Overview of Cranfield University's Hydrogen Research

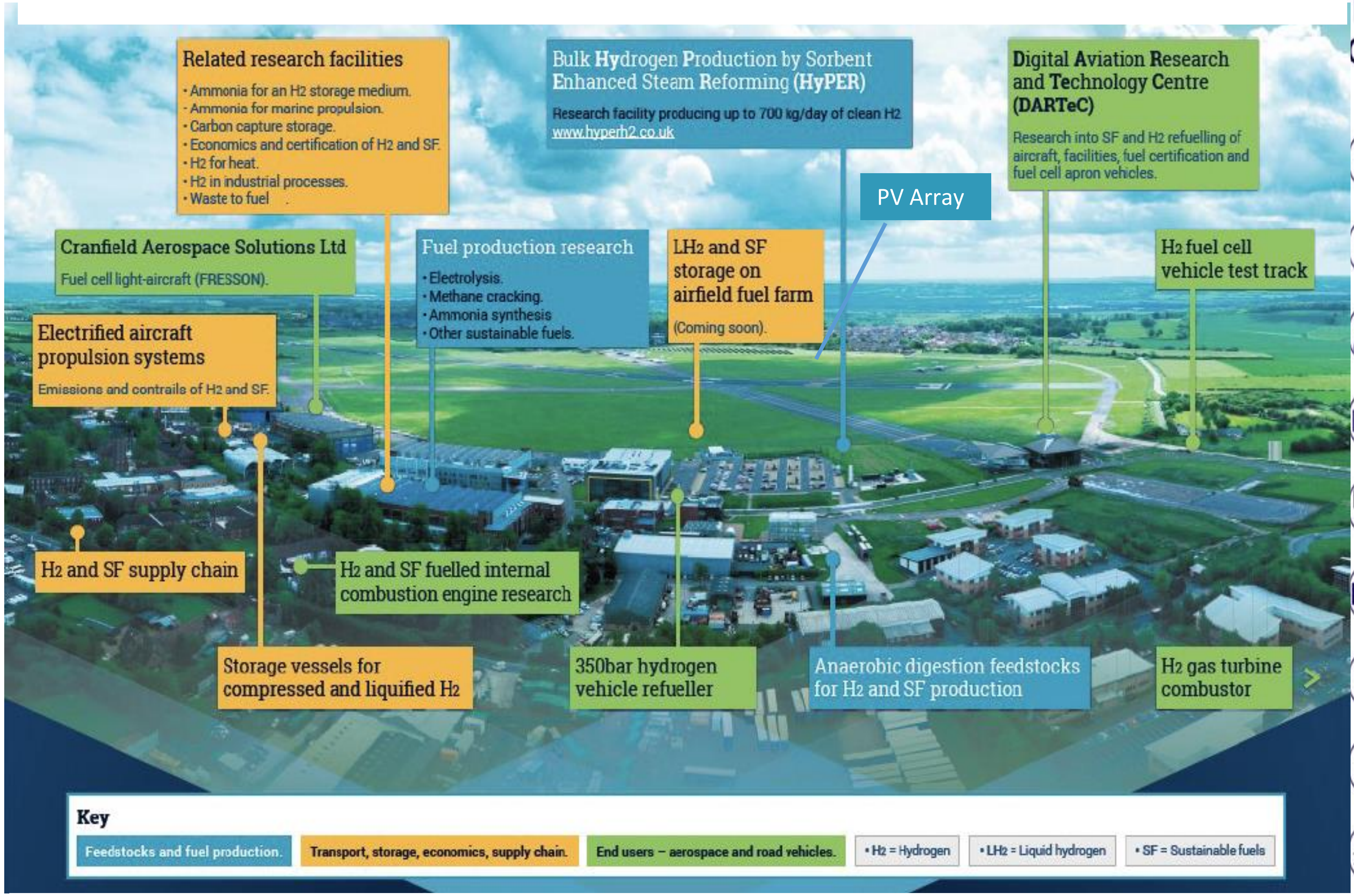
Cranfield University

Professor Upul Wijayantha
Head, Centre for Renewable and Low Carbon Energy

www.cranfield.ac.uk

10th January 2024

Gaseous H_2, liq.H_2 and SFs research across Cranfield aligned to the UK Government's 10-point plan (TRL 1-6)



The Ten Point Plan for a Green Industrial Revolution

Point 1
Advancing Offshore Wind

Point 2
Driving the Growth of Low Carbon Hydrogen

Point 3
Delivering New and Advanced Nuclear Power

Point 4
Accelerating the Shift to Zero Emission Vehicles

Point 5
Green Public Transport, Cycling and Walking

Point 6
Jet Zero and Green Ships

Point 7
Greener Buildings

Point 8
Investing in Carbon Capture, Usage and Storage

Point 9
Protecting Our Natural Environment

Point 10
Green Finance and Innovation

1 MW low carbon H_2 production pilot plant

HyPER

£10M
Investment

25%
Lower LCOH

700
kg-H_2 / day

95%
H_2 Purity

GTI ENERGY
solutions that transform

Cranfield University

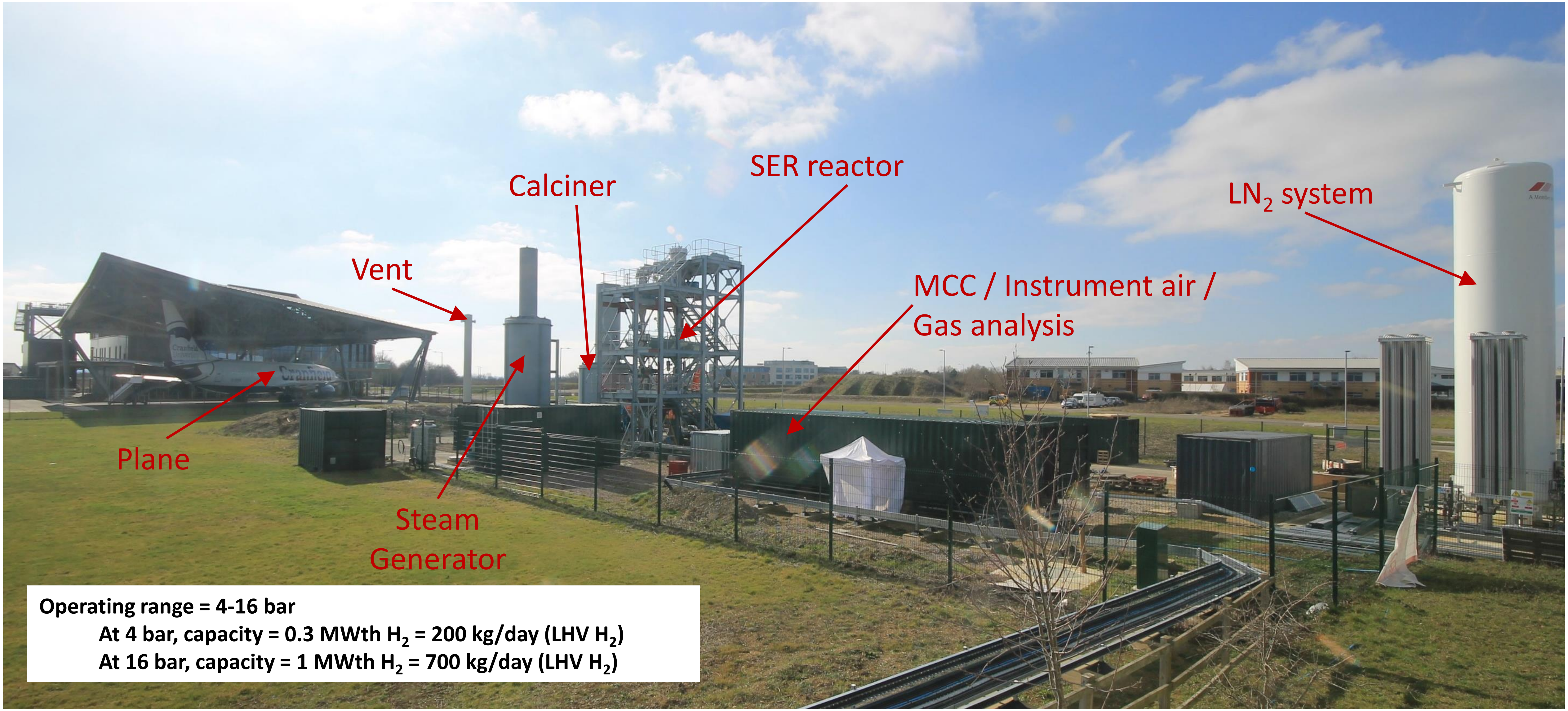
BABCOCK
ALTRAD

Department for Business, Energy & Industrial Strategy

LCRI LOW-CARBON RESOURCES INITIATIVE

HyDEX

HyPER



Operating range = 4-16 bar

At 4 bar, capacity = 0.3 MWth H_2 = 200 kg/day (LHV H_2)

At 16 bar, capacity = 1 MWth H_2 = 700 kg/day (LHV H_2)

HyPER

Sorption Enhanced Reforming (SER)

$$CH_4 + 2H_2O + \text{Heat(a)} \longrightarrow 4H_2 + CO_2$$

$$CaO + CO_2 \longrightarrow CaCO_3 + \text{Heat(b)}$$

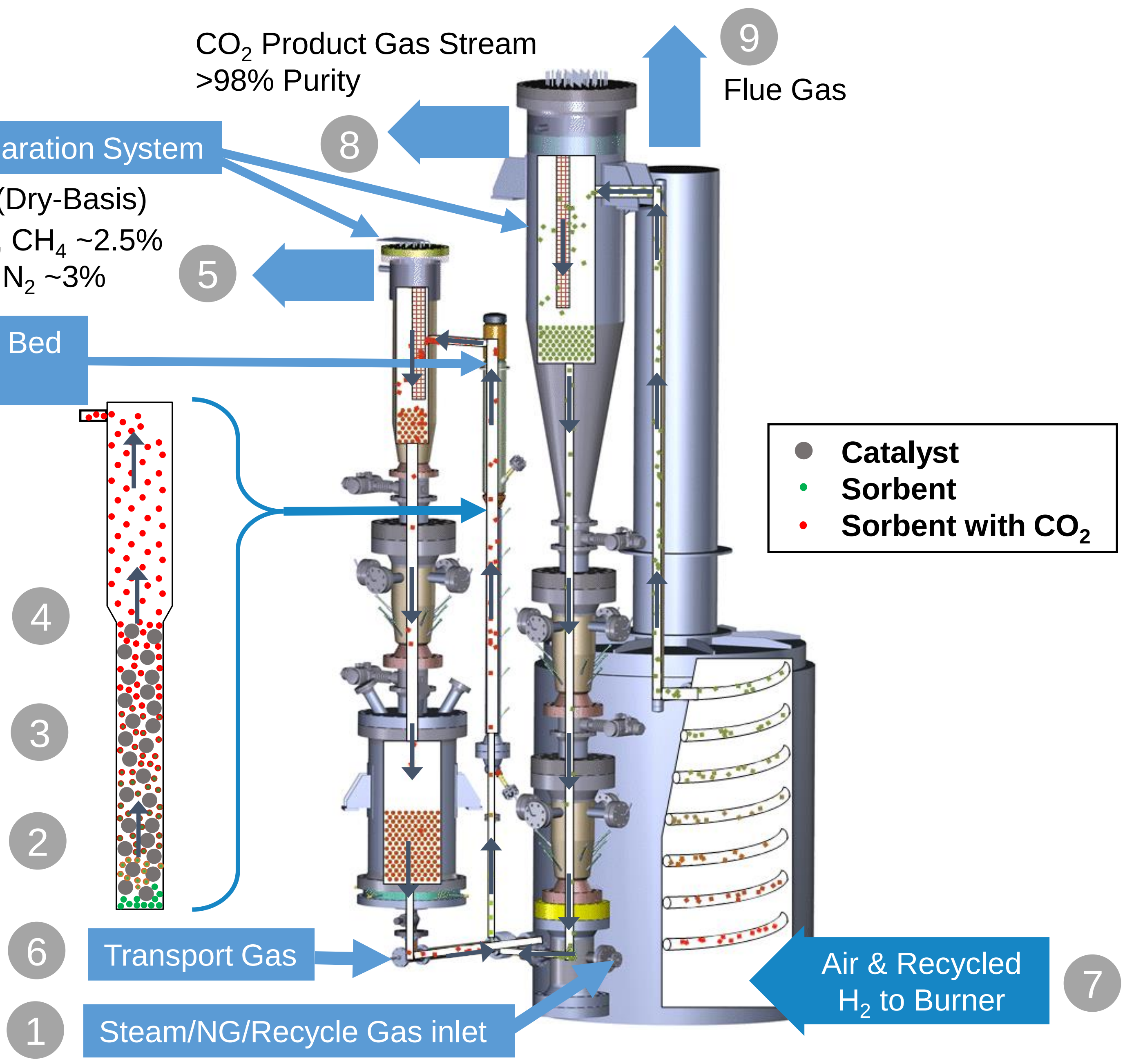
$$CH_4 + 2H_2O + CaO \longrightarrow 4H_2 + CaCO_3$$

Heat(b) ~ 95% Heat(a)

Sorbent elutriates through reactor to filter while heavier catalyst remains

CO_2 absorbed by sorbent forcing more CO_2 to form (Water-Gas Shift)

Steam Methane Reforming produces H_2, CO & CO_2



Bulk **Hy**drogen **P**roduction by ‘Sorbent **E**nhanced’ Steam **R**eforming

Phase 1 – Feasibility	**May – September 2019**
Phase 2 – Demonstration	**January 2020 – May 2024**
Phase 3 – Extended Testing	**June 2024 – July 2024**

Current Consortium

Cranfield University	**Project Lead and Technology Development**
Doosan Babcock	**Engineering Partner**
Gas Technology Institute	**Technology Owner and Techno-economics**

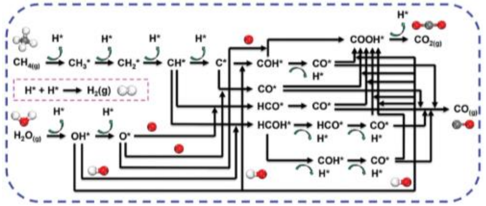
Compared to SMR+CCS or ATR+CCS, SE-SMR technology can achieve:

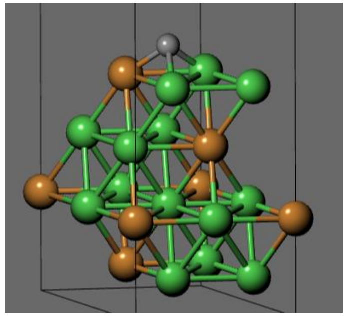
- ~25% lower Levelised Cost of Hydrogen
- >50% reduction in CAPEX with similar OPEX
- ~97% CO_2 capture rates with equivalent H_2 purity
- <40% lower carbon footprint
- Smaller physical footprint due to integrated nature of the SE-SMR process

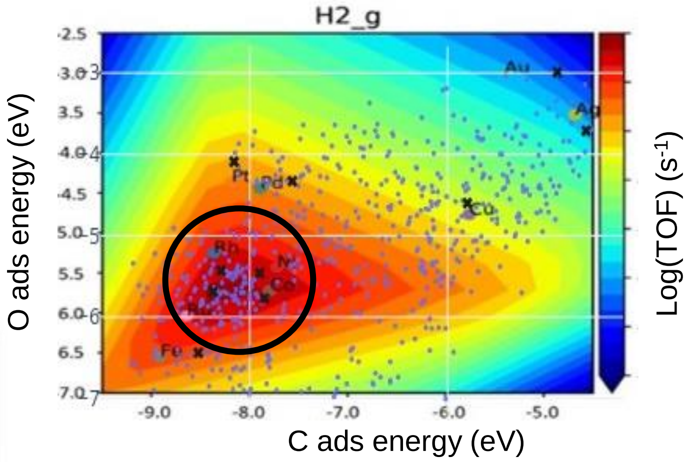
Novel catalysts for HyPER

Development of novel bi/tri-metallic catalysts for (sorption-enhanced) steam methane reforming

- Screening alloys based on SMR activity, and C and O adsorption energies
- Microkinetic modelling and DFT-calculated adsorption used to aid screening
- Synthesisation of the most promising materials followed by characterisation and testing in bench scale reactor
- Currently looking at sulphation resistant catalysts



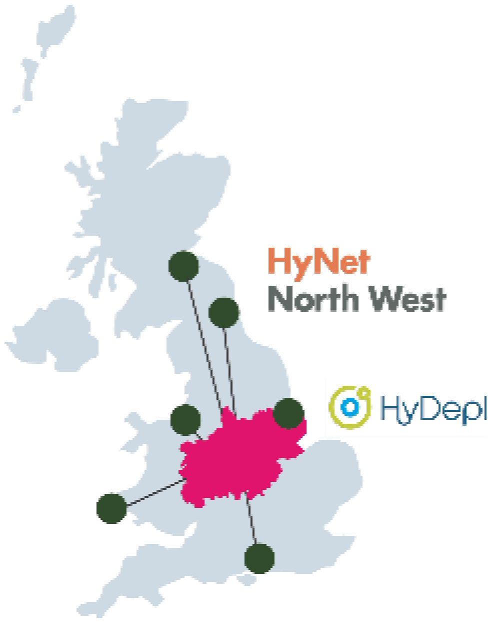




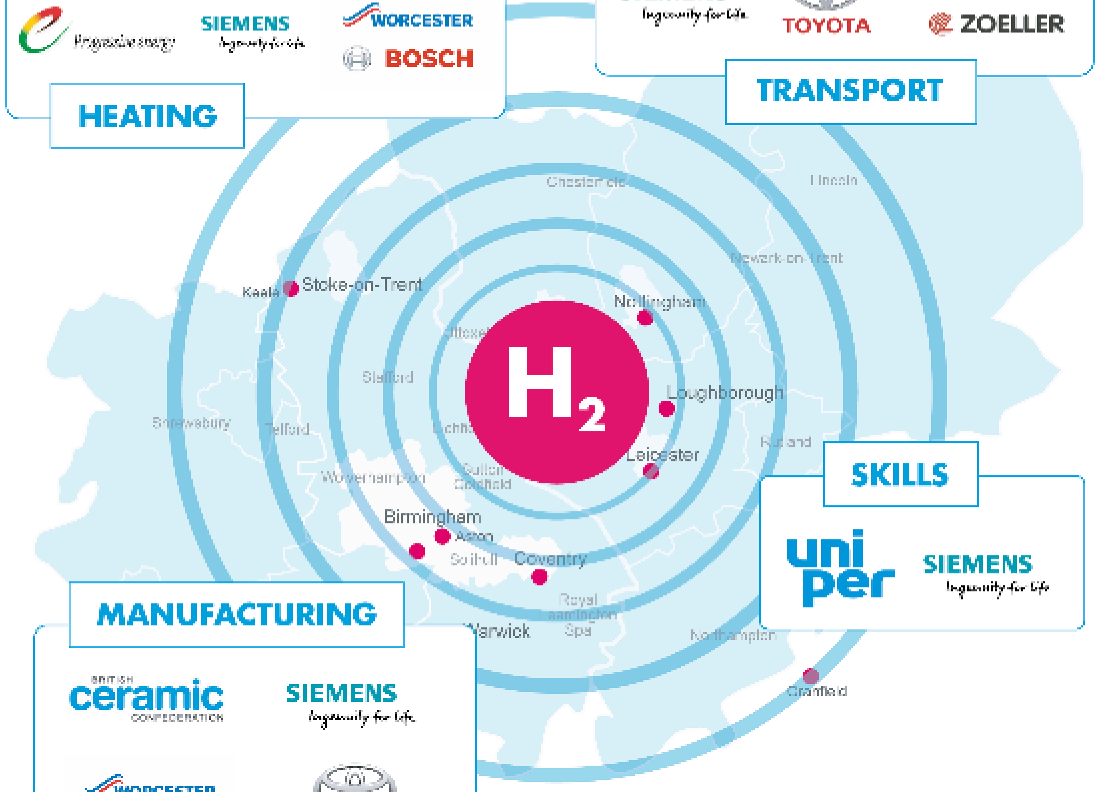
Ni-Metalloid and Ni-alloy based catalysts

HyDEX

The University of Nottingham · Cranfield University · Keele University · University of Birmingham · Loughborough University · Aston University Birmingham · Warwick, The University of Warwick



- Demonstrators
- New products development
- Skills



HEATING

TRANSPORT

SKILLS

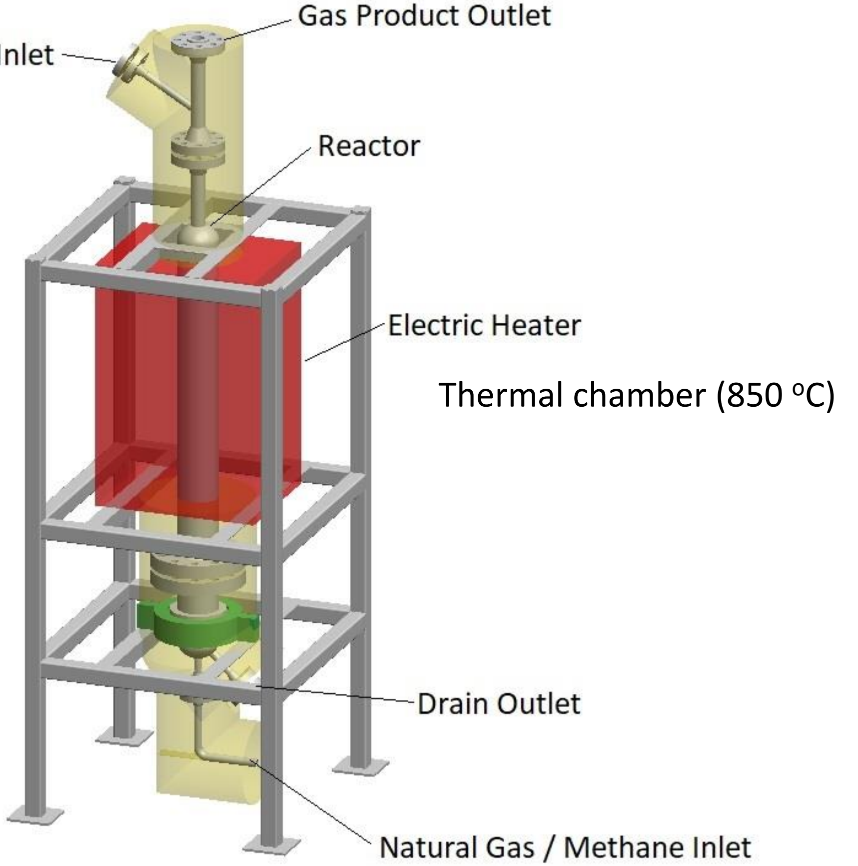
MANUFACTURING

Regional focus, national impact, internationally networked

International academic partners

Turquoise H_2 Pilot (HyDEX)

$CH_4 \rightarrow C + 2H_2$ (on Fe/carbon based catalysts)

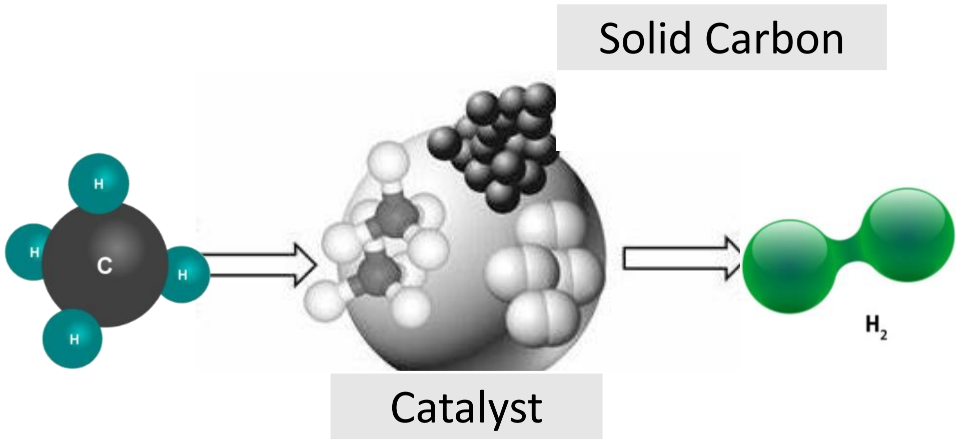


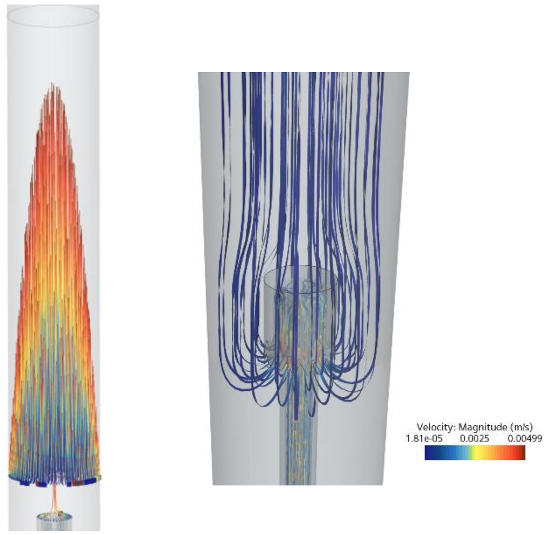
At 1 bar, = 14 kg/day (LHV H_2)

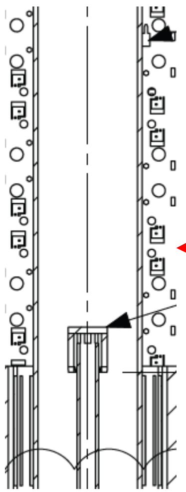
Operational in spring 2024

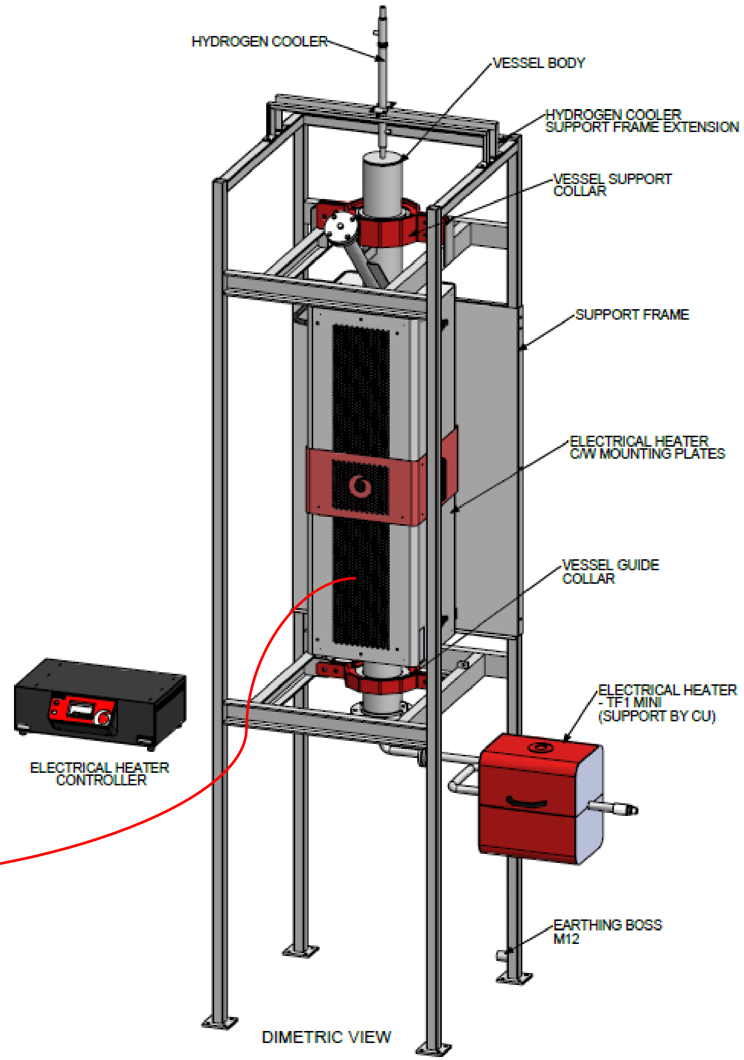
- **When fossil based CH_4 is used, H_2 production is *carbon neutral***
- **When bio-CH_4 is used, H_2 production is *carbon negative*. (footprint less than that of renewable electrolysis).**

Turquoise H_2 Pilot (HyDEX)









Reducing the cost of Turquoise H_2: Potential Routes

11 - 15 kWh/kg H_2

Electrolysis: ~ 55 kWh/kg H_2

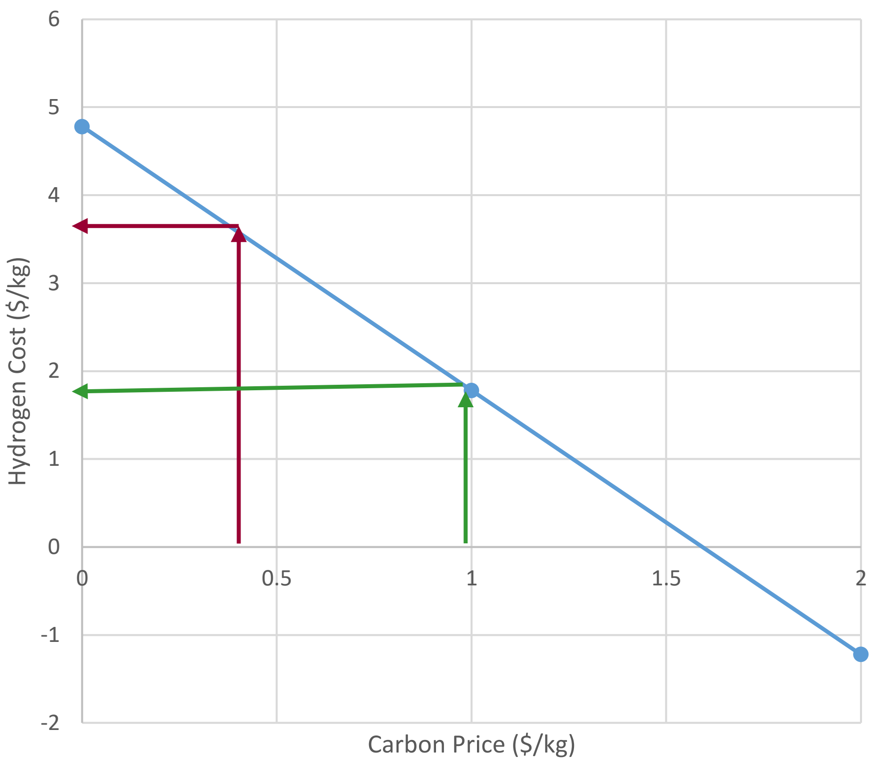
Equation:	CH_4	$\rightarrow$	C	+	$2H_2$
Moles:	1		1		2
Molar Mass:	16		12		4

Every **kg** of hydrogen produced gives **3kg** of carbon

- Use waste heat
- Add Value to Carbon by-product

Adding value to the Carbon in Turquoise H_2 : How?

- Cost of lower grade carbon ranges from **$0.4 - 1/kg**
- Cost of special grade carbon can go up to **$2/kg**



Carbon Steel
Supercapacitors
Batteries
Tyres
Air/water purifications
Road infrastructures
Wind Turbines
Mobile Phones
Soil Nutrients (biochar)
Cosmetics
Phase change materials

- **US DoE target for cost of hydrogen at $1/kg by 2030**

HyDEX

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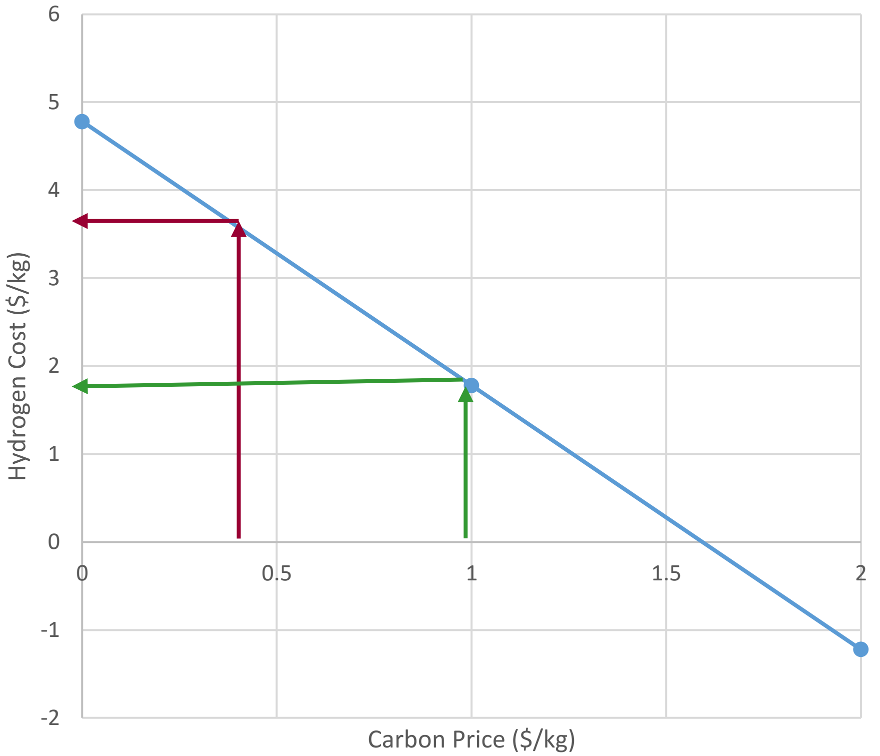

Carbon Steel
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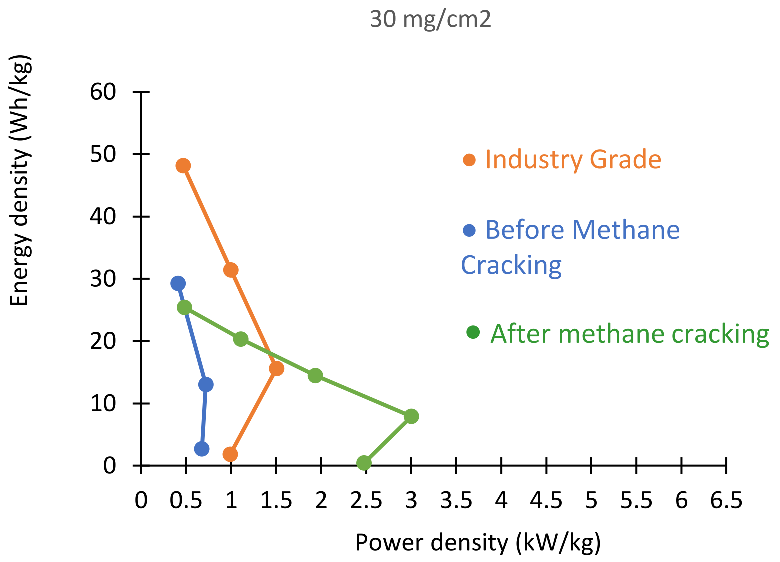
Magnetic properties

- **US DoE target for cost of hydrogen at $1/kg by 2030**

Adding value to the Carbon in Turquoise H_2 : How?

Application 1: Supercapacitors

Supercapacitors made using the by-product carbon outperformed the industrial grade carbon in high power for high mass loadings



Application 2: Magnetic properties (in data storage)

Application 3: Soil Nutrients

Application 4: Phase Change Materials

Biogas Production

Anaerobic digestion of sewage sludge, municipal solid waste and energy crops

Thermal and biological pre-treatments to boost anaerobic digestion performance

Green Hydrogen Production

We work very closely with HyWaves which is an R&D company that develops green hydrogen technologies for high-efficiency and low-cost renewable-to-H_2 production.

HyWaves has patented solar-to-H_2 power management and control system architecture (H2Top) that has already been successfully demonstrated at Cranfield at a small prototype level.

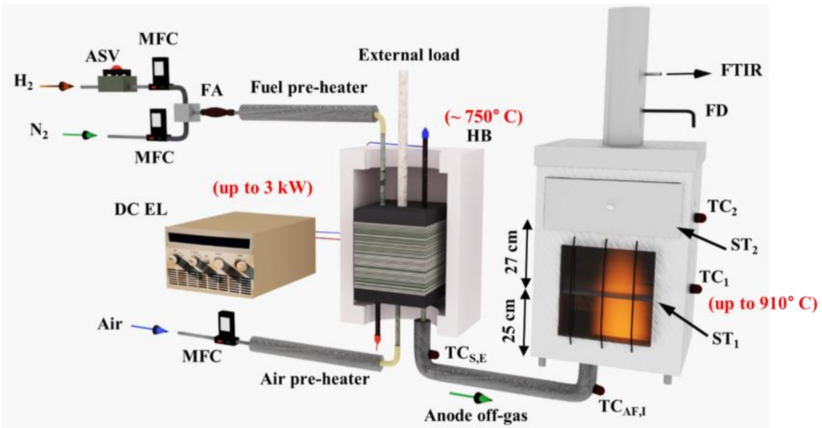
The H2Top system harnesses the advantages of a direct-current connection between any DC renewable power source (e.g. PV, batteries) to be directly used to power H_2 electrolysers without a requirement for any power conversion stages.

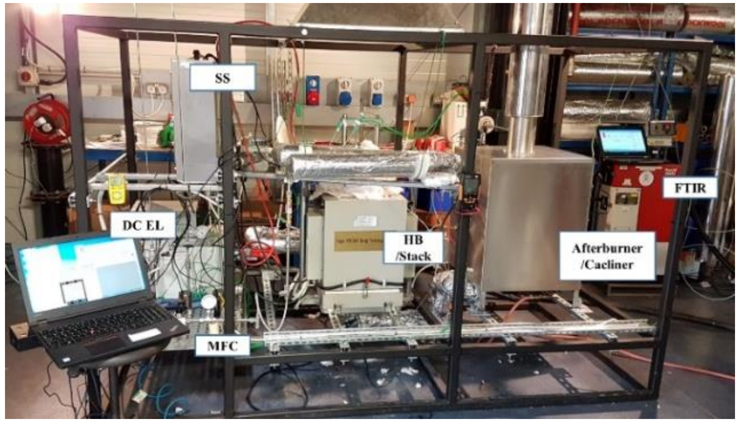
The H2Top would significantly reduce the CAPEX of current Green H_2 system and lower the cost to be competitive to blue and grey H_2.

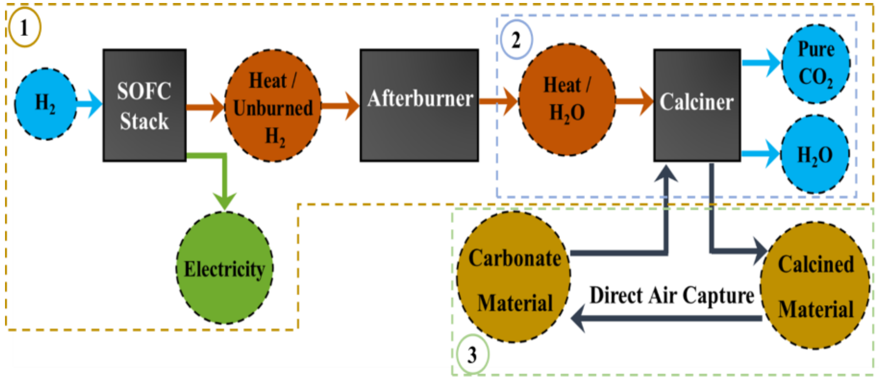
SOFC-integrated calciner for DAC

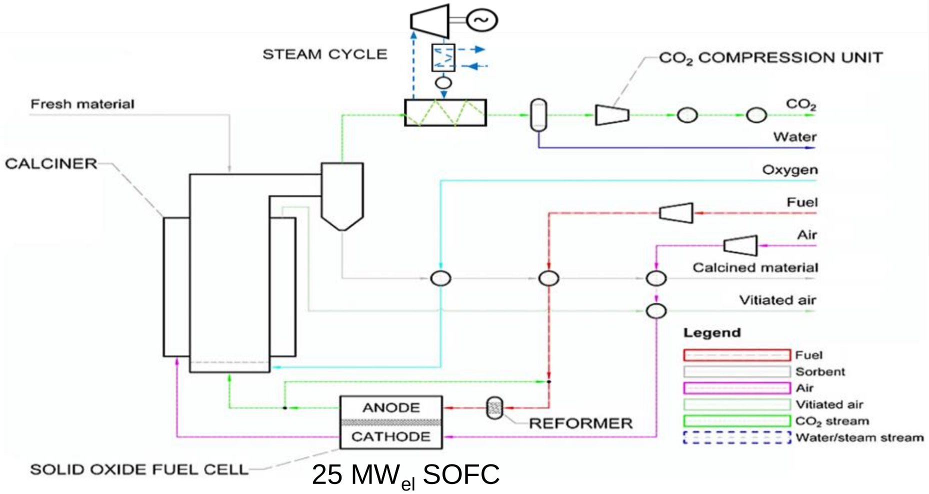
BEN Project (£2.9m) – Design and demonstration of SOFC-integrated calciner

Cranfield kW-scale Solid Oxide facility



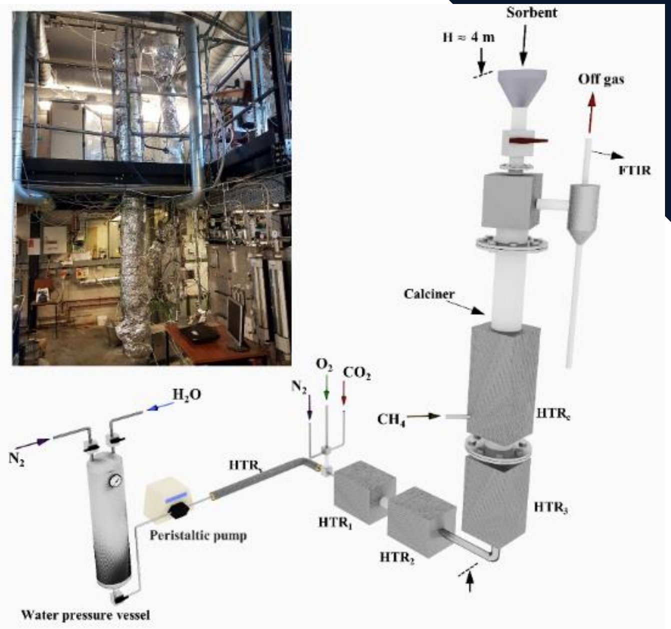






25 MW_{el} SOFC

39.2 -74.9 £/t_{CO2}



Innovate UK

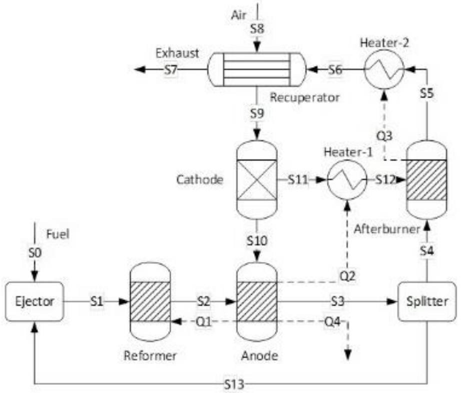
BEN

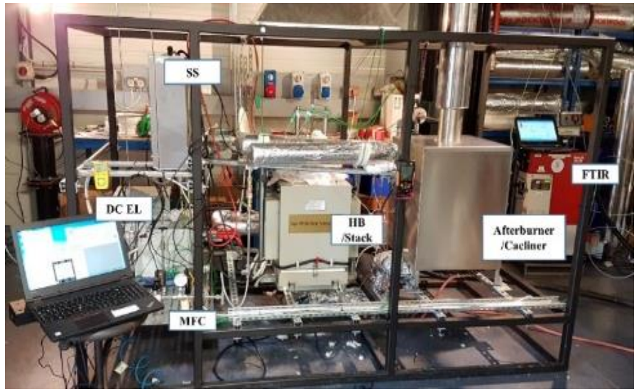
the ENGINEER collaborate to innovate

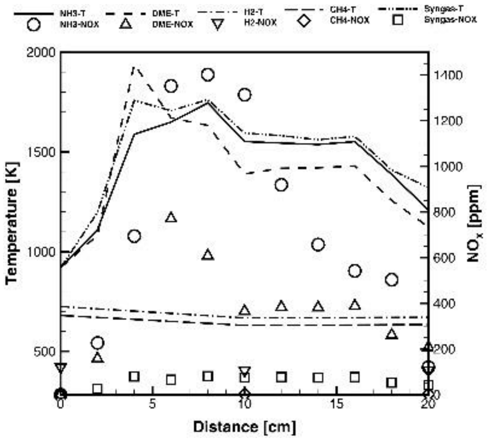
ENERGY & ENVIRONMENT

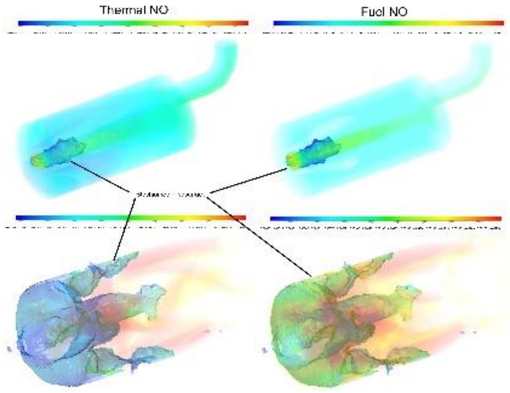
WINNER

Ammonia as a sustainable fuel

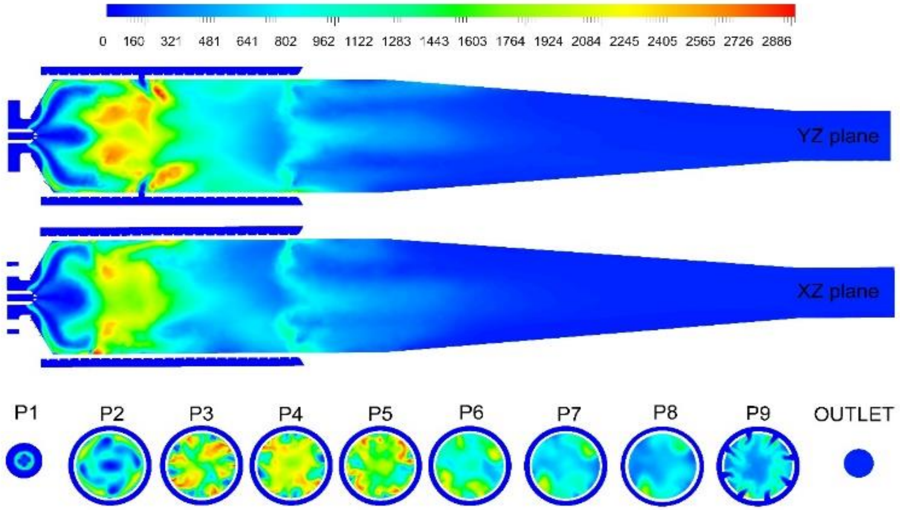








Direct ammonia-fed SOFC



Ammonia combustion

Materials Degradation and Lifing for Energy Engineering

Materials Degradation inc.
Post H_2-Combustion

Biofuel Options

Modelling and
'Digital Twins'

Materials Degradation and Lifing

Interactions with stress

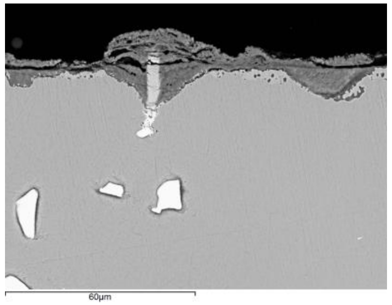
Repair and Recycling

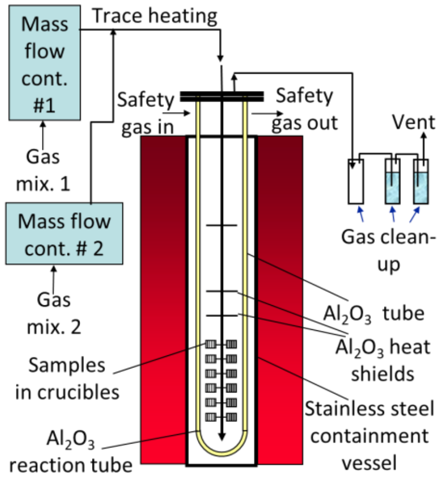
Materials in Extreme Environments inc. Supercritical-CO_2

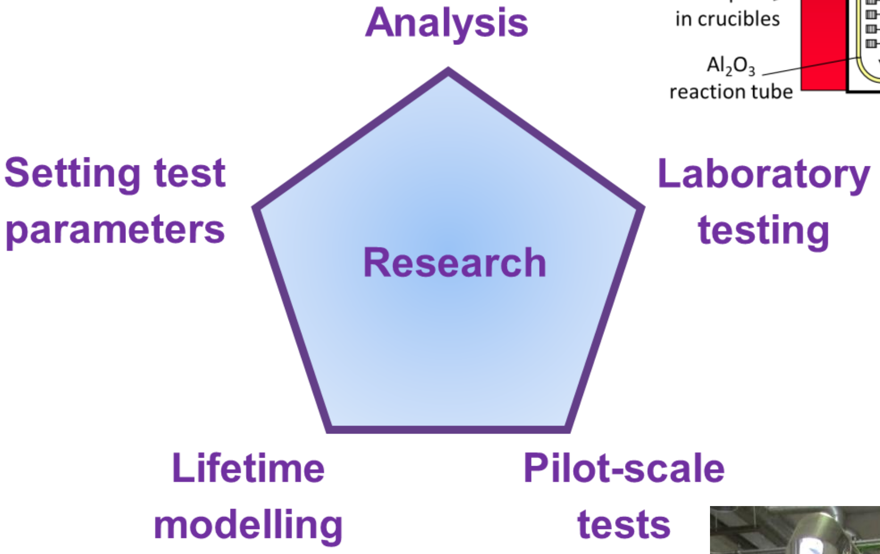
Plastic Lifecycles and Fuels

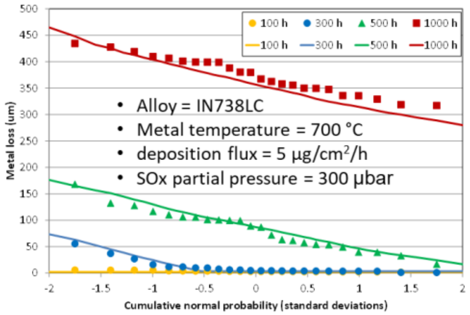
Seawater Electrolysis

Pyrolysis Oil Processing via Electro-Chemistry for Recycling









Contact: j.sumner@cranfield.ac.uk

LH_2 – Fuelled Aircraft: CU Thought-leadership Example

Innovation Waves to Accelerate Decarbonisation

Innovation Wave 1
10-15 Years
Focus: Certification


Innovation Wave 2a
20+ Years
Focus: Efficiency


Innovation Wave 2b
20+ Years
Focus: FC Certification


Innovation Wave 3
30+ Years
Focus: Turbo-cryo-electric

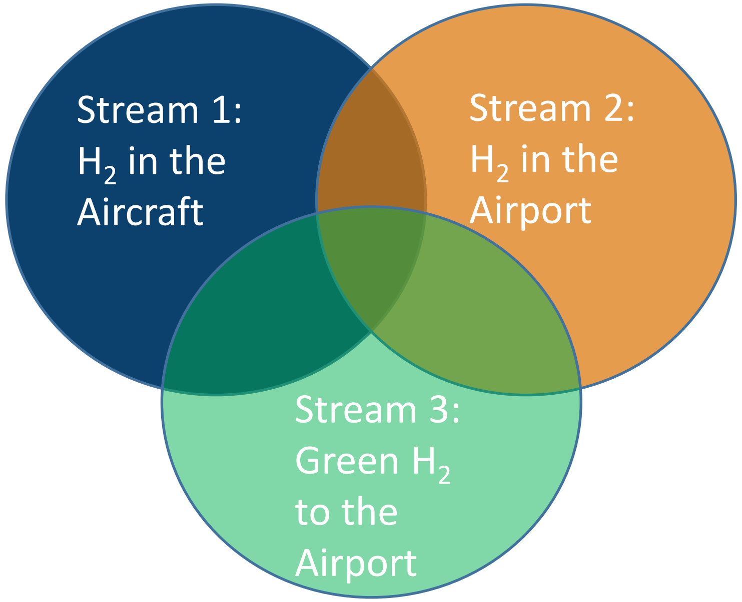


https://www.airbus.com/en/innovation/zero-emission/hydrogen/zeroe

https://www.ati.org.uk/flyzero/

UK-ARC H_2 Group Scope:

Thematic Areas and Mapping of Expertise and Ambitions



H_2 in the Aircraft
H_2 aircraft design and performance analysis
H_2 propulsion system design, integration, and performance analysis (gas turbines (including advanced cycles – intercooling, recuperation, pressure rise combustion etc.), fuel cells, hybrid and turboelectric + distributed propulsion).
LH_2 tank design, manufacturing, and aircraft integration
LH_2 tank fluid movement modelling (sloshing), sensors and gauging
LH_2 fuel system thermal management and control (fuel supply system from tanks to “consumer” (either fuel cell or gas turbine))
Solid state storage
Aircraft engine and combustion noise
Low NOx H_2 Combustion
Contrails modelling and aircraft trajectory optimisation for contrail avoidance (incl. trade-offs with mission fuel burn).
Hybrid/Dual/Blended-fuels
Technoeconomic Environmental Risk Assessments (TERA) (Mission level and over the life cycle) & Pathways towards decarbonising aviation
Materials and Manufacturing
Certification

Thank you

upul.Wijayantha@cranfield.ac.uk