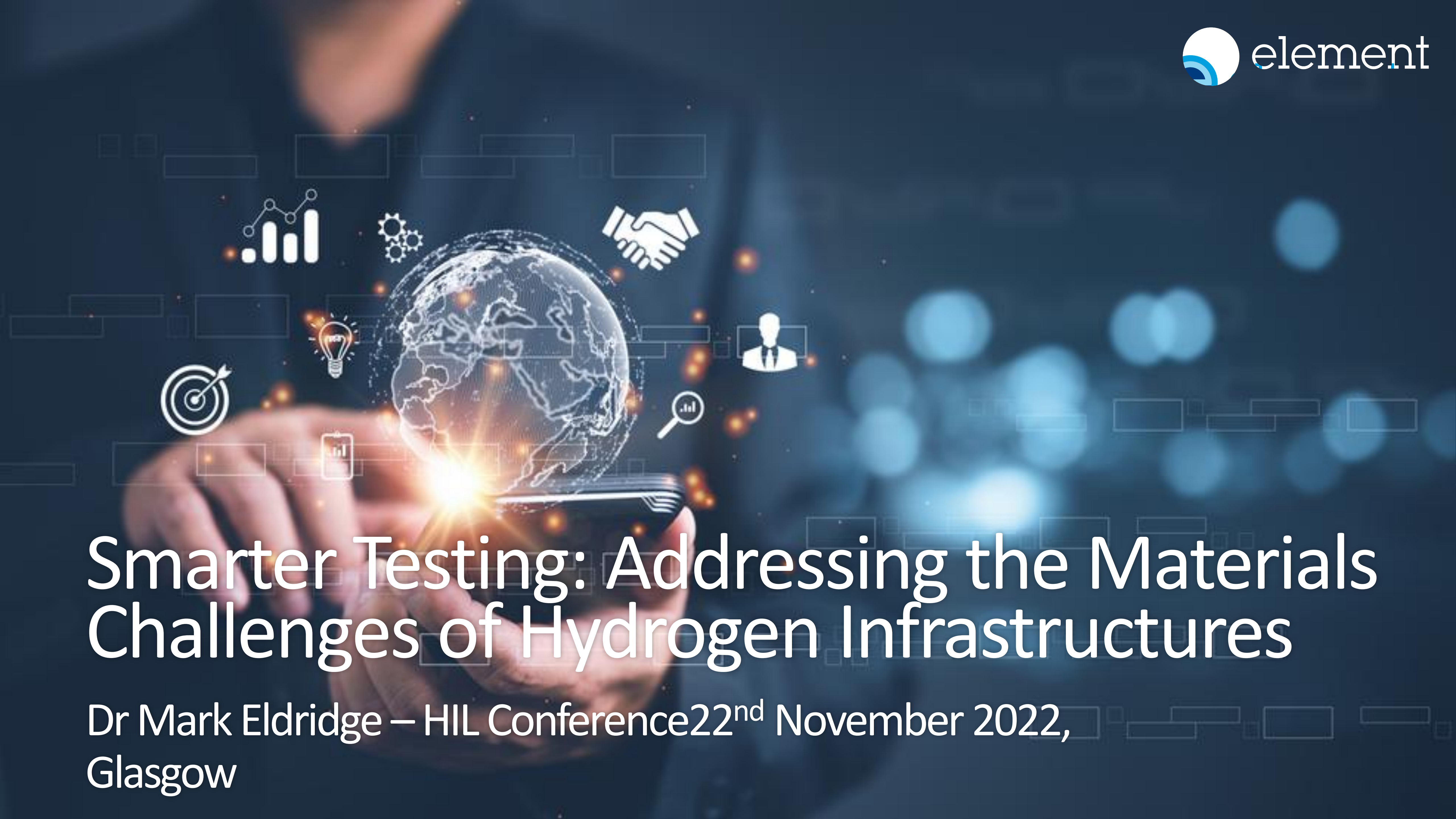

# Smarter Testing: Addressing the Materials Challenges of Hydrogen Infrastructures

Dr Mark Eldridge – HIL Conference22nd November 2022, Glasgow

# Smarter Testing

To Test:

'a procedure/measures intended to establish the quality, performance, or reliability of something, especially before it is taken into widespread use'.





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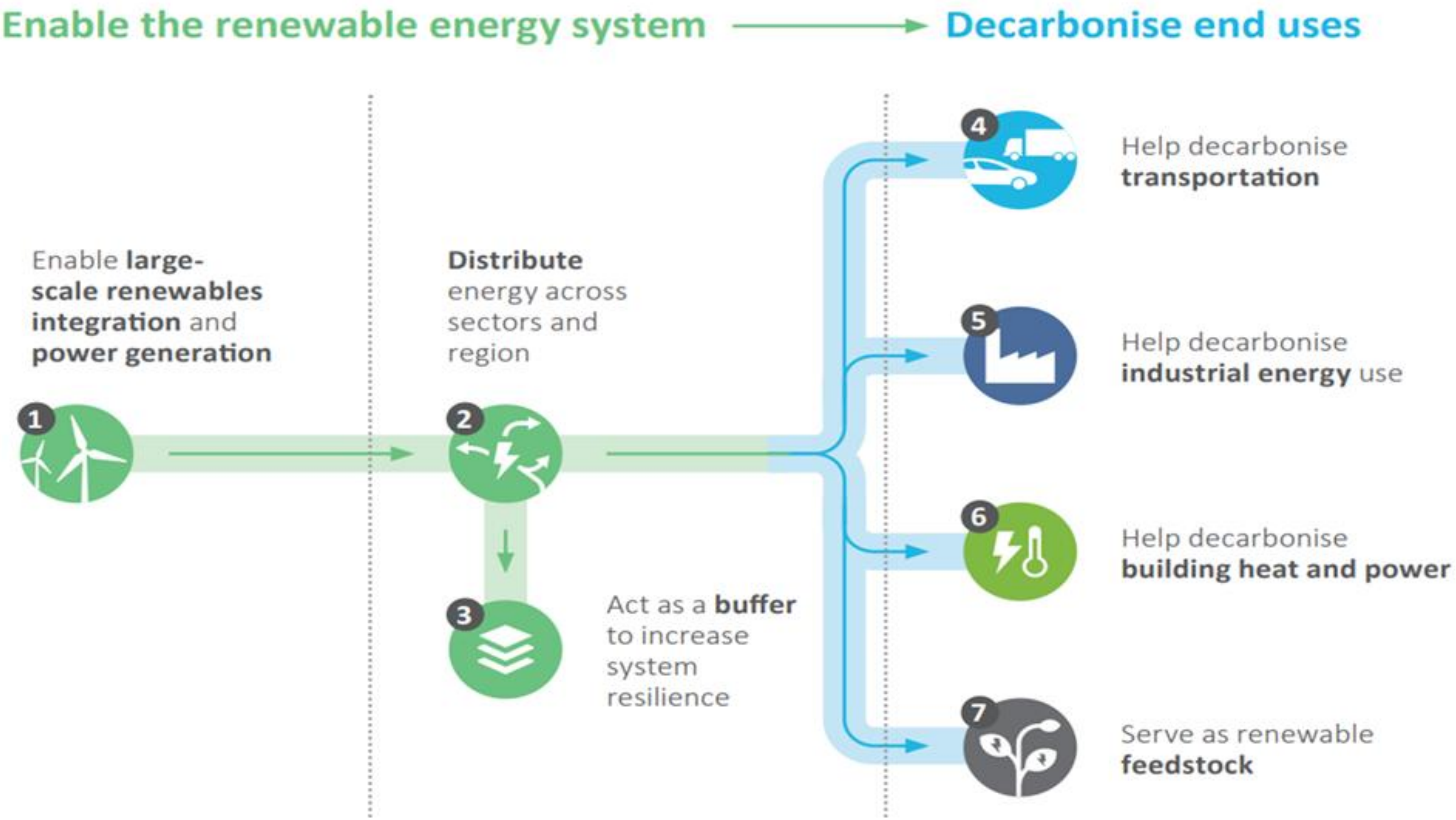
# H2 is an elegant Energy Vector




Ref: Irena

# Perspectives are Key

# H2 We need to look at the whole system

**Resources**

- Coal
- Natural Gas
- Biomass/Waste
- Nuclear
- Solar & Wind

**Production**

- Gasification
- Reforming
- Pyrolysis
- WATER Electrolysis
- Photo and Bio Catalysis
- Thermochemical Cycles

Carbon Capture Use and Storage (CCUS)

BLUE HYDROGEN

GREEN HYDROGEN

**Storage & Transport**

- Compressed Gaseous H2
- Liquid H2
- Ammonia
- Liquid Organic Carriers
- Hydrides and Solids
- Pipelines
- Road
- Rail
- Shipping

**Utilisation (End Use)**

- Chemical Feedstock
- Aerospace
- Mobility
- Energy Plants & Storage
- Combined Heat and Power

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# System, Product  Scalability, Time and Cost

- Global H2 ~ 75 million tonnes per year - demand > projected to 621 million tonnes 2050.
- 75 Million Tonnes is Grey – without little or no CCUS infrastructure.

- e.g.Paris Orly Airport - filling up 30 percent of flights H2 - 270 tons of ‘liquid’ hydrogen per

- Largest single liquefier - 32 tonnes per day (TPD), global capacity is 350 tonnes per day.

- Liquifaction – energy losses (~40%), Safety, Scale….

- Hydrogen from Electrolysis - 18 gigawatt-hours every day - one typical nuclear plant 900
- If the electricity is produced through solar power, 44 square kilometers of solar panels would be needed—a footprint representing three times the entire surface area of the airport.

- Largest hydrogen-electrolysis plants today ~20 megawatts of capacity - maximum production of just 0.5 gigawatt-hours a day—A growth factor of 50x.

Hydrogen Liquifaction (Review Article) *Energy Environ. Sci.*, 2022, **15**, 2690-2731

International Energy Agency (IEA), Energy Technology Perspectives 2020, Paris, France, 2020.

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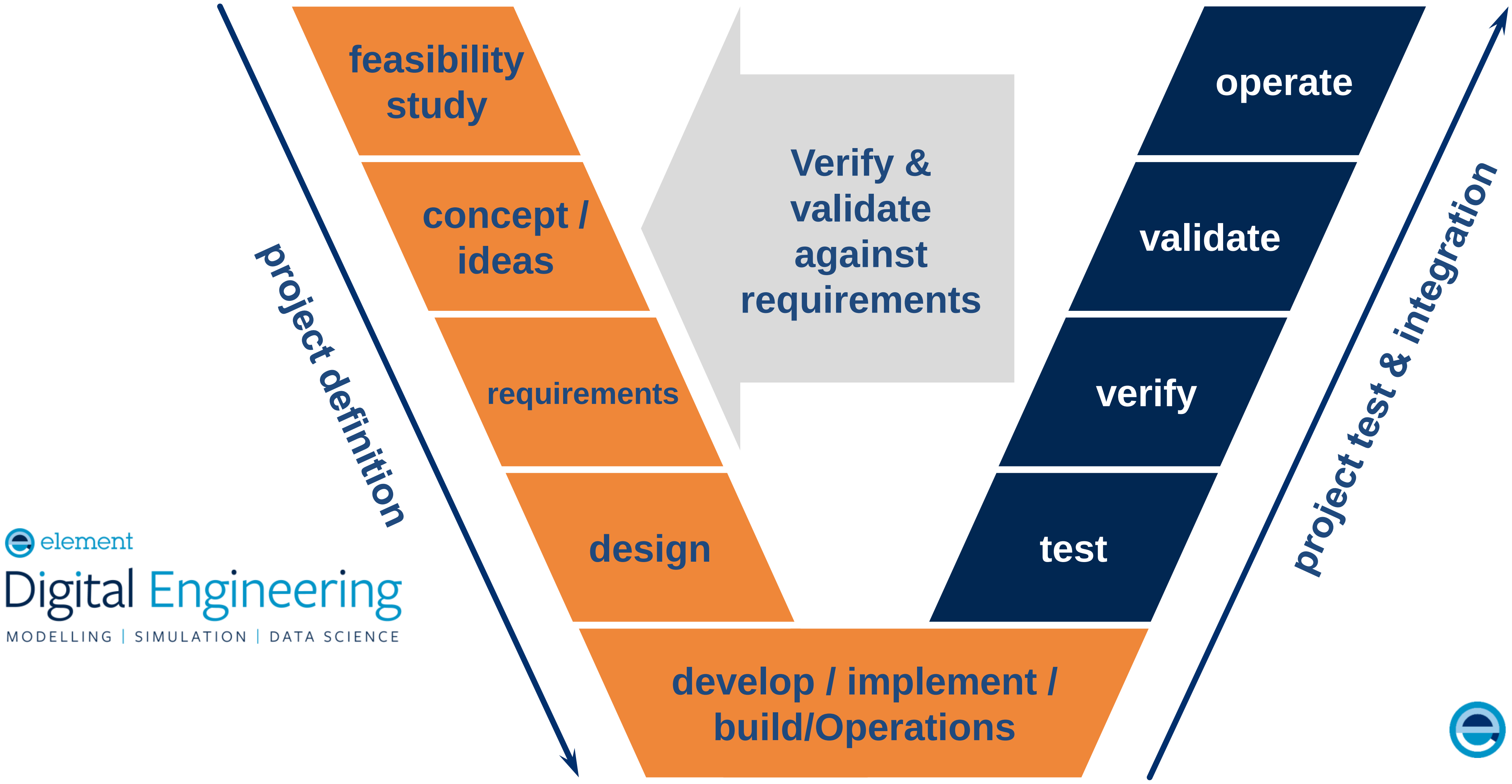
# Smarter Testing: Combination Physical Testing and Digital Engineering

## Across Full Product, (and System) Development Life Cycle

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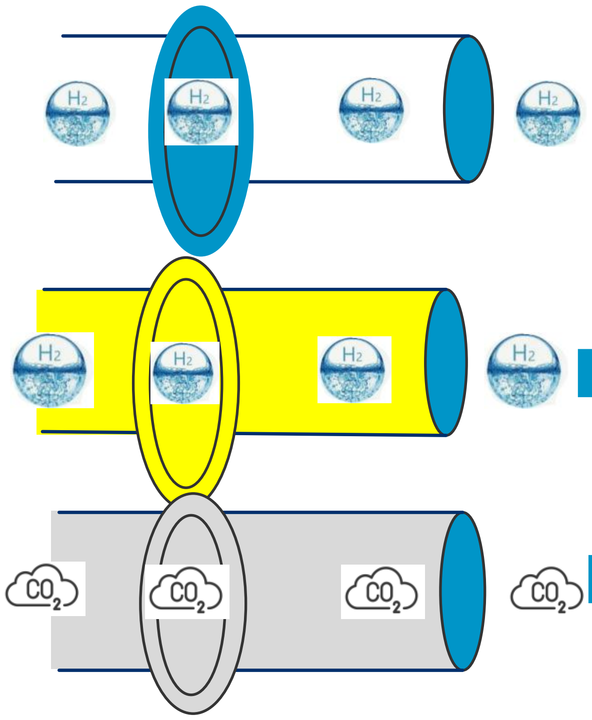
# H2 Piping – Evolving Infrastructures

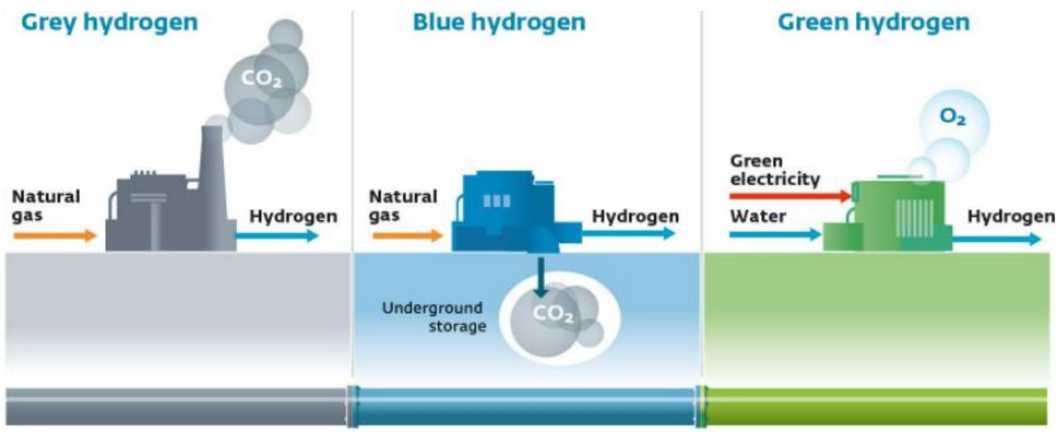



Metallic Pipe / Welds / Fittings / Jointing / Coatings / Seals

Non Metallic Polymer/composite Pipe / Joints / Fittings / Coatings / Seals / Permeation

CO2 Pipelines

- H2 Blends
- Impurities
- 100% Hydrogen
- Cryogenics

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# Physical Experience

## PRODUCTION

## TRANSPORT AND STORAGE

## UTILISATION

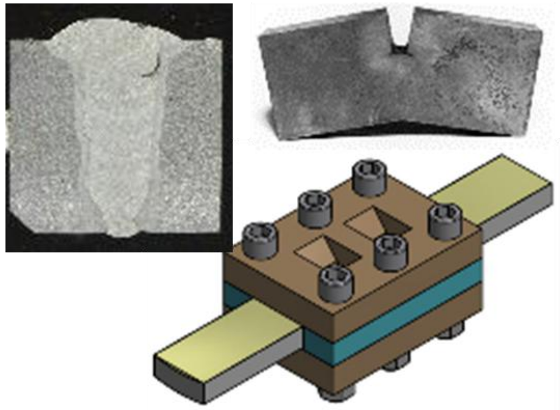
**Fracture mechanics & ECA**

**Corrosion**

**Coatings**

**Polymers/Composites**

Pipeline installation & operation, input data, ECA analysis, In-situ fracture testing, Riser fatigue testing, Reeling, AUT validation



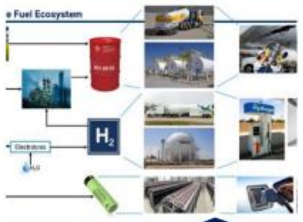
Weld & material integrity HPHT, Sweet & Sour operations, Full Ring Testing, Inhibitor Testing, Failure Analysis

FJC, Chemical resistance, CD testing, Subsea insulation, HPHT testing, CUI, Electrochemical, Inspections, Failure Analysis

Flexible pipes, Umbilicals, Elastomer seal testing, Composite ageing, HPHT: $H_2S$, $CO_2$, Hydrocarbon compatibility


Gas Turbine Technologies


Hydrogen Storage




Prod, Transport, Refueling Infrastructure

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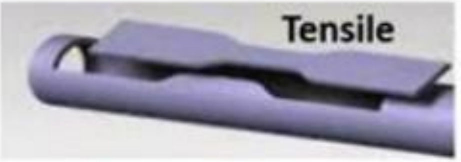
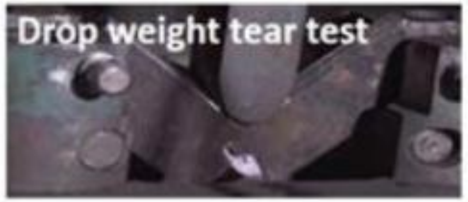
# Examples for Metallics

## Mechanical properties - Hydrogen effect







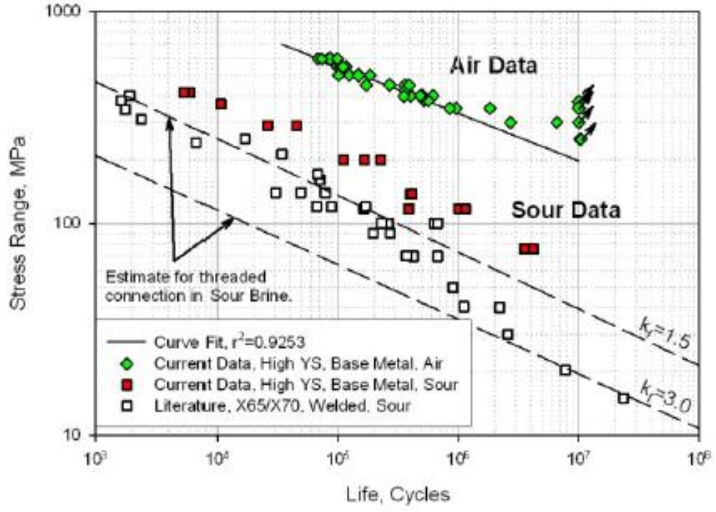


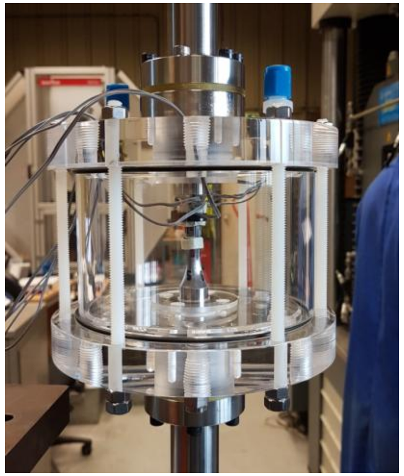
| Limited or no effect | Some effect | Significant effect | Unknown/ High strain rate |
|---|---|---|---|

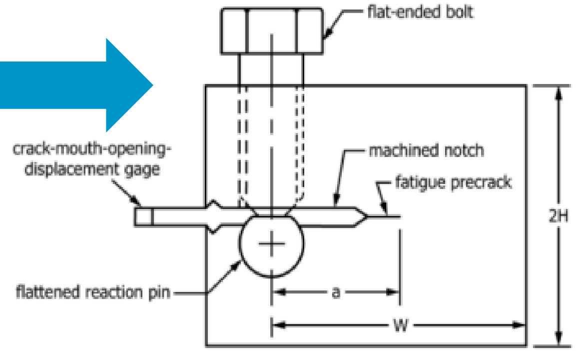
| Generic property | Pipeline Steel Parameters | Effect of Hydrogen |
|---|---|---|
| Strength | Yield (0.2% or 0.5% proof stress) | Limited effect |
| | Ultimate tensile strength (UTS) | Limited effect |
| | YS/UTS ratio (Y/T) | Limited effect |
| | Young's Modulus (E) | No effect |
| | Poisson's ratio (ν) | No effect |
| Ductility | Elongation (Total) | Significant reduction |
| | Elongation (Uniform) | Limited effect |
| Charpy impact | Charpy impact energy | Limited data found, High strain rate |
| Crack propagation resistance | Drop weight tear test (DWTT) | No data found on DWTT, but possibly limited effect due to high strain rate |
| Fracture toughness | K/J/CTOD initiation fracture toughness | Some reduction |
| | J/CTOD ductile tearing resistance | Significant reduction |
| Fatigue | Fatigue threshold stress intensity factor range (ΔKth) | slight reduction in some cases |
| | Fatigue Crack growth rate | Significant increase: many variables |
| | S-N fatigue line | Effect observed more strongly in high stress LCF region |

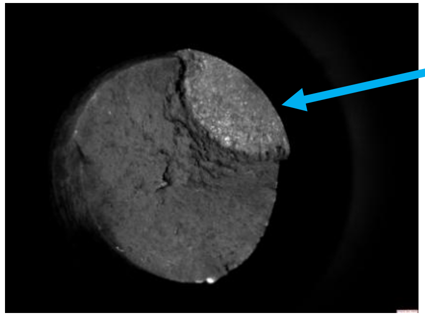
Source - UK HSE

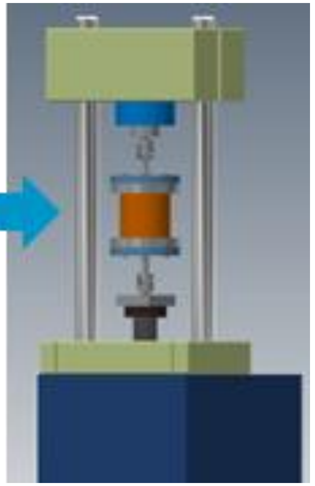
# Fatigue Endurance - in-situ

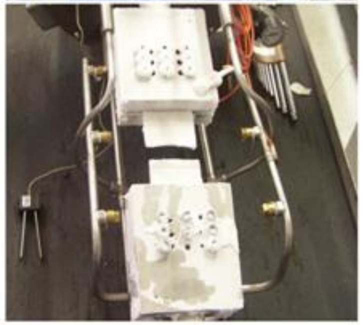




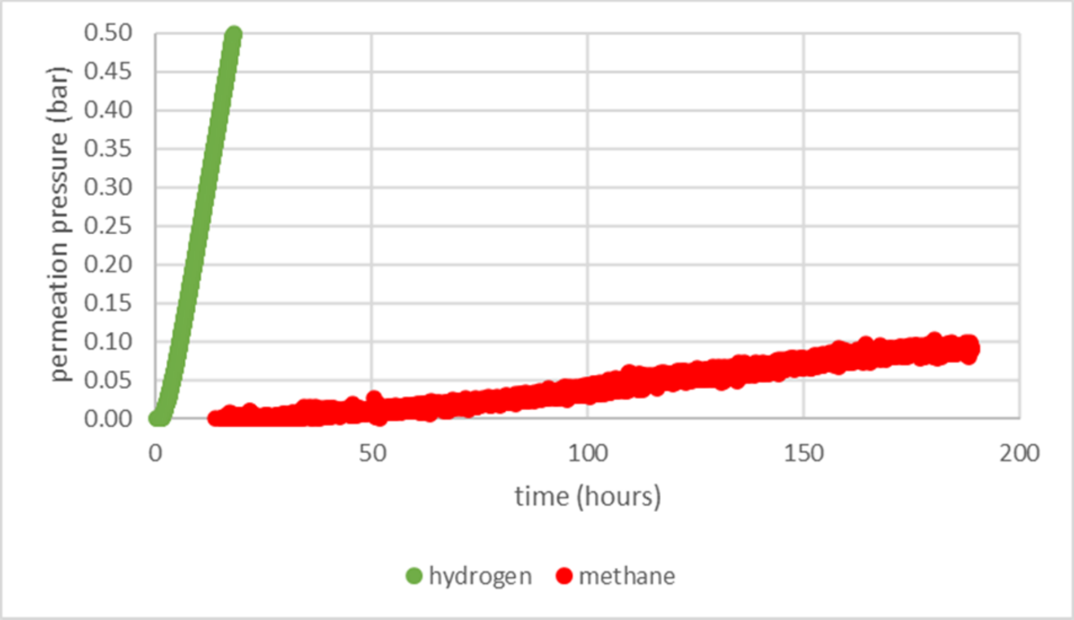


ASME B31.12 Standard on Hydrogen Piping and Pipelines contains requirements for piping in gaseous and liquid hydrogen service and pipelines in gaseous hydrogen service.

# Non-Metallic Effects of H2

## Permeation

Thermoplastic hydrogen 40 bar 40 °C:




## Rapid Gas Decompression with H2

- Carbon dioxide has for years caused RGD damage:

# THERMAL SHOCK

- High temperature soak followed by high flow low temperature fluid
  - 700 gpm liquid hydrogen
  - 500 gpm liquid nitrogen
- Low temperature soak followed by high flow high temperature fluid
  - Oxygen at 4,500 psi and 700 deg. F
  - Nitrogen at 4,500 psi and 550 deg. F
  - Nitrogen at 2,500 psi and 1,500 deg. F
  - Nitrogen at 1500 psi and 1,100 deg. F

# PROPULSION DEVELOPMENT TESTING

## (NTS/Element)

# Digital Experience

## PRODUCTION

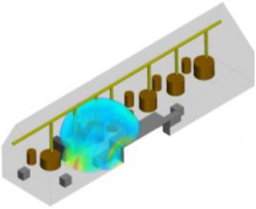
## TRANSPORT AND STORAGE

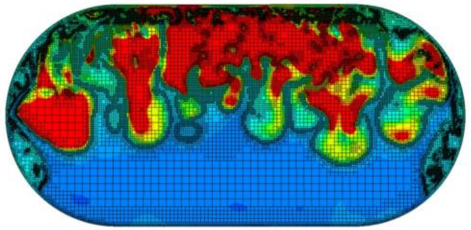
## UTILISATION

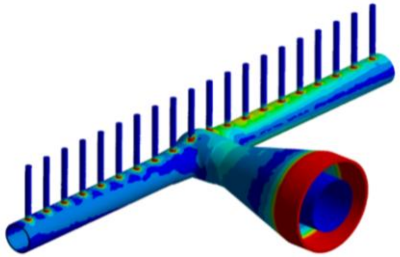
- EXPLOSION RISK AND CONSEQUENCE MODELLING OF ELECTROLYSERS
- ELECTROCHEMICAL MODELLING OF ELECTROLISER STACKS
- PLUME DISPERSION AND IGNITION RISK MODELLING

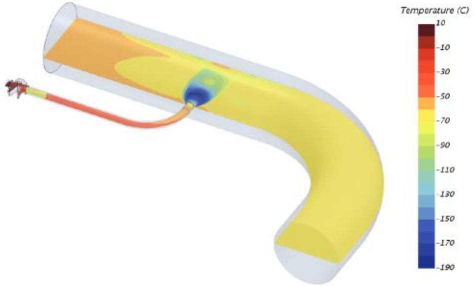
- SYSTEM-LEVEL MODELLING OF STORAGE CONTAINER RE-FUELLING OR DISCHARGE OPERATIONS
- THERMO- AND FLUID DYNAMICS OF CRYOGENIC HYDROGEN STORAGE AND TRANSPORT
- LEAKS AND EXPLOSION MODELLING OF TRANSPORT INFRASTRUCTURE
- PLUME DISPERSION AND IGNITION RISK MODELLING

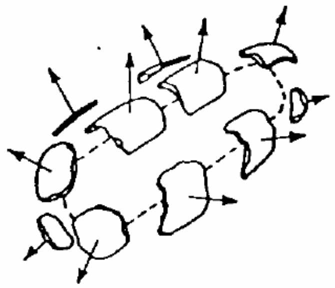
- FUEL CELL THERMAL AND FLUID DYNAMIC MODELLING AND OPTIMISATION
- FUEL CELL EXPLOSION AND CONSEQUENCE ANALYSIS

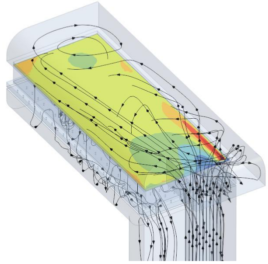






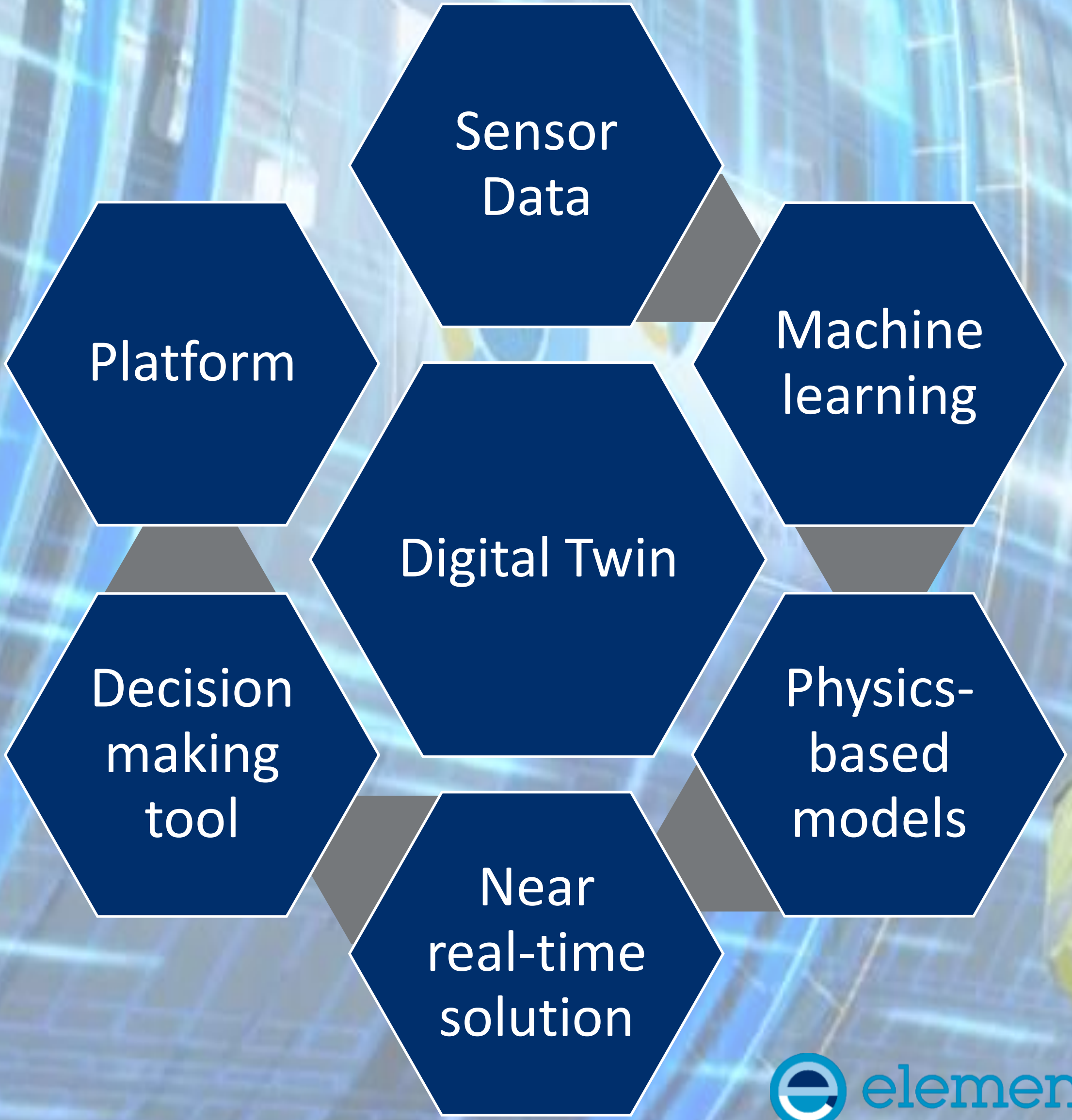




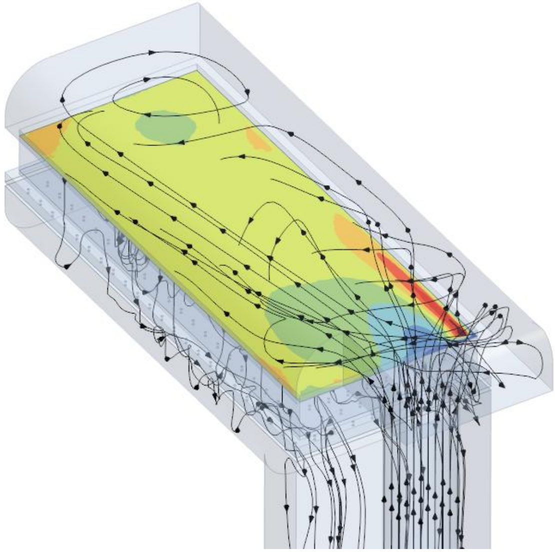
# Digital Asset Management

- Digital twin technology for real time condition assessment
- Life extension / extended time between overhaul
- Maintenance based on actual use not conservative design assessment



# Hydrogen fuel cell performance optimisation

The client received a solution which helped reduce wear of fuel cell whilst in operation saving costs of maintenance over time.

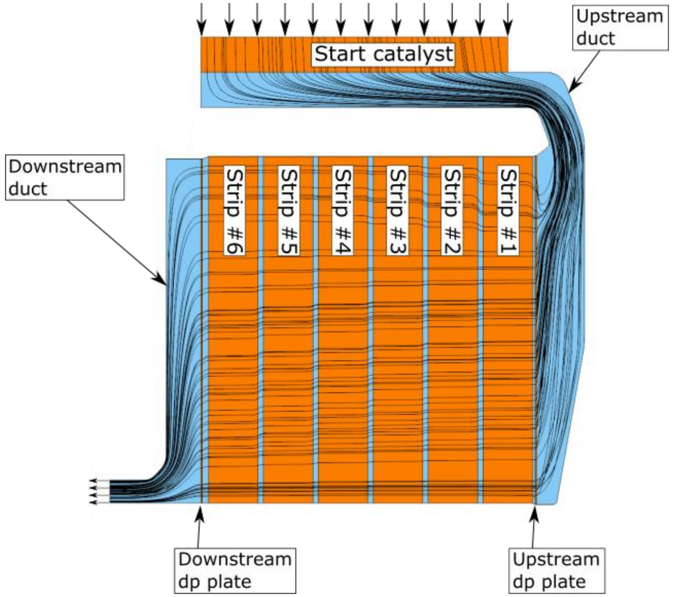


## Challenge

Norton Straw were approached by a fuel cell manufacturer to support the troubleshooting of in-service operation of their fuel cell.

## Our work

- Computational Fluid Dynamics models were built and used to predict flow distribution and characterize non-uniformity in the catalyst and the cell itself.
- The team proposed a design modification consisting of porous strips used to improve flow uniformity within the fuel cell.



# Hydrogen Bus Fuel Tank Integrity

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Digital Engineering


## Challenge

Our customer designs fuel storage systems for hydrogen vehicles, which must reach a very high standard of integrity. They asked for our support in using analysis to demonstrate the strength of their design.

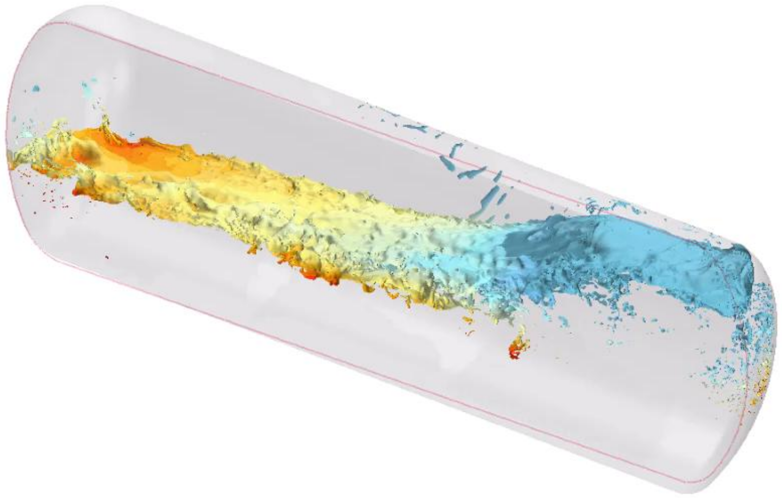
## Our work

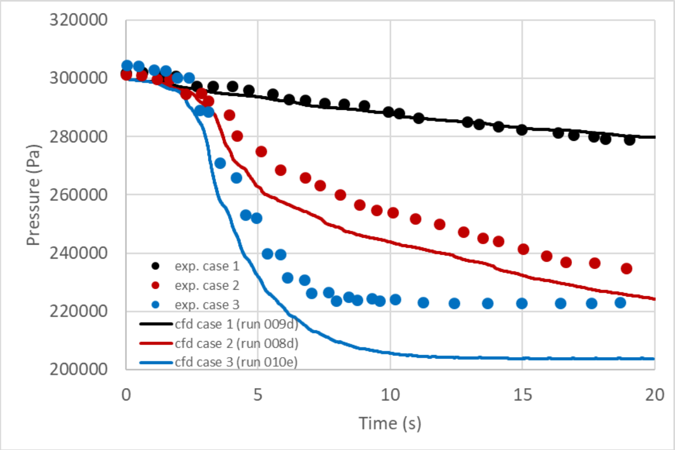
We used advanced Finite Element Analysis (FEA) modelling to determine the range of stresses in the system from static and dynamic loads. We then used our expertise in integrity assessment to assess the strength and life of the fuel storage system.

## Outcome

We provided our client with a responsive analysis service that quickly identified areas where the design could be improved and suggested modifications. This has led to an ongoing support arrangement.

# CFD - Sloshing of cryogenic hydrogen tanks






## The Challenge

Cryogenic, liquid hydrogen storage in aerospace applications carries the risk over-pressurization due to sloshing-induced hydrogen boil-off.

## Our Approach

We implemented a calibrated boiling model in the commercial CFD tool StarCCM+. This model was validated against experimental data and used to produce insights regarding sloshing-induced hydrogen boil-off.

## The Outcome

We delivered significant, new insights into the behaviour of liquid hydrogen sloshing to a UK government-funded Aerospace program.

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# Safety: Explosion modelling and structural response

## Challenge

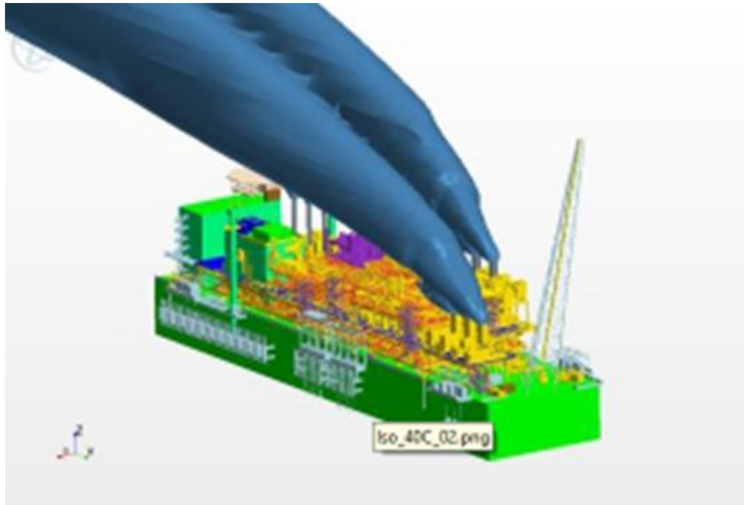
- Safety studies for FPSO
- Dispersion, helideck safety & blast response
- Simulation used to support FPSO design

## Outcome

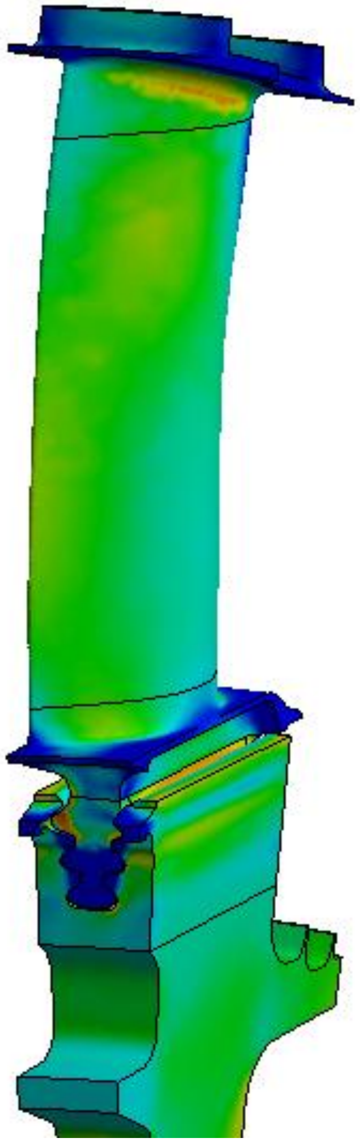
Explosion risk assessment generated, submitted and accepted by the safety authorities. The vessel is now in service.

## Our work

- Simulation used to assess consequences of accidental gas releases and quantify blast over-pressures along with assessment of helideck safety and structural response



# Turbine Component Lifing



**Our Experience**

- Development of novel materials test programs to support
  - Constitutive model development
  - Creep-fatigue lifing models
  - Corrosion / coating models

- Lifing model development
  - Classical N/Nf and t/tr approaches
  - Development of ductility exhaustion methods, e/ef
  - Combined Creep-Fatigue

- Implementation to Finite Element Analysis
  - Development of User Elements / UMATs for industry standard solvers
  - Development of bespoke FEA solutions

- Methods development to support life extension of UK Nuclear AGRs

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# 1D MODEL BENCHMARKING

Through benchmarking against results from Internal 1D Modelling tools, Element Digital Engineering are evaluating two software platforms, to model flow rates, pressures and temperatures across the internal air, oil, and fuel systems.

Full results due mid=2023.

Phase 1. Individual Components

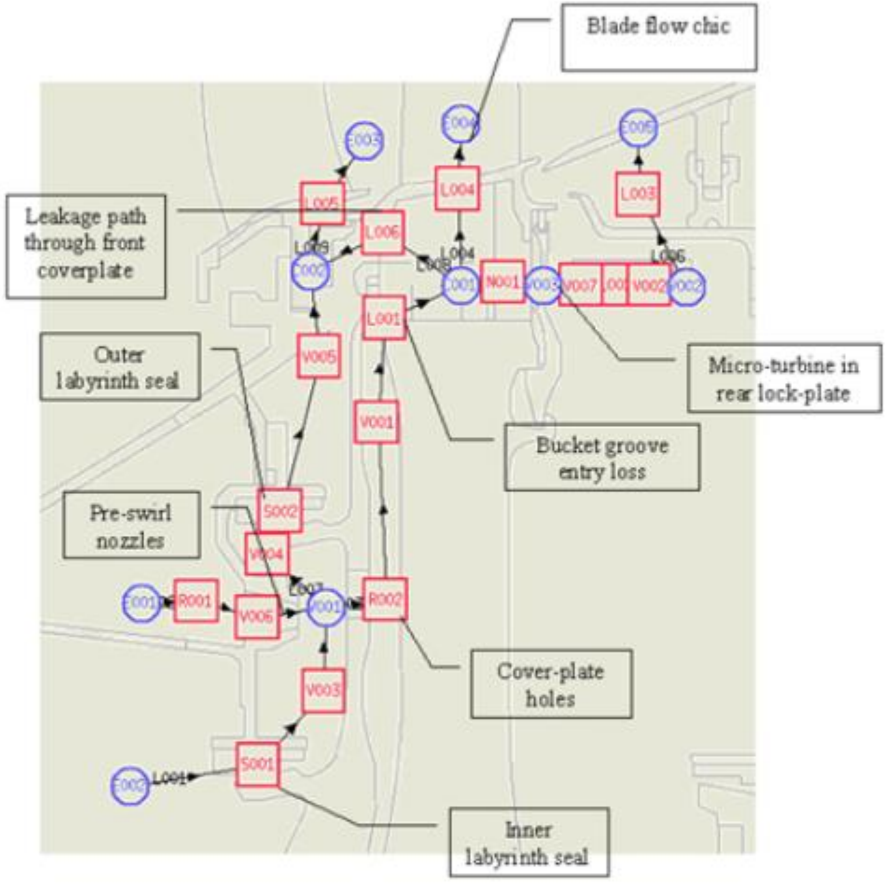
- Compare the functionality of relevant components
- Create customised components by importing Client scripting

Phase 2. Sub-system Modelling

- Evaluate the performance of simplified sub-system models, e.g. the HP turbine blade feed system (right).

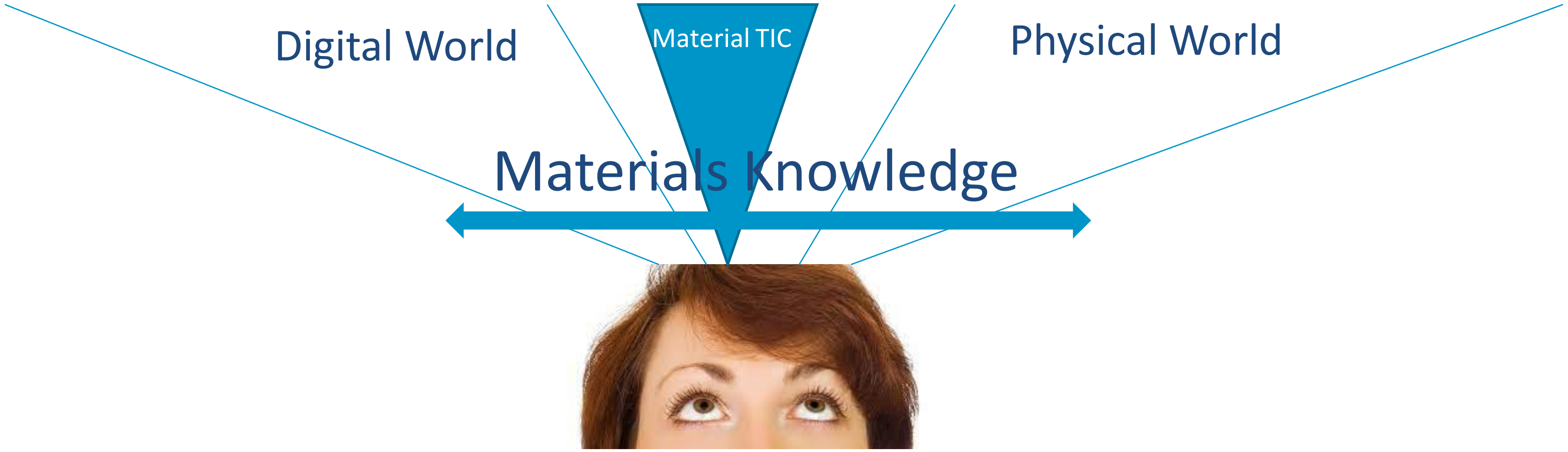
Phase 3. Full Engine Modelling

- Test full-scale engine models with interactions between sub-systems.



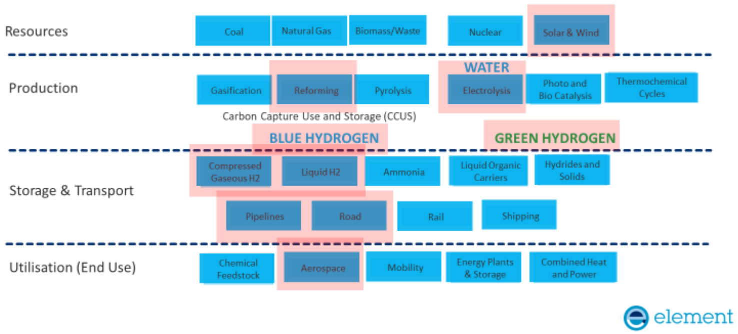
# Element – Assuring Your Energy Transition

**PRODUCTION** **TRANSPORT AND STORAGE** **UTILISATION**

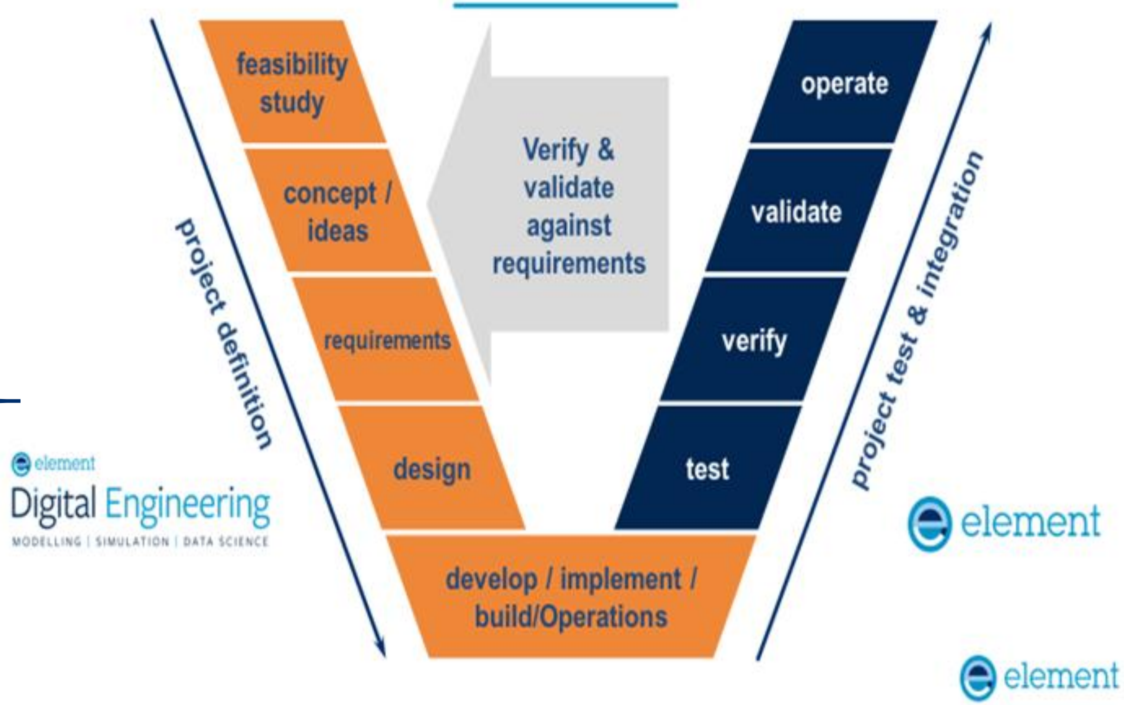


# Smarter Testing: Systems and Component Level

H2 We need to look at the whole system




Combination of Testing and Digital Engineering
: Full Product Development Life Cycle

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# Thank you for listening…..

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