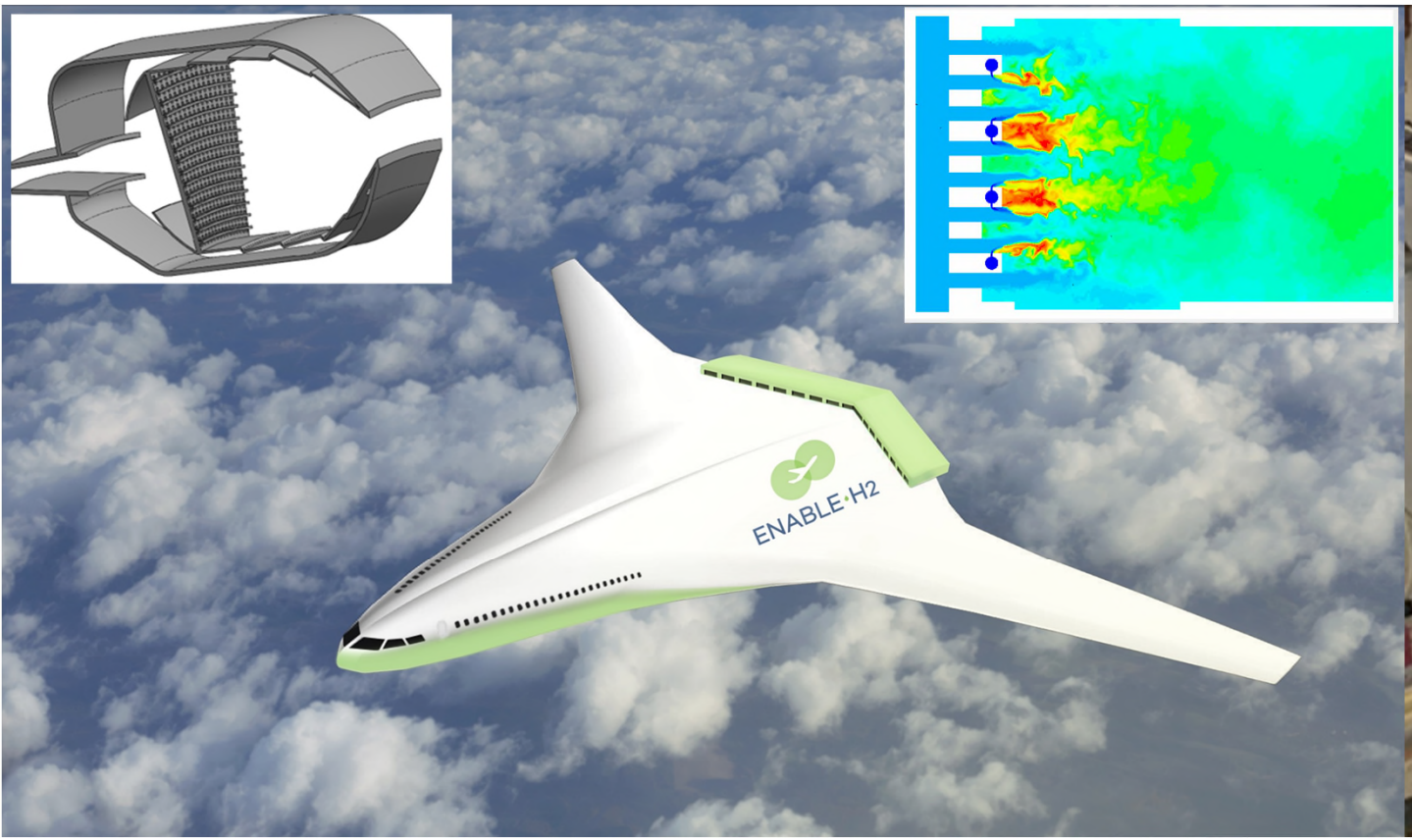
Hydrogen and Decarbonisation Workshop:

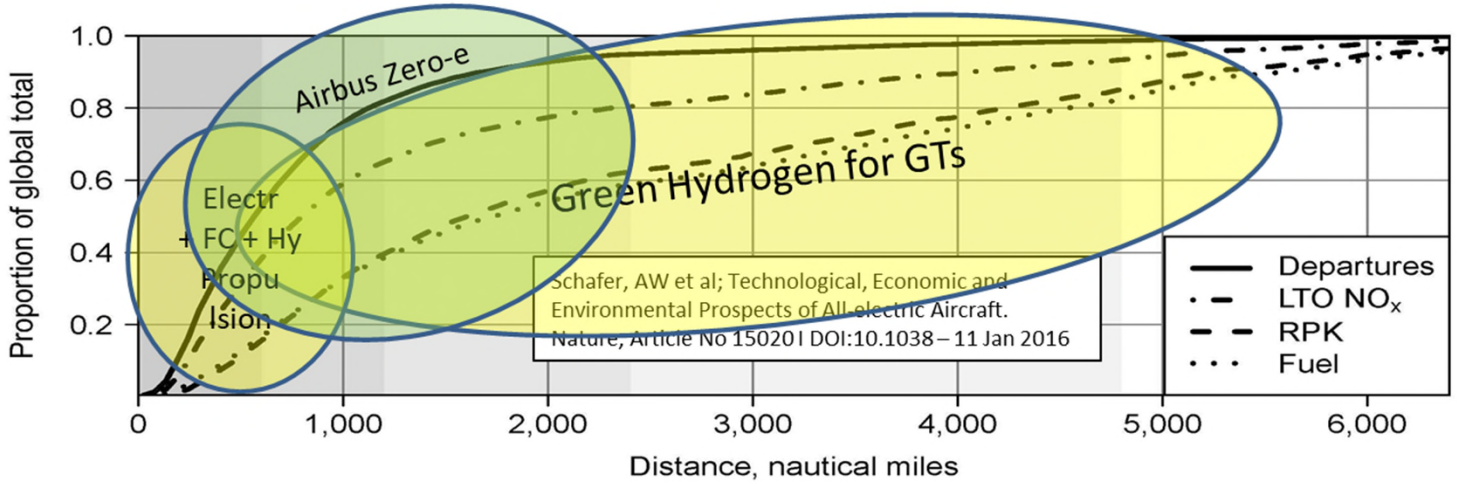
Hydrogen R&D

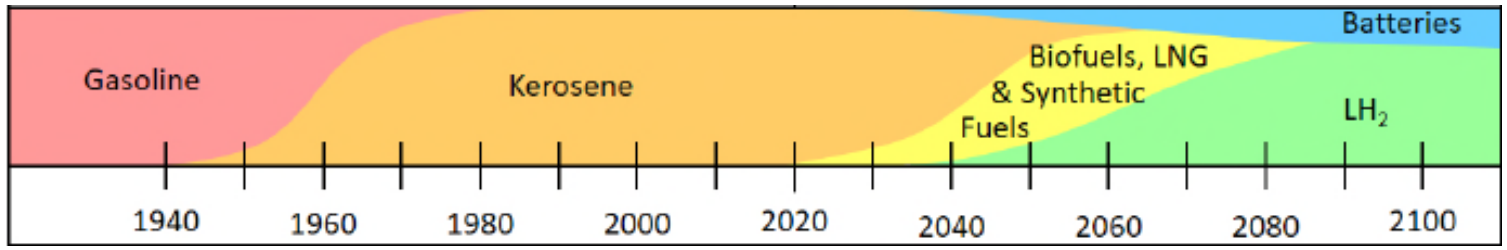
Dr. Vishal (Bobby) Sethi
Head - Low Emissions Technologies and Combustion (LETC) Group
Centre for Propulsion and Thermal Power Engineering
Cranfield University



Civil Aviation Sustainability

Protect the Environment and the Economy!





Abbreviations
Electr: Electric
FC: Fuel Cells
GTs: Gas Turbines
Hy Propulsion: Hybrid Propulsion
LNG: Liquefied Natural Gas
LTO: Landing and Take-Off Cycle
RPK: Revenue per Passenger Kilometre

Green Propulsion Technologies are Key!

Sustainability

- **Decarbonise** ⇒
  Zero Carbon – Not "Net Zero"!
- **Minimise Non-CO_2 Emissions** ⇒
  NOx, Contrails, Noise
- **Improve Energy Efficiency** ⇒
  Advanced, Disruptive Tech.
- **Do not Curb Aviation Growth** ⇒
  Protect the economy!
- **Invest and Attract Diverse Talent** ⇒
  Infrastructure, R&D, Education

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/

Civil Aviation Sustainability: H_2 and Propulsion Systems

CU Research Track Record (not Exhaustive)

H_2 Projects involving H_2 / LH_2 R&D

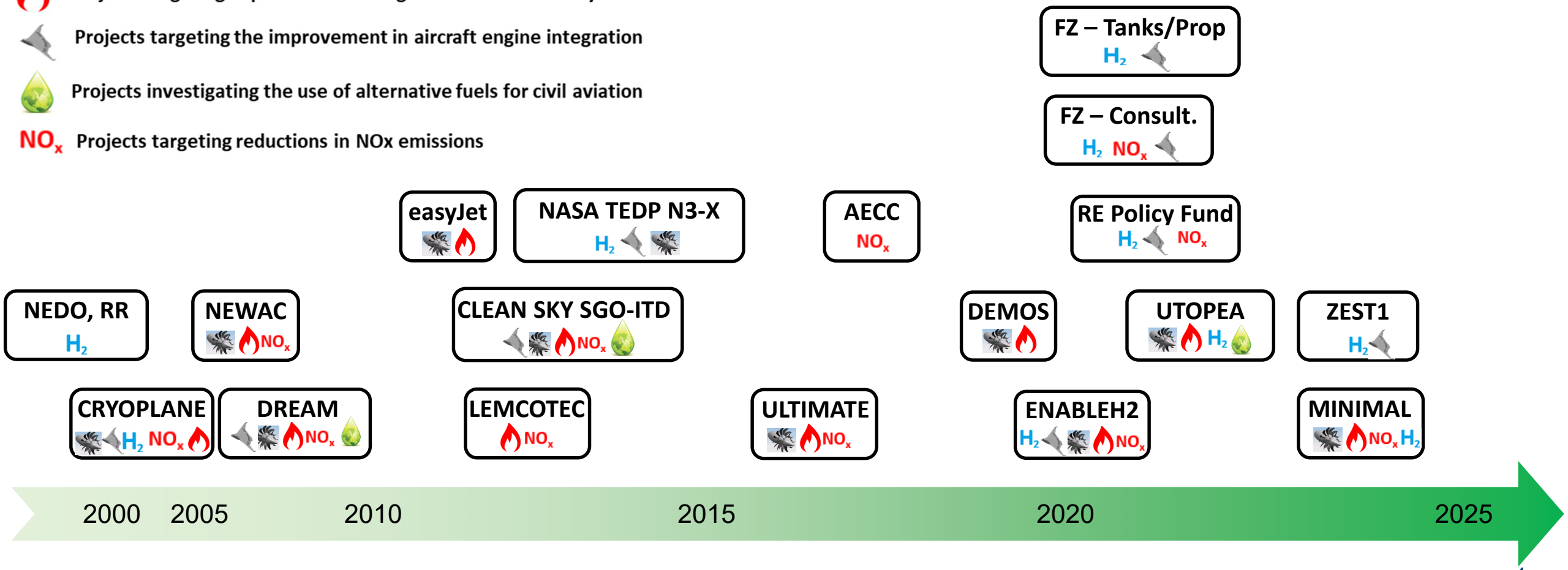
Projects targeting improvement in engine propulsive efficiency

Projects targeting improvement in engine thermal efficiency

Projects targeting the improvement in aircraft engine integration

Projects investigating the use of alternative fuels for civil aviation

NO_x Projects targeting reductions in NOx emissions



The Case for LH_2 for Civil Aviation

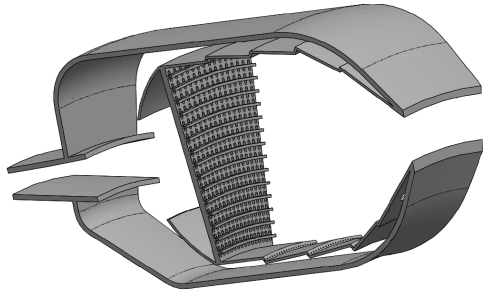
Alternative Fuels and Production Routes		Drop-in replacements		LNG			LH_2	
		Bio-fuels (from algae)	Synthetic Kerosene	Conventional / Fracking	Biomass	Synthetic LNG	Non-renewable	Renewable / Nuclear
Effect on Emissions relative to Jet-A1								
At Mission Level	CO_2							
	Energy Efficiency							
	NO_x							
	CO and UHC							
	Soot / Particulates							
	Water Vapour							
	Contrails							
Over the Life Cycle (well to wake)	CO_2 emissions							
	CH_4 emissions (leakage)							
	Long Term Sustainability							
Effect on Costs relative to Jet-A1								
Short-Medium Term (up to 2050)	Fuel Production Costs							
	Aircraft Engineering Costs							
	Airport Integration Costs							
	Life Cycle Costs							
Long Term (beyond 2050)	Fuel Production Costs							
	Aircraft Engineering Costs							
	Airport Integration Costs							
	Life Cycle Costs							
Effect on Safety relative to Jet-A1								
Actual Safety Record in Transportation								
Likely Public Perception of Safety								

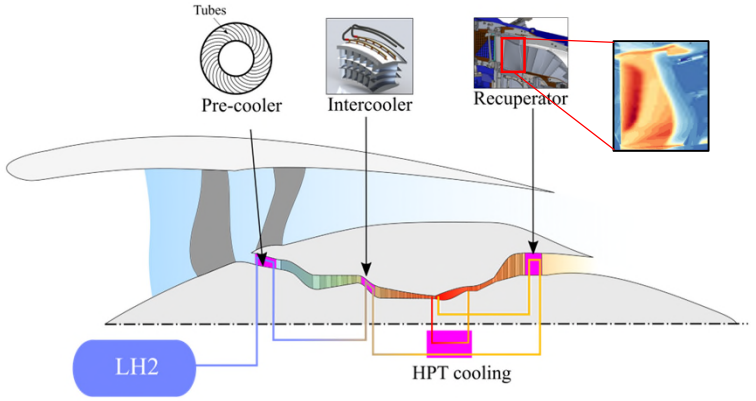
Key						
				Inferior to Jet-A1		No clear benefit re. Jet-A1
		Indicates greater uncertainty		Superior to Jet-A1		Significant benefit re. Jet-A1

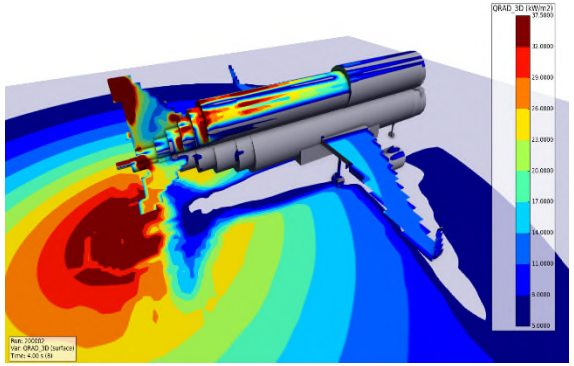
ENABLEH2

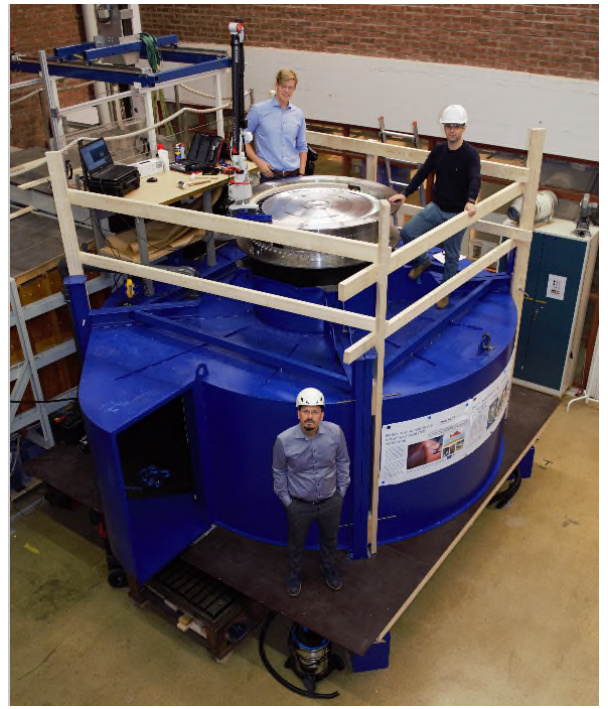
Project Overview

- EU H2020 Project ~4M€, 30+ Key Civil Aviation Stakeholders (partners + industry advisory board members)
- Maturing key enabling technologies for LH_2 which will contribute to decarbonising civil aviation (TRL 2 – TRL4):
    1. Hydrogen micromix combustion – ultra low NOx
    2. Fuel system heat management – exploiting LH_2's formidable heat sink potential
    3. Technology evaluation – Technoeconomic Environmental Risk Assessment (TERA)
- Addressing key challenges/scepticism – economic viability and safety
- Establishing roadmaps for the introduction of LH_2









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Good Collaboration between Key Civil Aviation Stakeholders

Project Consortium

Cranfield University
CHALMERS
LSBU
SAFRAN
GKN AEROSPACE
EUROPEAN HYDROGEN ASSOCIATION
Heathrow
ARTTIC

Industry Advisory Board

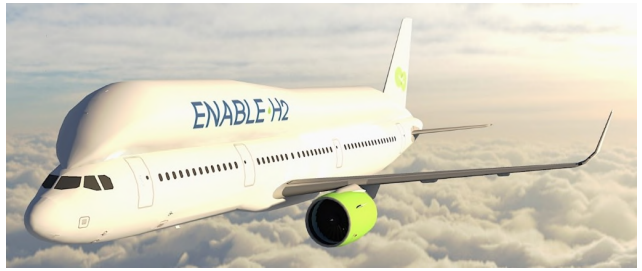
AIRBUS
ROLLS ROYCE
MTU Aero Engines
IAG INTERNATIONAL AIRLINES GROUP
easyJet
Lufthansa Technik
IATA
ICAO · OACI · ИКАО
REACTION ENGINES
DASSAULT AVIATION
Infosys Navigate your next
Air Liquide
TOTAL
GEXCON
SIEMENS energy
ABENGOA
MHPS
ACI AIRPORTS COUNCIL INTERNATIONAL
HyEnergy
Clean Sky 2 JOINT UNDERTAKING
FLY ZERO
AEROSPACE TECHNOLOGY INSTITUTE
EASA European Aviation Safety Agency
MOOG
IMI

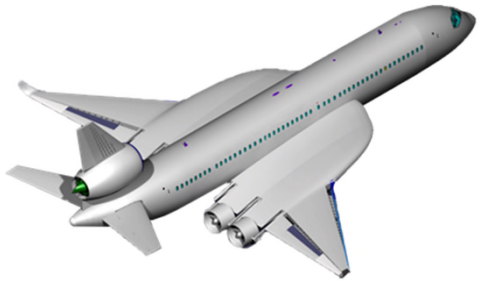
ENABLE·H2

The ENABLEH2 project is receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 769241

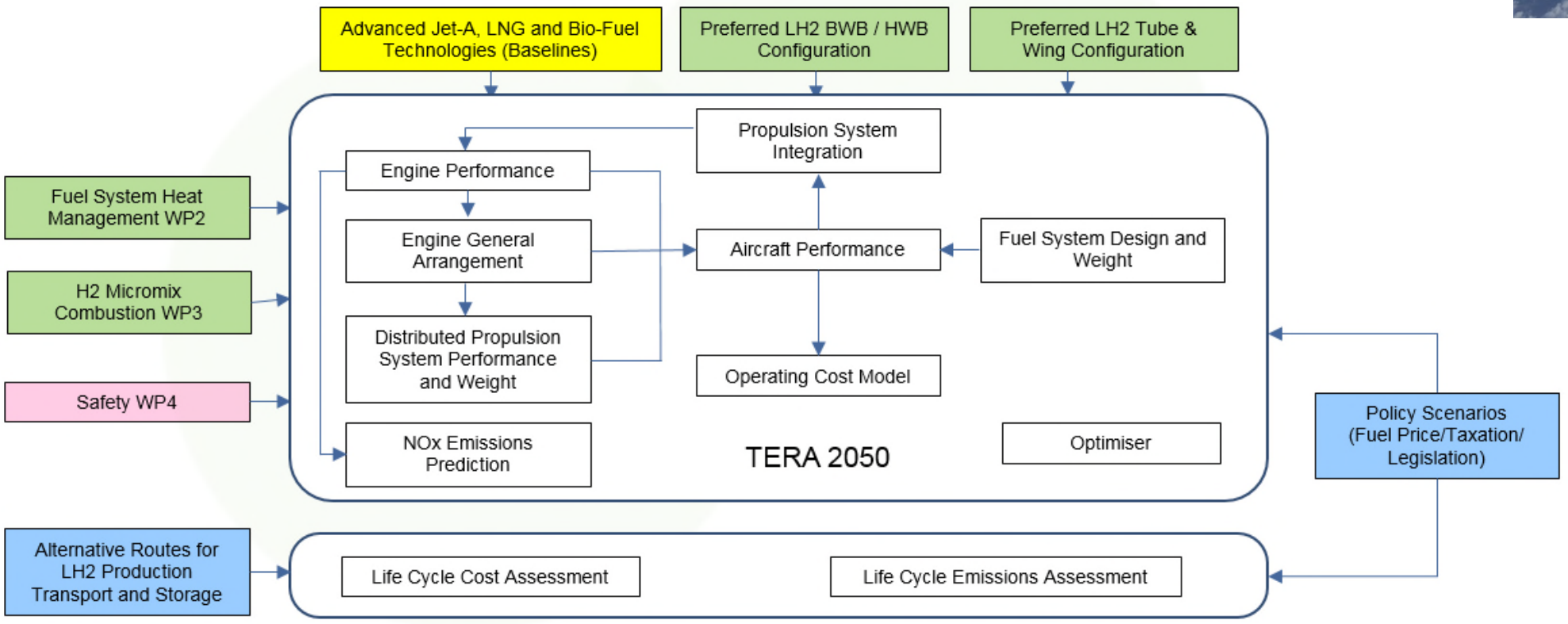
ENABLEH2 Project Overview

Technology Evaluation – TERA (WP1)





SAFRAN Group, Isikveren and Turnbull



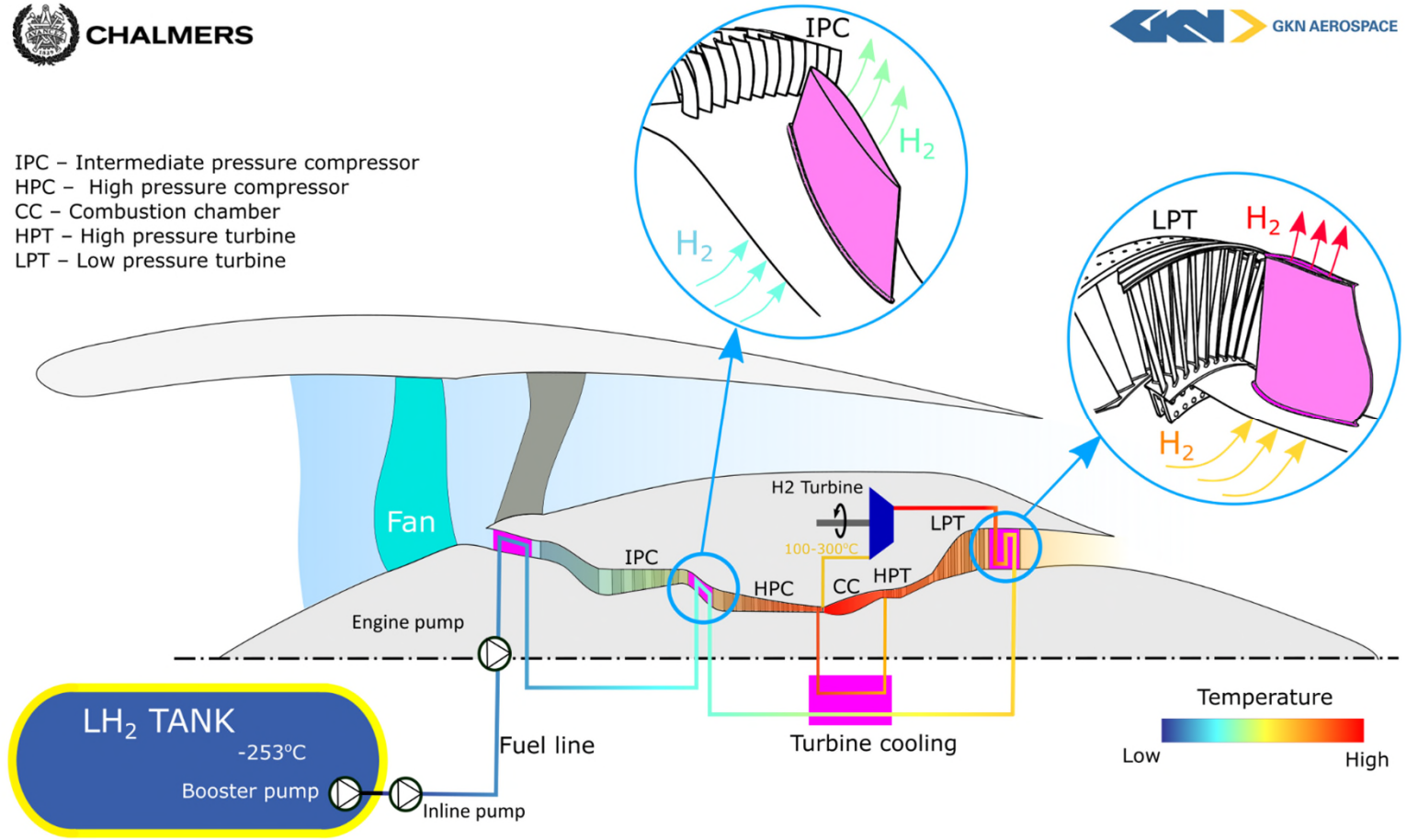
ENABLEH2 Project Overview

Fuel System heat Management (WP2)

Develop heat management concepts

Explore synergies

Investigate the integrated performance



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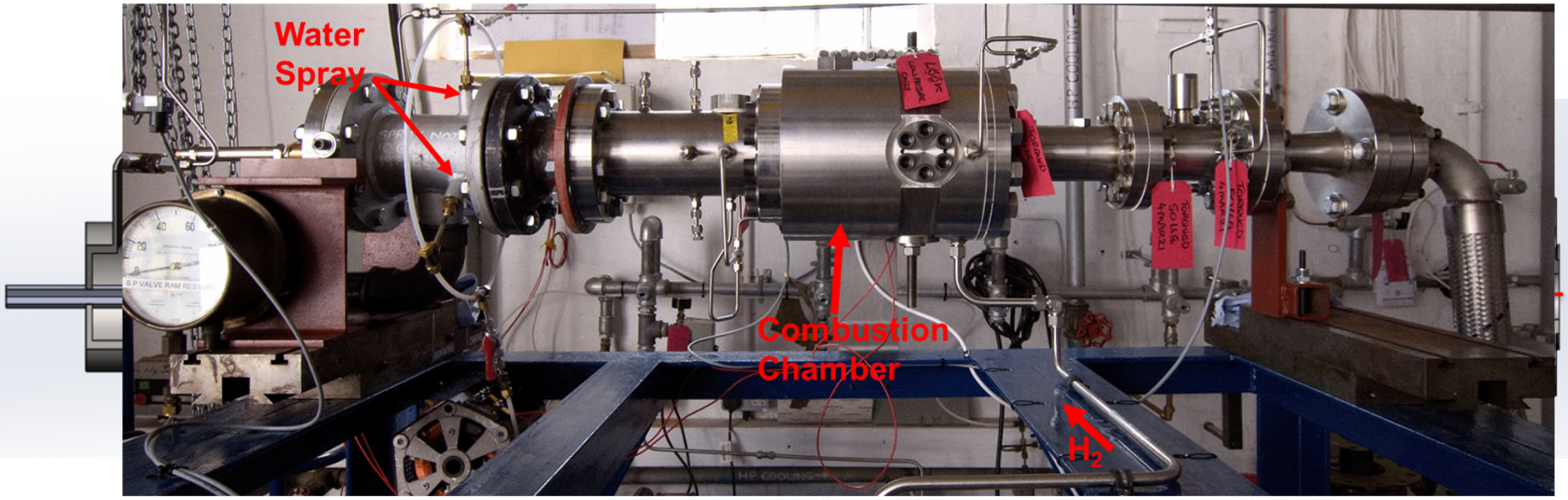
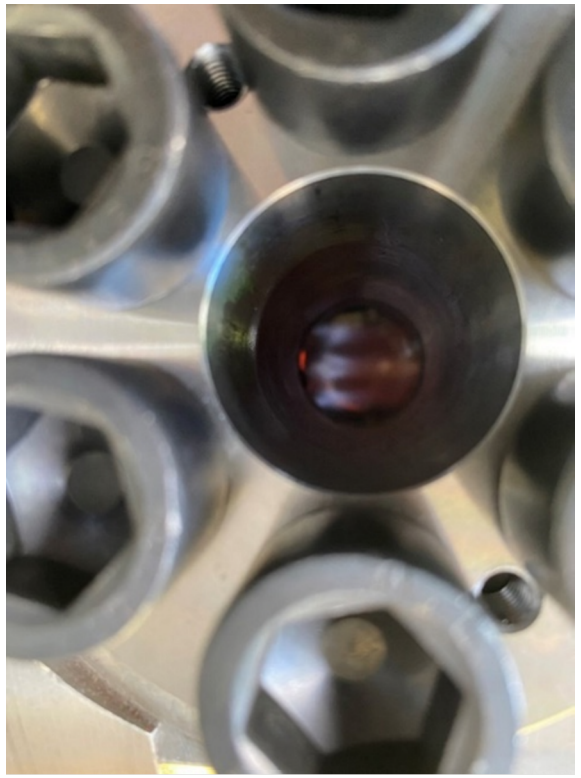
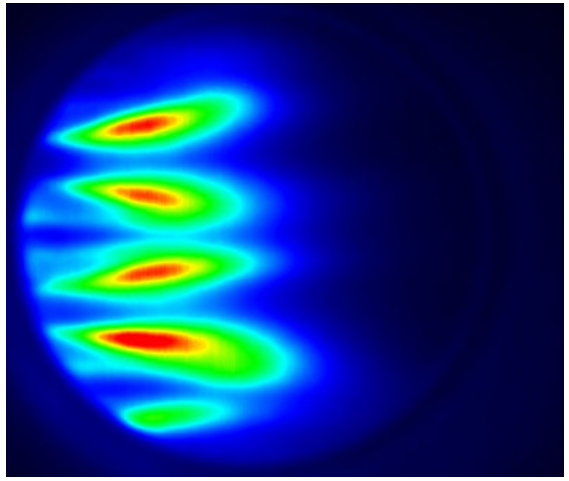
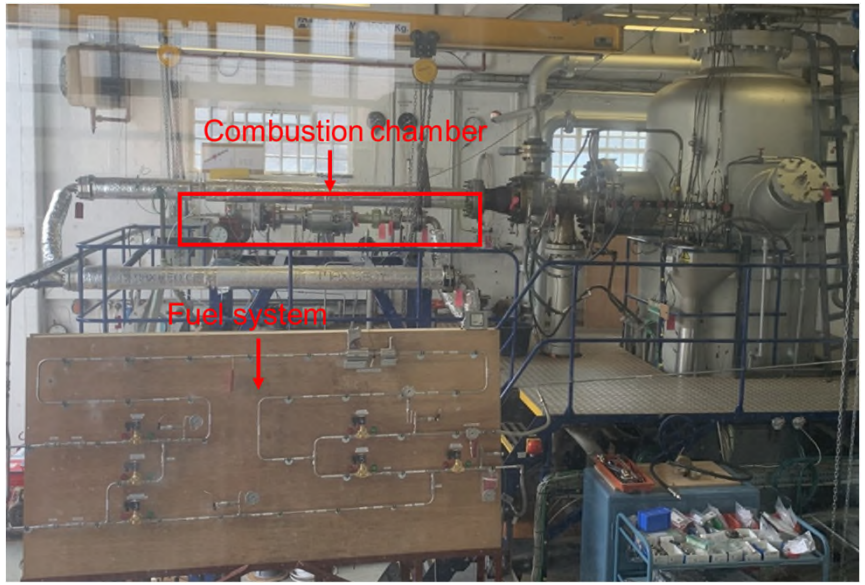
ENABLEH2 Project Overview

Low NOx H2 Micromix Combustion (WP3)



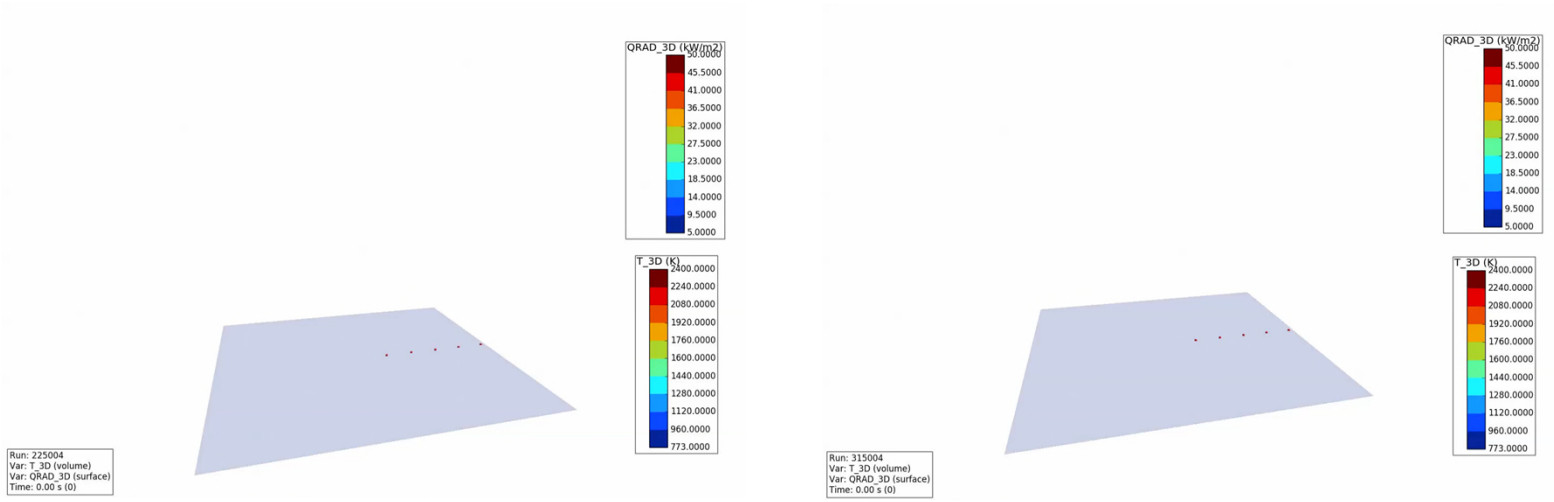






ENABLEH2 Project Overview
Safety (WP4)

- Dispersion LH_2 clouds
  - Hazardous distance study
- RE test facility: LH_2 tank leak
  - LH_2 Leak – Dispersion
  - Explosion overpressure
- Aircraft crash scenarios
  - Pool Fire simulations
  - LH_2 vs LNG vs JET A
- Aircraft refuelling study
  - LH_2 leak + explosion o/p



Liquid Hydrogen

Jet A (Kerosene)

Comparison combustion product temperature and radiation heat flux

ENABLEH2 Project Overview
Safety (WP4)

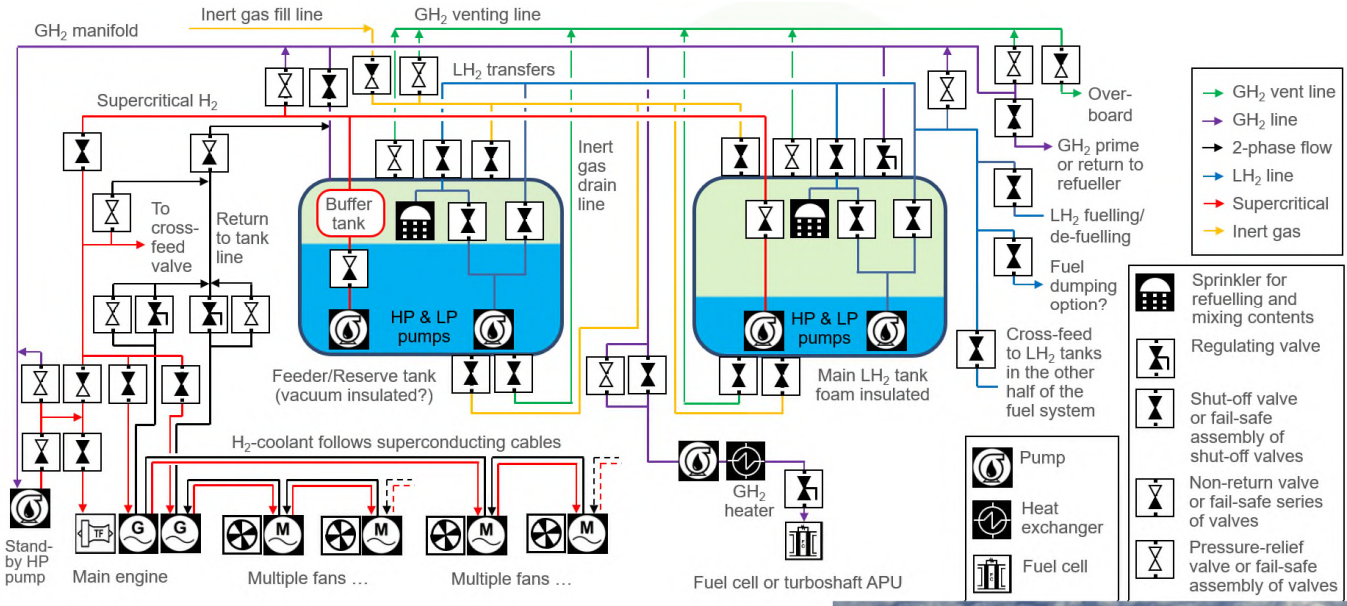
- PHA at Heathrow: Aircraft manufacturers, Airline, fire service
- New hazards examined or increases in severity and/or likelihood of harm
- Overall pragmatic & positive

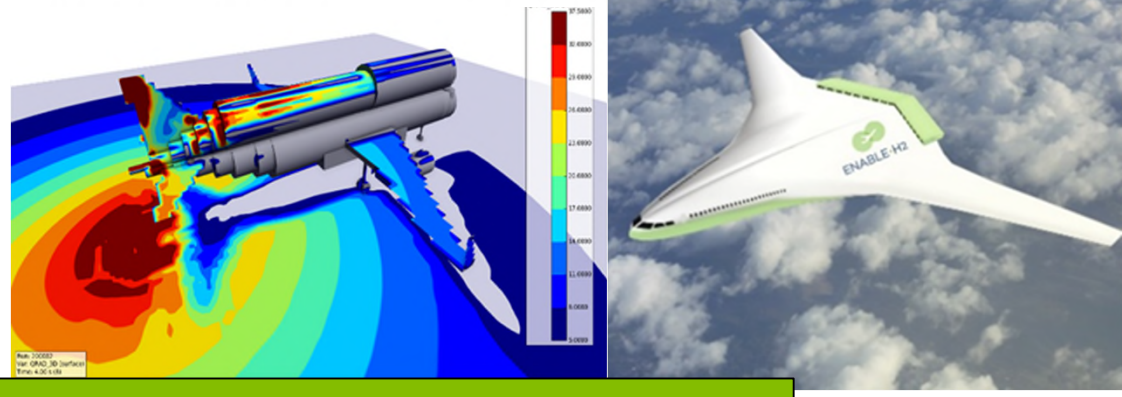
Storage, on-site generation	Fuelling (and ground transport)	Taxiing, take off, landing	Firefighting
• Scale & location • Explosion • Existing mitigation	• Underground/ vehicle/ robot supply • Cryogenic/ fire hazards • Many unknowns	• Fuel leaks • Runway excursion • Similar hazards and prevention to Jet A	• Largescale change • Protocols & standards • Training & equipment • Whole fire service

[6,7,8]

Zero Emissions Systems Technologies 1
(ZEST1)

- **WP1.4.1: "LH_2 Technology Development"**
  - LH_2 Composite Tank and Engine Feed
  - LH_2 Gauging, Sensors and Tank Fluid Movement modelling
- **WP1.4.2: "LH_2 Safety, Regulations and Airport Operations"**
  - LH_2 Safety Development
  - LH_2 Airport Regulations Development
  - LH_2 Ground Infrastructure and Airport Operations
- **WP1.4.3: "LH_2 Systems Development, Control and Evaluation"**
  - LH_2 Systems Design and Control
  - LH_2 Thermal and Fluid Modelling



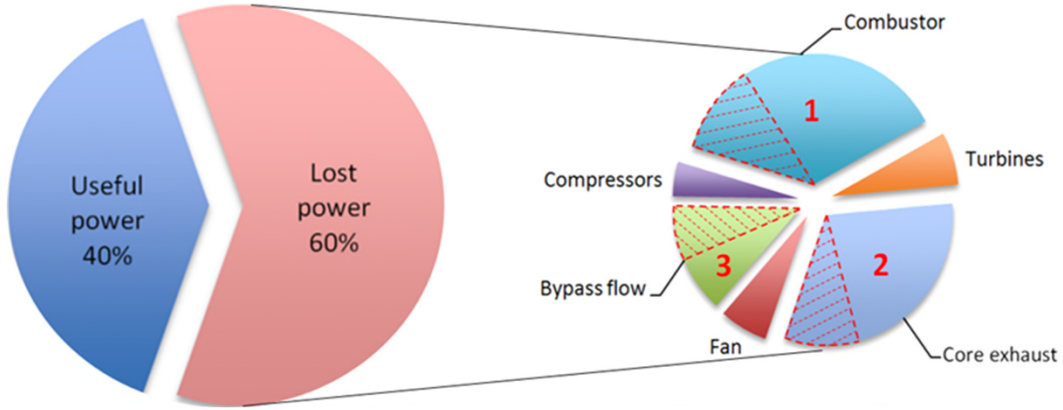


Delivery of multi-fidelity modelling suite for LH_2 tanks, gauging, sensors, sloshing, thermal management and control
Definition of infrastructure requirements, safety and airport operational protocols
Important (early) engagement with key civil aviation stakeholders including certification bodies
Definition of future experimental campaigns for validating models and maturing technologies to expedite EIS

Minimum Environmental Impact Ultra-Efficient Cores for Aircraft Propulsion (MINIMAL)

Project Partners:

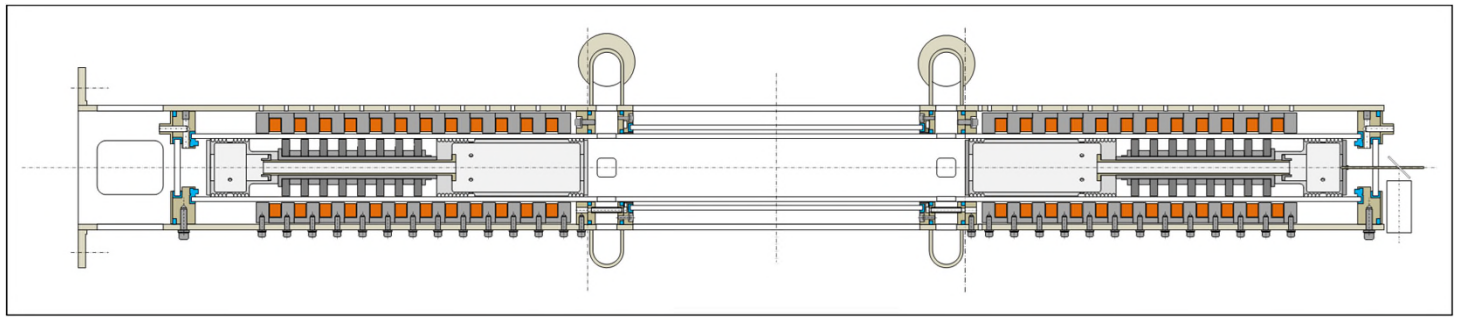
- Arttic innovation, Bauhaus Luftfahrt, MTU
- Aristotle University of Thessaloniki
- Technical University Delft
- Chalmers University (Coordinator), GKN Aerospace
- Cranfield University, Reaction Engines, Rolls Royce UK



"Assessing the potential of disruptive propulsion technologies to address the major loss sources of aero engines"

The MINIMAL project is receiving funding from the European Union's Horizon Europe research and innovation programme under grant agreement No: 101056863

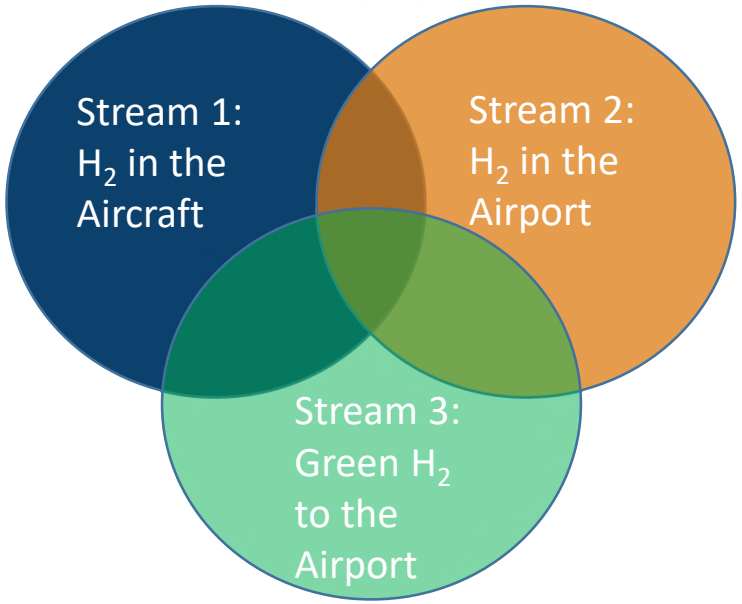
UK partners are being funded by UKRI (IUK), Project No: 10040930 under the Horizon Europe Guarantee.



CU and RRUK are investigating an Opposed Free Piston-Based, H_2-fuelled Pressure Rise Combustion System

UK-ARC H_2 Group (CU – lead) Scope:

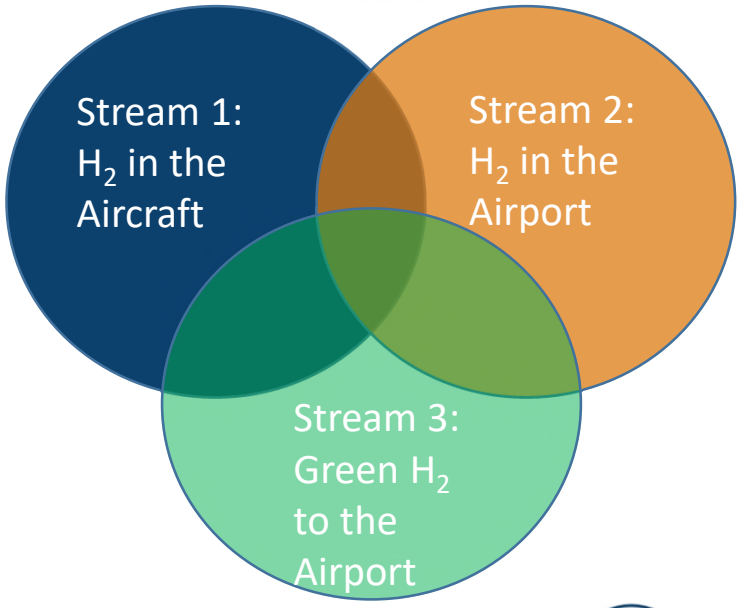
Thematic Areas and Mapping of Expertise and Ambitions



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

UK-ARC H_2 Group (CU – lead) Scope:

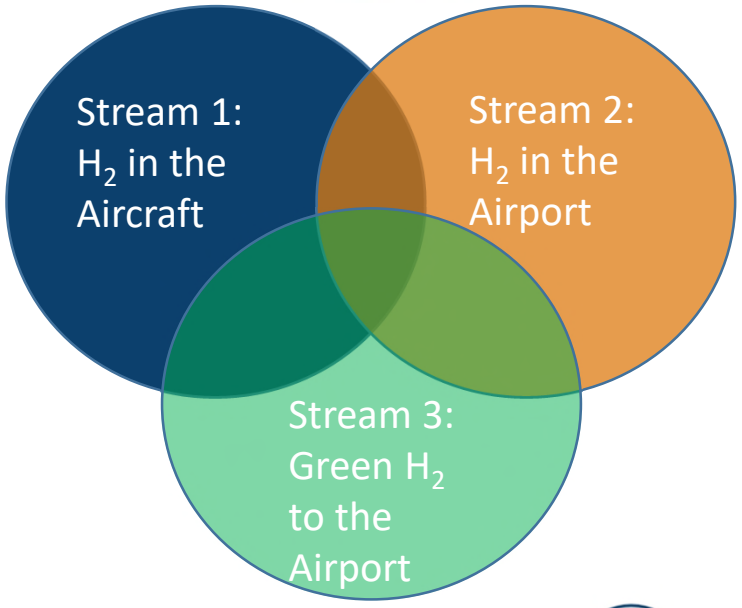
Thematic Areas and Mapping of Expertise and Ambitions



H_2 in the Airport
H_2 aircraft ground operations and airport infrastructure
H_2 safety (airport, storage, aircraft, refuelling)
Airport design for electric aviation

UK-ARC H_2 Group (CU – lead) Scope:

Thematic Areas and Mapping of Expertise and Ambitions



H_2 to the Airport
H_2, NG and nuclear gas turbines and rotating equipment for land and marine
H_2 from renewables
H_2 from fossil fuels and CCS
Seawater electrolysis (necessary to protect freshwater supplies)
H_2 / other routes for making SAF
Non-fossil production of lubricants
Automotive and FCs and ICEs for marine

UK AEROSPACE RESEARCH CONSORTIUM

UKRI Engineering and Physical Sciences Research Council

Advancing UK Aerospace Research through University Collaboration

UK-ARC facilitates and promotes value-added aerospace research projects across university boundaries and with the sector. As a growing community with a net zero focus, UK-ARC connects experts and stakeholders, expands use of university research facilities and builds international collaborations.

Roger Gardner: r.gardner@cranfield.ac.uk, tel: 07831 174503
Donna Lynch: donna.lynch@cranfield.ac.uk

www.ukarc.ac.uk

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The ENABLEH2 project is receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 769241

Thank you!

Cranfield University

London South Bank University

GKN AEROSPACE

SAFRAN

EHA EUROPEAN HYDROGEN ASSOCIATION

Heathrow

ARTTIC

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