body should be initiated in parallel with the real-world testing programme.

Development of multi-redundancy safety architecture

As defined in this project, the 2oo3 voting logic architecture incorporating a dedicated light source health monitor provides a functional safety framework aligned with IEC 61508 Safety Instrumented System requirements. Further engineering development of this architecture – including hardware, signal, and logic-level redundancy layers – will be required to support SIL-rated deployment in safety-critical applications in propulsion and aerospace sectors.

Miniaturisation for body-worn applications

The body-worn personal detection use case identified during industry engagement requires further development in order to make the optical unit small enough to be compatible with clip-on or wearable deployment. Alongside miniaturisation, warm-up time characterisation and battery life optimisation will need to be addressed to meet operational specifications for the personal protection market.

Aerospace certification pathway

Our engagement with ZeroAvia identified aviation-specific regulatory requirements under the Civil Aviation Authority framework that apply to airborne installations, in addition to standard ATEX certification. A structured aerospace qualification programme that covers the full environmental test regime – including dynamic temperature, humidity, and pressure cycling representative of ascent, cruise, and descent profiles – will be required to support deployment in commercial aviation hydrogen-electric propulsion systems.

Appendix 1: Industry interview questions

Understanding existing hydrogen-sensing applications

1. What types of hydrogen sensors are installed currently in your live environment?
2. Can you tell us about the installation / deployment of sensors in your live environments (How are they installed, any special arrangements for power, light source?)
3. Please indicate the approximate cost and operational lifespan of the hydrogen sensor.
4. What data accuracy levels are required for the application? Is the data transmitted remotely or integrated into an Operational Technology (OT) environment?
5. How is the sensor data processed? What are typical measurement intervals for this application?
6. What are the current real-time challenges associated with hydrogen-sensing applications?
7. Do you have a test environment available for validating sensor functionality? Would your organisation be willing to provide access for sensor installation and functional testing?

Understanding testbed and certification requirements

8. Do you recommend any live test environments or certification bodies relevant to this application?

Understanding potential use-cases for photonics-based hydrogen sensor

9. Do you see potential for photonics-based hydrogen sensing, and if so, what would be key advantages from your perspective?
10. If your industry were to adopt a photonics-based hydrogen sensor, for what applications would it be most suitably deployed?

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