SGUK GREEN ECONOMY FRAMEWORK

British High Commission Singapore

Cranfield Environment and Agrifood

HyDEX

Singapore-UK Jet Zero Workshops

Workshop 2: Hydrogen

26 March 2024

UKRI Research England

Before we start...

- No fire alarms expected
- Toilets
- Wi-Fi:
- Please join the conversation about today's event on social media:

  #UKSGEF
  #UKSingaporeJetZero
  @HyDEXMidlands
  @CranfieldUniversity

Time	Agenda
10:00-10:30	Arrival & Reception (coffee/tea/ snacks)
10:30-11:00	Welcome & Introduction: Lauren Babuik (Head of Nature, Climate and Energy, British High Commission Singapore)
11:00-11:15	Welcome and overview, intent of the workshops: Professor Ron Corstanje
11:15-11:30	Overview of The Midlands Hydrogen Ecosystem: Faye McAnulla (HyDEX Programme Director)
11:30 -12:00	UK presentation on Hydrogen: Dr. Sharon George (Keele University), Dr. Sandun Dissanayake (Cranfield University), Dr. Tongtong Zhang (University of Birmingham), Prof Kumar Patchigolla (Teeside University) and Dr. Nahid Yazdani (University of Nottingham)
12:00-12:30	Singapore presentation on Hydrogen: Dr. Paul Liu (Nanyang Technological University) and Dr Wong Roong Jien (A*star)
12:30-13:30	Lunch & Networking
13:30-14:45	Roundtable Discussion (All participants)
14:45-15:15	Afternoon refreshments
15:15-15:45	General feedback and room level discussion (All participants)
15:45-16:00	Recap and closure of workshop (Professor Ron Corstanje)

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Singapore UK Jet Zero Workshops

- ***Green aviation*** is one of the priority sectors identified in the UK-Singapore Green Economy Framework and in the UK Jet Zero strategy.
- ***Creating collaboration and promotional activities for both UK and Singapore businesses and research communities***
- Establish ***a comprehensive and strategic roadmap for aviation ecosystem decarbonisation***

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Challenges in Aviation Decarbonization

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Some Key facts and figures

Aviation's CO_2 emissions make up about **2.5%** of global totals, but is potentially much higher due to the **non-CO_2 effects**

Non-CO_2 impacts contribute **two-thirds** of aviation's net radiative forcing

By 2050, a projected **10 billion** air passengers will travel **22 trillion km** annually, generating nearly **2,000 Mt** of CO_2

From **2005 to 2019**, aviation fuel efficiency improved by ~ **39%**, but absolute emissions growth far more than efficiency gains

Why is Aviation a difficult sector to decarbonise ?

Long replacement time for aeroplane
(commercial aircraft can last between 20 to 30yrs)

Challenges around regulatory support

Investment required for decarbonisation
(e.g., Capital expenditure on SAF production facilities is estimated at up to $1.45 trillion over 30 years)

Requirement for global collaboration and coordination

Bold investment and breakthroughs required in R&D

Passenger reluctance on the cost of decarbonisation solutions

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Solutions for Jet Zero

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Utilisation of alternative fuels

- Sustainable Aviation Fuel (SAF)
- Hydrogen (H_2)
- Electric (propulsion)
- Ammonia (NH_3)

Improvements in aircraft fuel efficiency

- Aircraft design
- Efficient engine
- Lightweight materials
- Improved systems

Enhancements in air traffic control & operational measures

- Optimised flight planning
- Dynamic airspace management
- Artificial Intelligence (AI)

Strategies for non-CO2 emission

- Alternative fuel
- Avoidance of Contrail cirrus formation
- Aircraft design
- Advanced engine technology

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Workshop 2: Hydrogen

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What: Challenges on developing the Hydrogen economy & supply chain for aviation

- Zero carbon emissions (in flight)
- Reduction in climate impact: 75%-90% reduction for H2 fuel cell; 50%-75% reduction for H2 turbine
- Improved air quality (NO2 reduction: 100% for fuel cell; 50%-80% for H2 turbine)

- Increased contrail coverage
- Aircraft, airport and air transport infrastructure redesign
- Cost: Carbon-free H2 production is 3 times CAF
- Short-range aircraft (H2 fuel cell)

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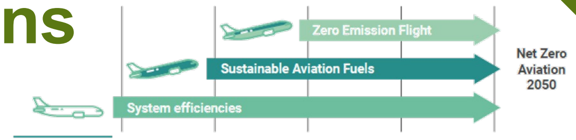
Workshop 3: Policy Ambitions



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What: Policy ambitions contrasted onto existing and future SAF and Hydrogen technological capabilities

Singapore: 20% in 2030, net zero by 2050

Regulatory tools	Supply & Demand-side Actions	Collaborations
SAF mandates: 2026 - Initial target of 1% SAF usage, over 1% in 2026, and 3-5% by 2030.	**Supply-side:** Regional SAF feedstock study and SAF production capacity program **Demand-side:** Corporate Buyers' Club; Offtake Mechanism for SAF; SAF procurement mechanism	**International collaboration:** "green lanes, SAF experience & knowledge sharing. **Industry collaboration:** MOU between CAAS and Airbus (SAF & Hydrogen)

UK: Net zero domestic and airport (2040)
Net zero UK (2050)

Regulatory tools	Direct support	Enabling activities
• **SAF mandate:** 10% in UK fuel mix by 2030 (in place by 2025) • UK Emission Trading Scheme (ETS)	• **SAF infrastructure:** £180 m UK SAF industry growth; £135 m Advanced Fuels Fund • **R&D:** e.g., £12 m UK SAF clearing house; £400 m Breakthrough Energy Catalyst	• Five-year delivery plan • **Set Emissions reduction trajectory** 35.4 $MtCO_2$ in 2030, 28.4 $MtCO_2$ in 2040, and 19.3 $MtCO_2$ in 2050

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Capabilities in the HyDEX Network

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The University of Birmingham

Working with Tyseley Energy Park (TEP) and other partners in the Midlands, the University of Birmingham is pioneering infrastructure solutions in renewable heat and power, energy storage and clean transport fuels in combination with advanced waste processing. TEP features a hydrogen refuelling station and integrated ammonia cracker.

The University of Nottingham

The University of Nottingham is home to world-leading expertise in powertrain research and hydrogen storage solutions, with impressive, purpose-built hydrogen laboratories situated in the Research Acceleration and Demonstration building on the Net Zero Flagship Jubilee Campus.

Our HyDEX demonstrator is focused on the development of the “Flex Fuel” engine, which has the ability to flex between hydrogen (H_2) and ammonia (NH_3) as a retrofit solution for existing heavy duty diesel engines using advanced technology.

Loughborough University

Our hydrogen research areas encompass all areas of hydrogen from production through to end use including storage, distribution, combustion, policy, economics and safety, sustainability analysis and lifecycle management.

The University of Warwick

Warwick’s focus is on exploring and demonstrating how to use renewable sources to produce hydrogen. A novel green hydrogen production system has been found to be more efficient than current methods of hydrogen production. The evaluation of the technical and economic performance of this system is a core theme in its work which will upscale this innovative green hydrogen production to full commercial scale.

Aston University

Aston University specialises in the production methods needed to provide a reliable, affordable and green supply of hydrogen. With a long history in gasification and pyrolysis research, the Energy and Bioproducts Research Institute (EBRI) at Aston carries out world-leading research into new and innovative ways of converting biomass into sources of sustainable energy such as hydrogen, using thermochemical, biological and catalytic processes.

Keele University

Keele University has a long been involved in hydrogen research and innovation. Using the campus as a living laboratory, the HyDEPLOY trial demonstrated that a blend of 20% hydrogen could be used in the heating network.

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Capabilities in Cranfield University

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Airside Hydrogen Production

Hydrogen based aviation

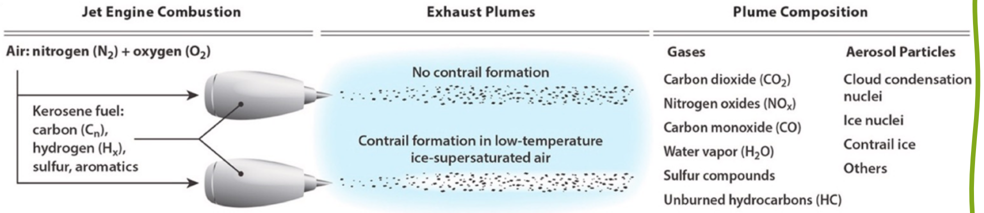
Environmentally friendly ways of making crop-based SAF

Mixed food-fuel cropping for SAF production by applying multi-cropping techniques.

Integration of hydrogen and SAF systems in the Cranfield Global Research Airport: Airport of the future

Cranfield's 'Living Laboratory' campus and airport of the future

Reducing the climate impact of aircraft (CO_2 and non-CO_2 emissions)



Aviation CO_2 and non-CO_2 emissions, adapted from Lee et al. (2021)

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Blueprint for Zero Emission Flight and Infrastructure

ENERGY INNOVATION

SYSTEMS INTEGRATION

ENABLING JET ZERO

Phase	TRL	Activity/deliverable
Research	1	Idea... basic principles investigation
	2	Concept development, core questions investigated through simulation/bench top component models
	3	Concept validation experiments/experimental core systems bench top tests
Development	4	Experimental bench top pre-prototype system in lab
	5	Small-scale prototype in relevant environment
	6	Integrated pilot scale demonstrator
Deployment/ commercialisation	7	Pre-commercial demonstrator
	8	MVP/commercial launch
	9	Commercialisation and product enhancement

Energy Innovation

Systems Integration

Enabling Jetzero

Utilization (TRL 6-9)

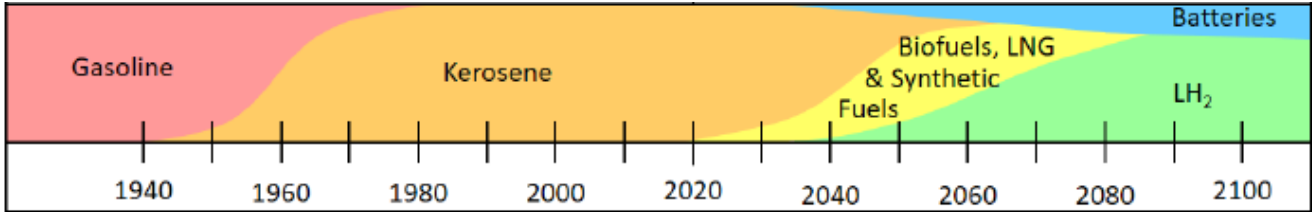
Innovation Wave 1
10-15 Years
Focus: Certification


Innovation Wave 2a
20+ Years
Focus: Efficiency


Innovation Wave 2b
20+ Years
Focus: FC Certification

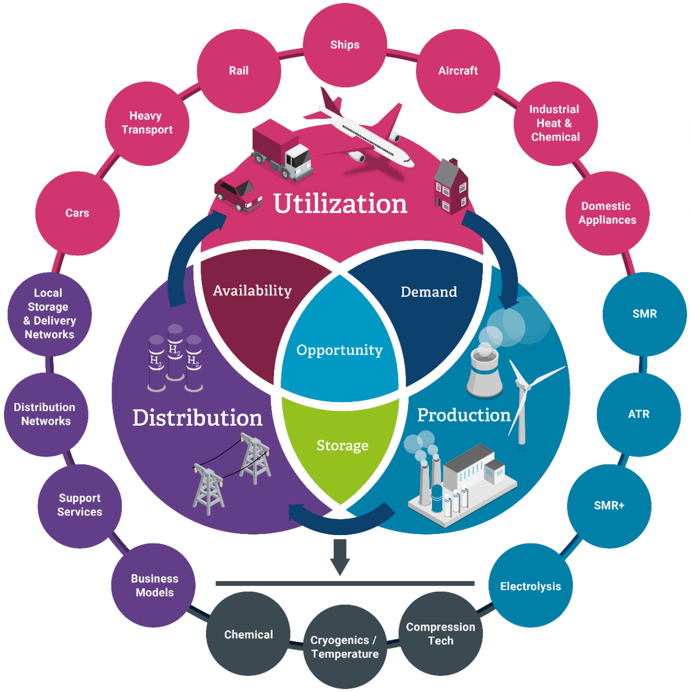

Innovation Wave 3
30+ Years
Focus: Turbo-cryo-electric

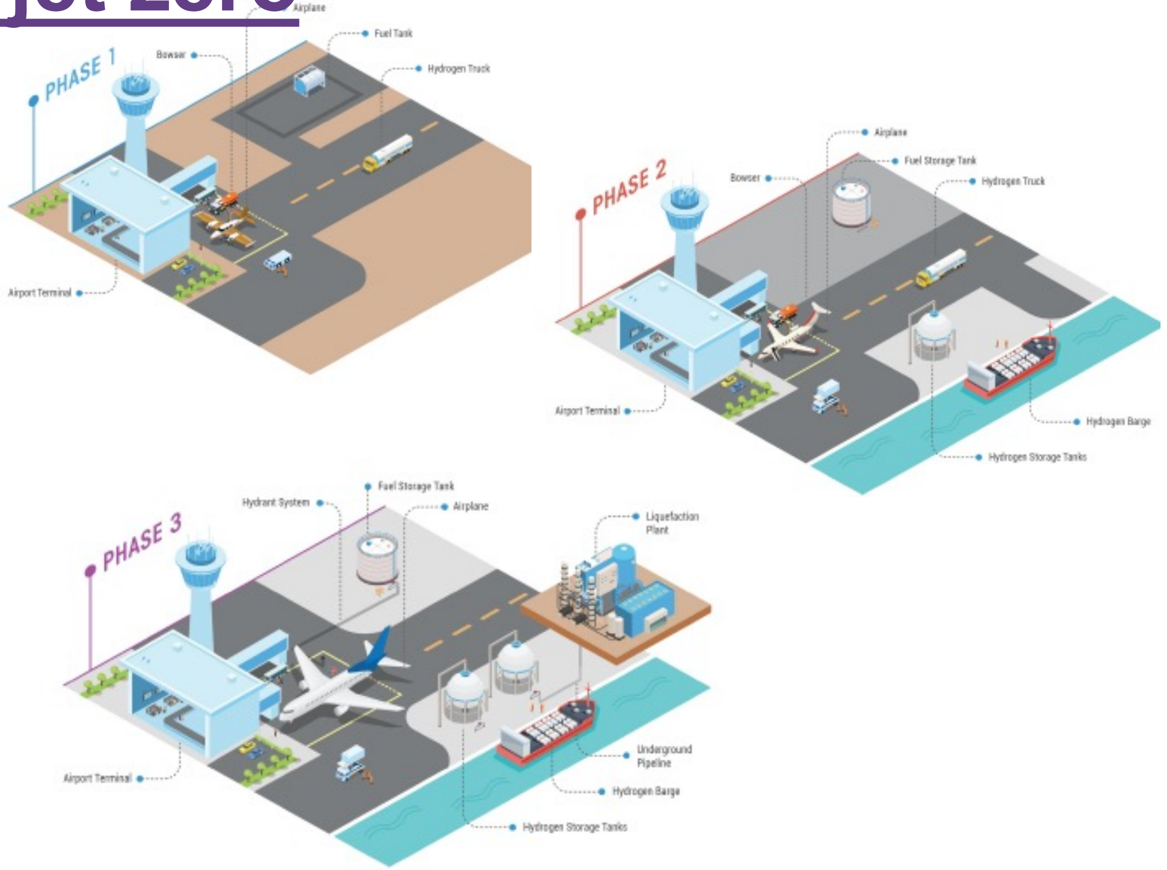




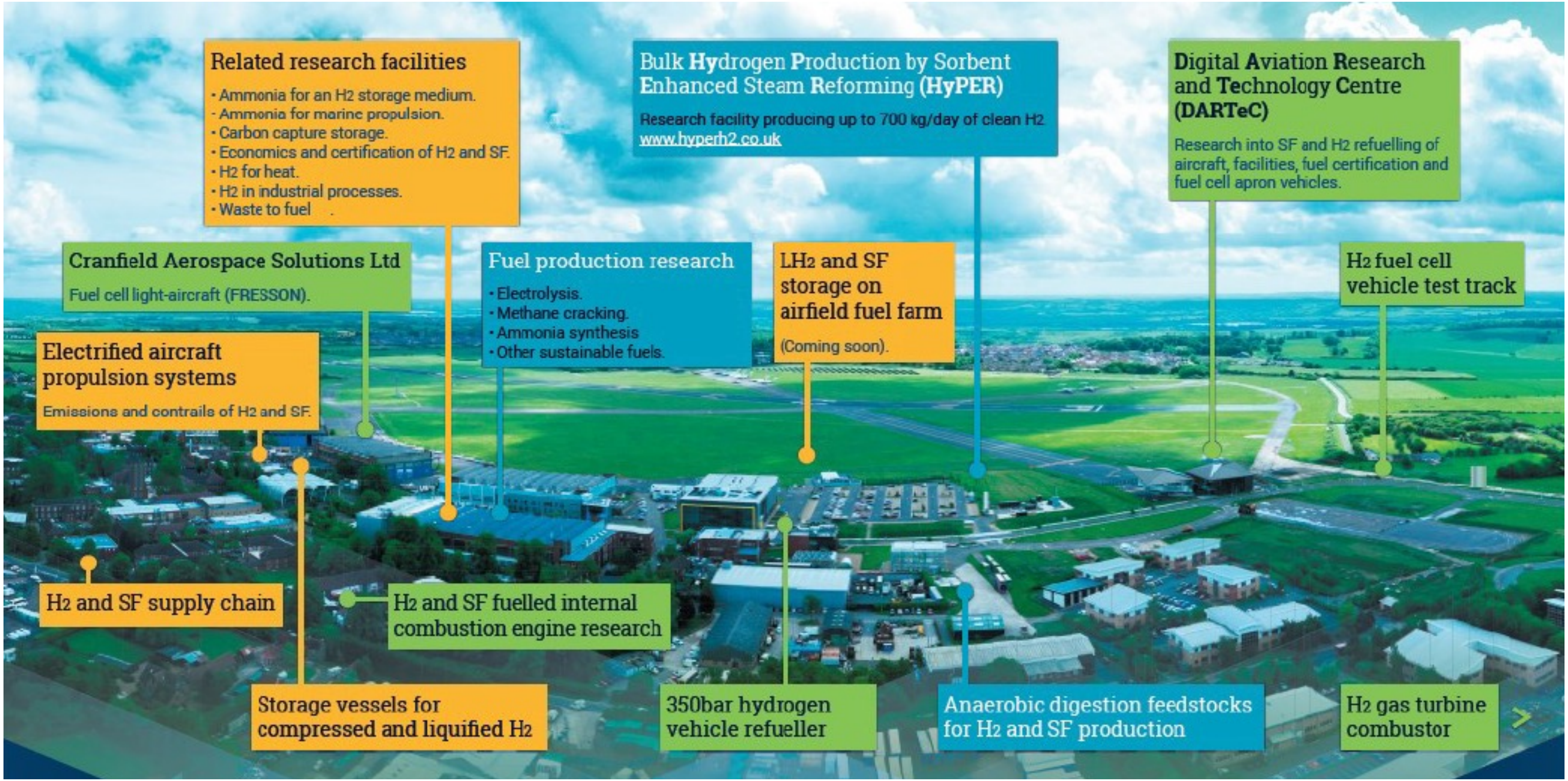
Enabling a H_2 integration ecosystem

The blue print for jet zero



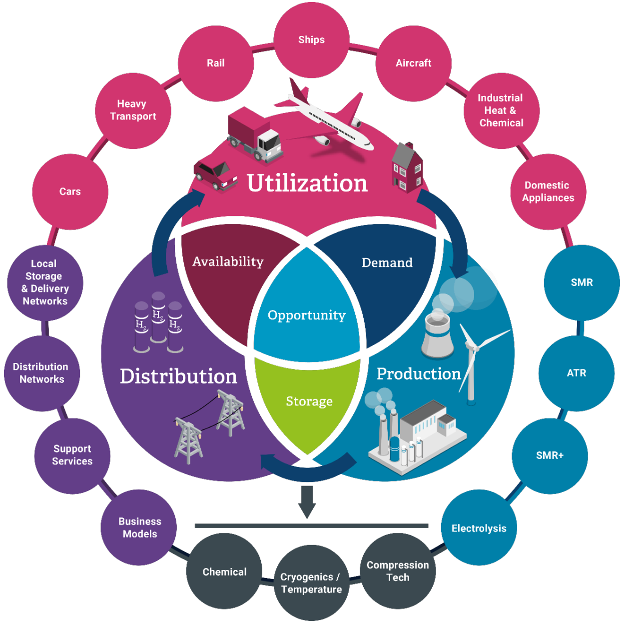


Cranfield’s Active Hydrogen Research Ecosystem



Feedstocks and fuel production. | Transport, storage, economics, supply chain. | End users – aerospace and road vehicles. | • H_2 = Hydrogen | • LH_2 = Liquid hydrogen | • SF = Sustainable fuels

Utilization (TRL 6-9)



ENABLE H2

Cranfield University

Net Zero Research Airport

Cranfield Aerospace Solutions

CAeS-7

GKN-40

How can we accelerate our journey?

With over £46 million of co-investment secured from Cranfield University and our partners, we have been awarded £24 million from UK RPIF to deliver three interrelated transformative infrastructure programmes to accelerate the journey to net zero:

ENERGY INNOVATION

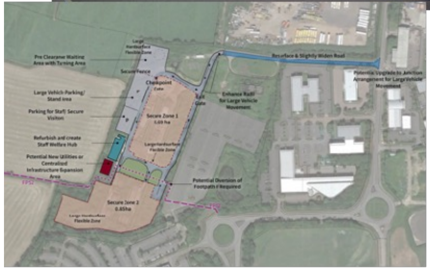
- **A new £12 million Hydrogen Integration Research Centre (HIRC)**: Enabling research linking developments in hydrogen production, storage, SAF, ammonia and hydrogen refuelling for mobility to accelerate TRLs 2-4 to Enable Jet Zero

SYSTEMS INTEGRATION

- **A £9 million investment in hydrogen gas turbine combustor testbed**. Hydrogen testbed that will enable hydrogen transition for aviation; to accelerate this expansion and modernisation is required to accelerate TRLs 4-6 to Enable Jet Zero

ENABLE JET ZERO

- **A £22 million investment in the Global Research Airport to drive net zero mobility.** Development and co-location of multiple fuels on one airport . TRLs 6-9 to Enable Jet Zero



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UK Presentation on Hydrogen

UKRI
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The Midlands Hydrogen Ecosystem

Faye McAnulla (HyDEX Programme Director)

Cranfield University

HyDEX

British High Commission Singapore

The Midlands Hydrogen Ecosystem

- Worcester-Bosch, Baxi and Cadent (hydrogen boilers and gas networks),
- Intelligent Energy (fuel cells),
- Alstom and Porterbrook (hydrogen trains),
- Toyota (hydrogen vehicles),
- Horiba-MIRA (vehicle test and host of R&D cluster),
- Caterpillar, Faun Zoeller and JCB (heavy vehicles), DVNGL, BSI, Cenex (established low carbon transport consultancy),
- Equans (District Heating Networks), SSE, Progressive Energy
- ITM Power nearby, Siemens and ENGIE are also working closely with regional partners in next-generation hydrogen production and storage.

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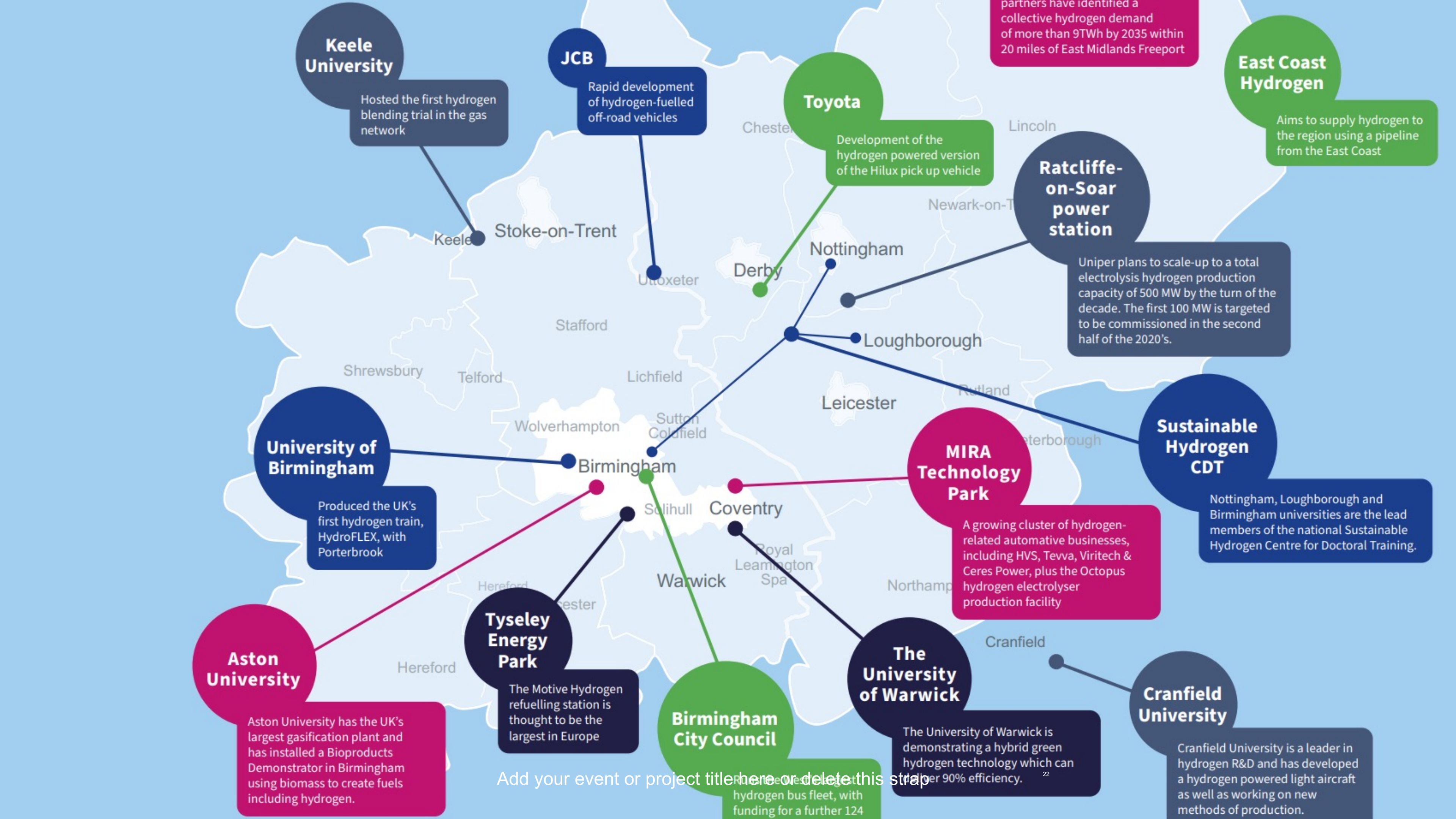


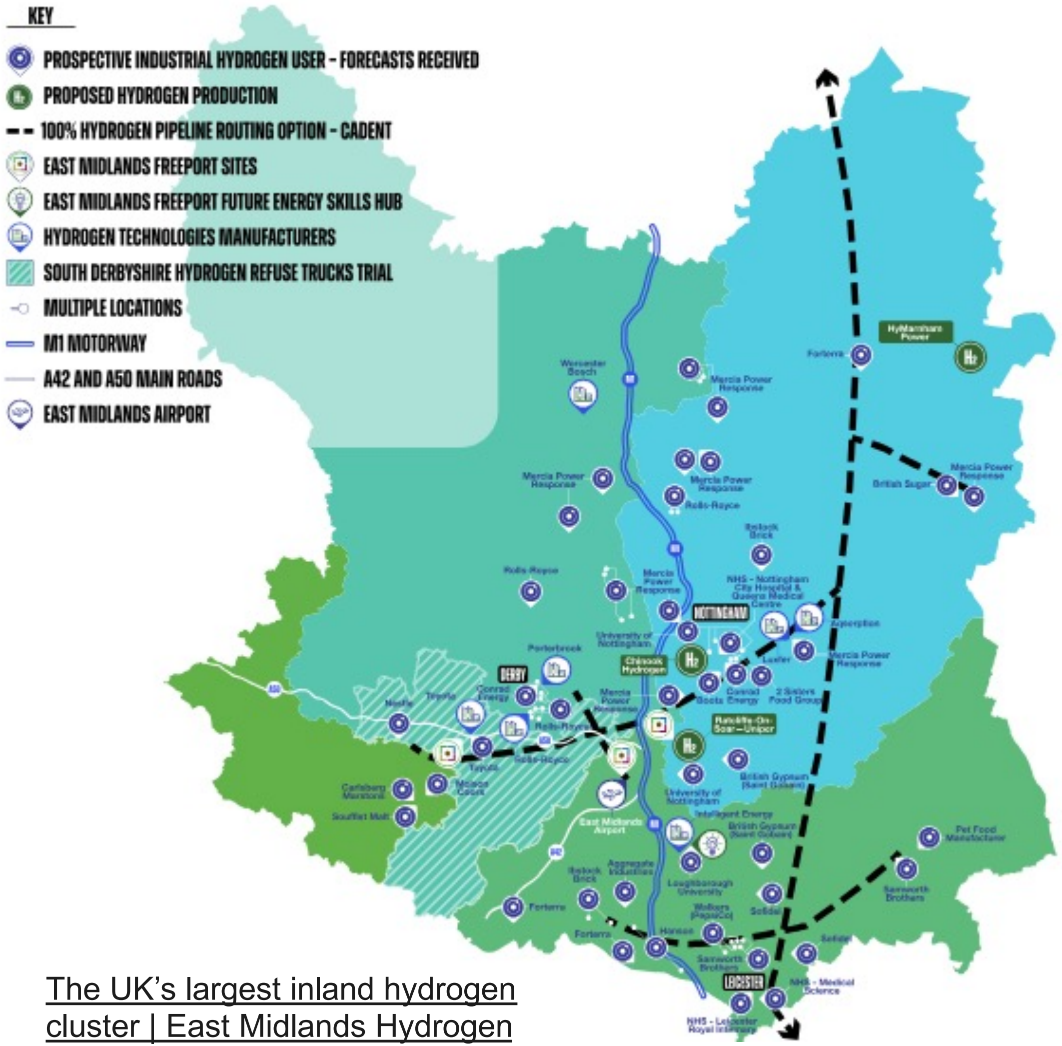
Add your event or project title here or delete this strap

East Midlands Hydrogen

- Cluster of hydrogen demand forecasts from around 70 industrial sites in the Nottinghamshire, Derbyshire and northern Leicestershire regions

- Major hydrogen pipeline

- More than 10TWh of hydrogen by 2040 in total, with carbon savings of 1.9 MT/yr (= 860,000 homes)



The UK's largest inland hydrogen cluster | East Midlands Hydrogen

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Sustainable Hydrogen
CENTRE FOR DOCTORAL TRAINING

HyDeploy

Cranfield University

HyDEX

UK BATTERY INDUSTRIALISATION CENTRE

Tyseley Energy Park, Birmingham

2synfuel

TCR500 Demonstrator Hohenberg Germany

- Successful Conversion of 2000 tonnes of Sewage Sludge
- 200 tonnes of Green Diesel Produced
- 30 Tonnes of Green H2 Produced
- Total Operating time 4000 Hours Continuous
- TRL 7-8

Next step – looking for investment to develop commercial site Tyseley Energy Park, Birmingham.

ENERGY RESEARCH ACCELERATOR

HyDEX

TYSELEY ENERGY PARK

HyDEX Demonstrators

ENERGY RESEARCH ACCELERATOR

Flex Dual-Fuel Heavy-Duty Engine

H2, NH3 … and more!

University of Nottingham
UK | CHINA | MALAYSIA

MAHLE Powertrain

clean air power™

Decarbonisation via Dual-Fuel Operation

100% Diesel Operation Possible!

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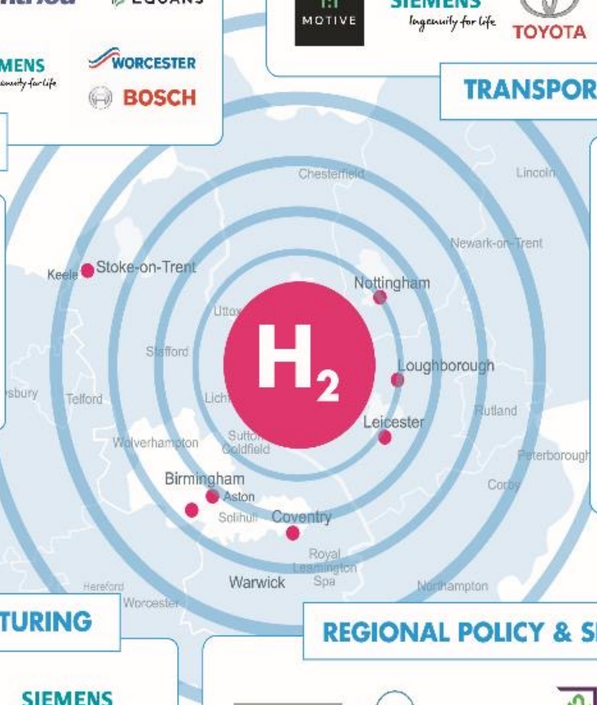
Funded by UKRI Research England

Delivered by ENERGY RESEARCH ACCELERATOR

Supported by MIDLANDS ENGINE

Regional focus, national impact, internationally networked

- Enable large-scale renewables integration and power generation
- Act as a buffer to increase energy network resilience
- Distribute energy across sectors and regions
- Decarbonise, Production, Transport, Heating and cooling Industrial processes



HEATING
Cadent Your Gas Network; centrica; EQUANS; Progressive energy; SIEMENS Ingenuity for life; WORCESTER BOSCH

TRANSPORT
MIRA; cenex; Intelligent Energy; JCB; MOTIVE; SIEMENS Ingenuity for life; TOYOTA; FAUN Kirchhoff Group; ZOELLER

PRODUCTION
EDF ENERGY; PROGRESSIVE ENERGY; uniper

INTERNATIONAL ACADEMIC PARTNERS
RWTH AACHEN UNIVERSITY; UNSW SYDNEY

ERA UNIVERSITY PARTNERS
Aston University Birmingham UK; University of Birmingham; Cranfield University; Keele University; University of Leicester; Loughborough University; University of Nottingham UK | China | Malaysia; Warwick The University of Warwick

MANUFACTURING
British Ceramic Confederation; SIEMENS Ingenuity for life; WORCESTER BOSCH; TOYOTA

REGIONAL POLICY & SKILLS
Black Country LEP; CWLEP Coventry & Warwickshire; D2N2; Greater Lincolnshire Local Enterprise Partnership; LLEP Leicester & Leicestershire Enterprise Partnership; The Marches Local Enterprise Partnership; Stoke-on-Trent & Staffordshire Enterprise Partnership

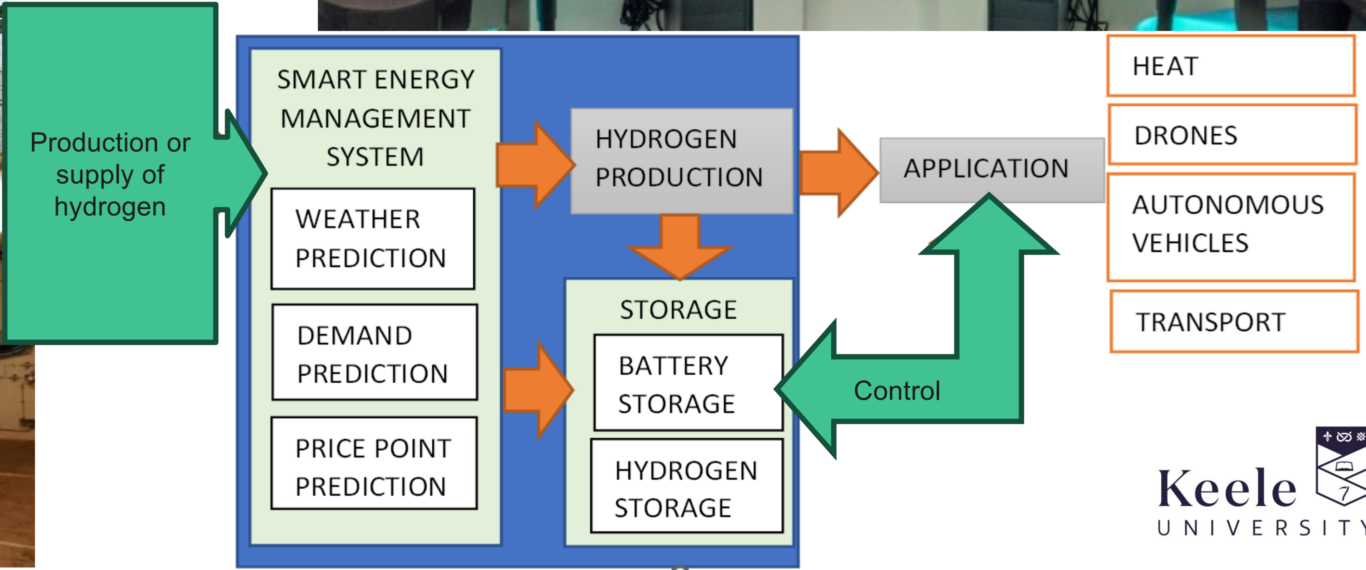
Hydrogen Capabilities in the UK

Keele Smart Hydrogen Network Demonstrator

Dr. Sharon George (Keele University)

Keele Smart Hydrogen Network Demonstrator

Demonstration and modelling of **hydrogen optimisation** through management and control
On-site prediction, and real-time verification trials
Perception and acceptance (commercial and public)



Keele UNIVERSITY

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Cranfield Hydrogen Production Demonstrators

Dr. Sandun Dissanayake (Cranfield University)

Cranfield University

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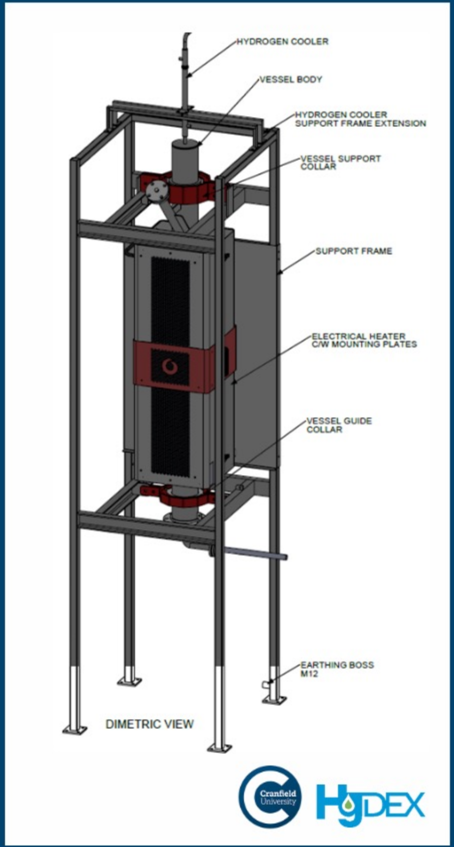
Blue Hydrogen Demonstrator



Turquoise Hydrogen Demonstrator

Bio-Methane Demonstrator

HyPER

200 kg/day (16 bar max)

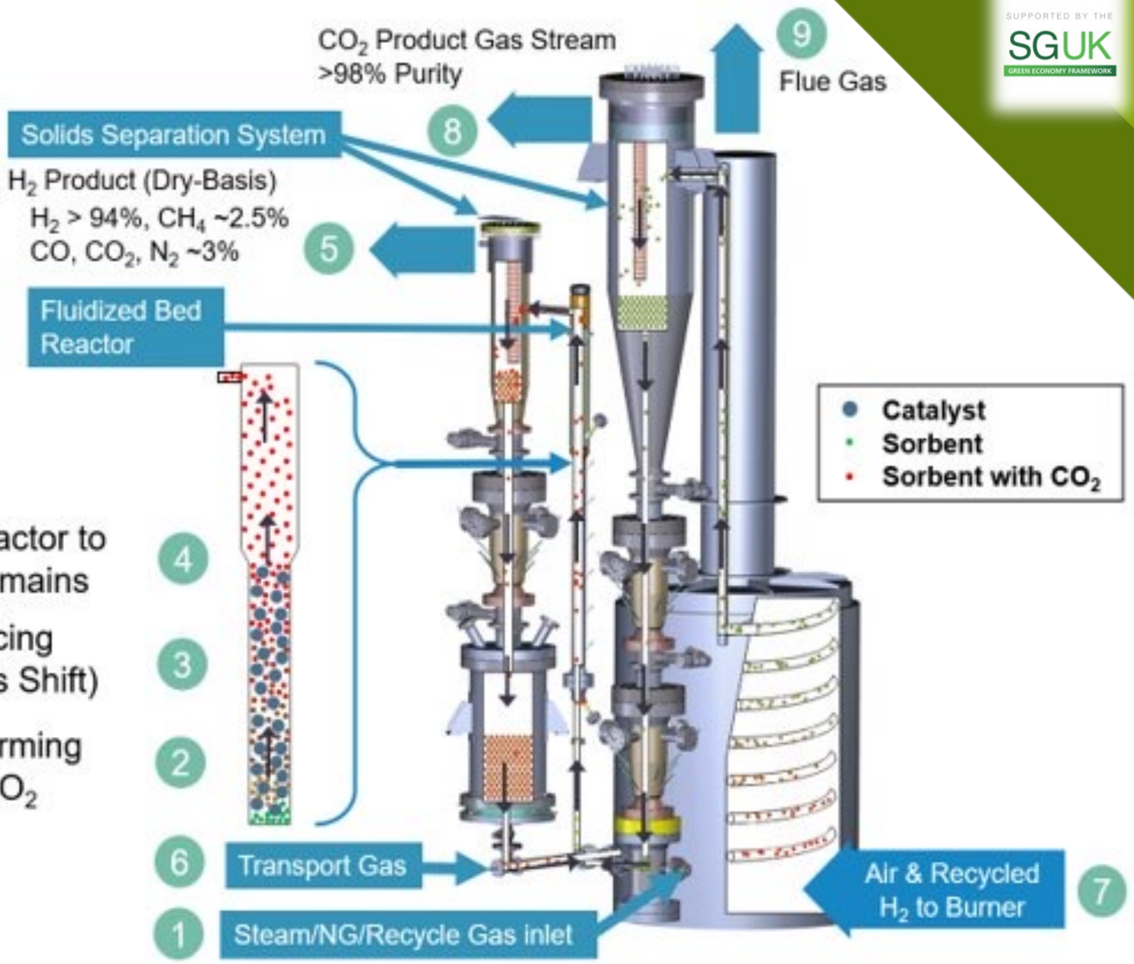
Sorption Enhanced Reforming (SER)

$$CH_4 + 2H_2O + Heat(a) \longrightarrow 4H_2 + CO_2$$
$$CaO + CO_2 \longrightarrow CaCO_3 + Heat(b)$$
$$CH_4 + 2H_2O + CaO \longrightarrow 4H_2 + CaCO_3$$
$$Heat(b) \sim 95\%\ Heat(a)$$

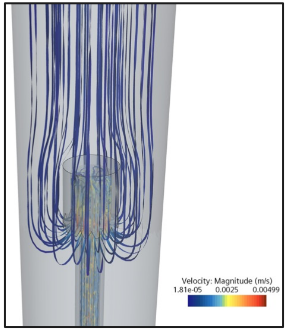
Sorbent elutriates through reactor to filter while heavier catalyst remains

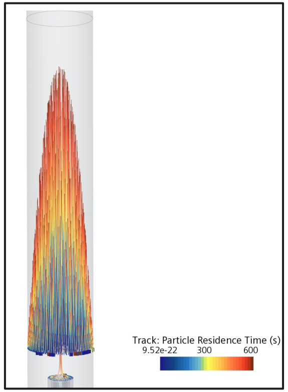
CO_2 absorbed by sorbent forcing more CO_2 to form (Water-Gas Shift)

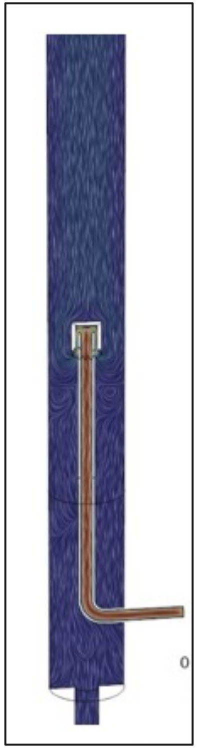
Steam Methane Reforming produces H_2, CO & CO_2

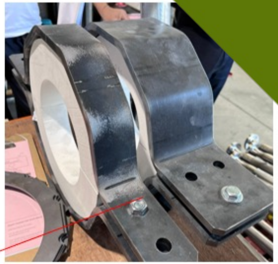


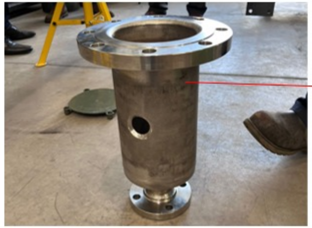
Turquoise Hydrogen Pilot (7kg/day)

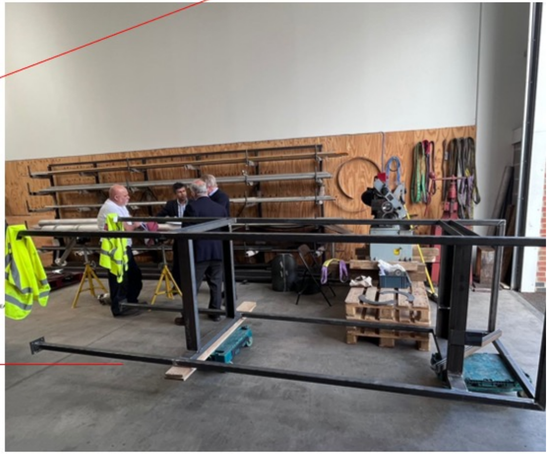












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Hydrogen Liquefaction and Storage

Dr. Tongtong Zhang (University of Birmingham)

Cranfield University

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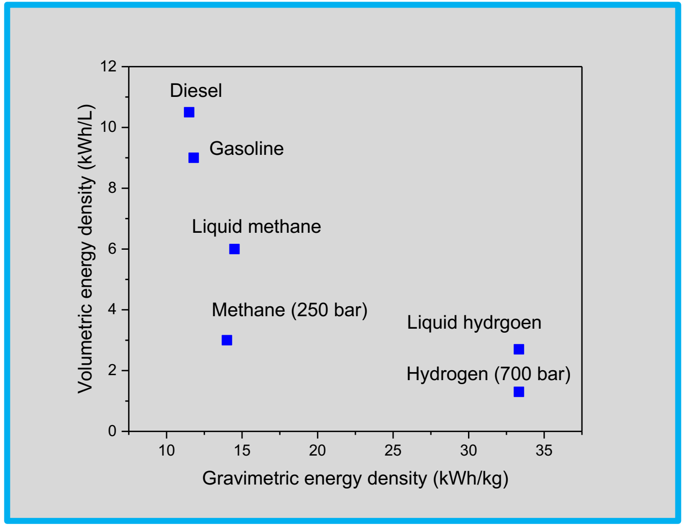
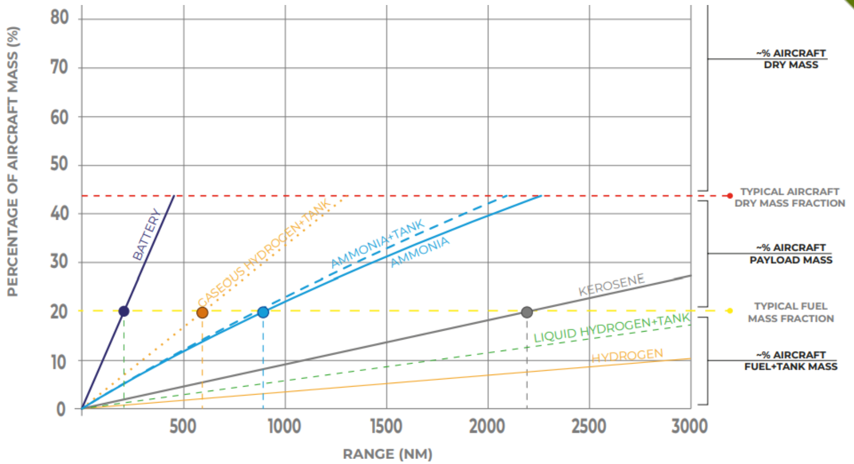
The need for Liquid Hydrogen

Liquid hydrogen has some salient characteristics



Fuel + tank storage mass and payload mass fractions vs aircraft range



Work by Aerospace Technology Institute – FlyZero

Liquid hydrogen application

- Liquid rocket fuel for rocketry applications
- Cool neutrons to be used in neutron scattering
- Long-distance energy transmission
- **Aviation technology**
- **Motor vehicles**

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY https://www.energy.gov/eere/fuelcells/hydrogen-storage

Hydrogen liquefaction

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Energy consumption performance - comparison between theoretical and commercial hydrogen liquefaction

Classical theoretical cycles
>10 kWh/kgLH$_2$
(Linde-Hampson and Claude cycles)

Large plants in-service
13.83 kWh/kgLH$_2$
(on average)

Optimised liquefaction cycles
<10 kWh/kgLH$_2$
(expander liquefaction cycles)

↓

Target for large-scale hydrogen liquefaction plants
6 kWh/kgLH$_2$
(US Department of Energy)

Minimum energy required
~3 kWh/kgLH$_2$
(thermodynamically ideal hydrogen liquefaction cycle)

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Zhang et al. (2023) Renewable and Sustainable Energy Reviews, 176, 113204

Hydrogen liquefaction

Future trend in hydrogen liquefaction technologies

Items	Current		Short to medium term	Long term
Liquefaction capacity	<3 tons/day	<50 tons/day	up to 150 tons/day	≥100 tons/day
Main refrigeration cycle	Brayton	Claude	High-pressure Claude	High-pressure Claude
Refrigeration medium	Helium	Hydrogen	Hydrogen	Hydrogen
Precooling cycle	Liquid nitrogen	Liquid nitrogen	Liquid nitrogen or mixed refrigerant	Mixed refrigerant
Feed pressure	10–15 bar	15–20 bar	20–25 bar	>20 bar
Compressor type	Reciprocating	Reciprocating	Reciprocating	Centrifugal
Specific energy consumption	>12.3 kWh/kgLH$_2$	>10.8 kWh/kgLH$_2$	7.7–10.8 kWh/kgLH$_2$	<9 kWh/kgLH$_2$
Investment cost (CAPEX)	++	O	–	–
Operating cost (OPEX)	–	O	+	++
CAPEX & OPEX	–	O	+	++

o Neutral (+) Strength (-) Weakness

Zhang et al. (2023) Renewable and Sustainable Energy Reviews, 176, 113204

Liquid hydrogen storage

Comparison between liquid-phase hydrogen storage methods

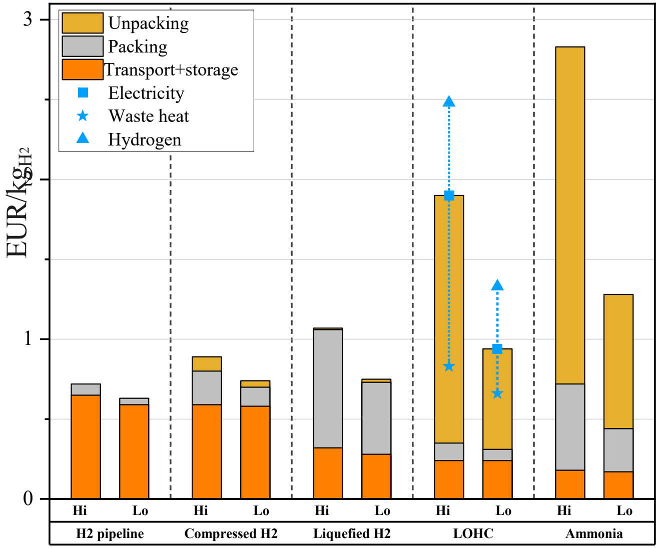
Assessment indicators		Liquid hydrogen	LOHC (MCH)	Ammonia
Technology maturity [a]	Conversion	Hydrogen liquefaction small scale: + Hydrogen liquefaction large scale: -	Hydrogenation: O	Haber-Bosch process: +
	Reconversion	Liquid hydrogen regasification: +	De-hydrogenation: O	Ammonia cracking: O
	Tank storage	O→+	+	+
	Transport	Truck: + Ship: O→+	Truck: + Ship: +	Truck: + Ship: +
	Supply chain integration	O→+	O	+
Conversion and reconversion total energy consumption [b]		Current stage: 25-40% LHV_{H2} Potential: ~18% LHV_{H2}	Current stage: 35-40% LHV_{H2} Potential: 25% LHV_{H2}	Conversion: 7-18% LHV_{H2} Reconversion: <20% LHV_{H2}
Hazards [c]		Flammable; no smell and flame visibility	Toluene; flammable; moderate toxicity (other LOHC can be safer)	Flammable; acute toxicity; precursor to air pollution; corrosive
Technology improvement needs		Hydrogen liquefaction plants efficiency; boil-off management; cryogenic energy recovery during regasification	Reconversion efficiency; conversion heat recovery	Conversion efficiency; hydrogen purification after ammonia cracking;
Supply chain developers		HySTRA; CSIRO; Air Liquide; Fortescue Metals Group	AHEAD; Chiyoda; Hydrogenious; Framatome; Clariant	Green ammonia consortium; IHI corporation; US department of Energy

Liquid hydrogen transportation

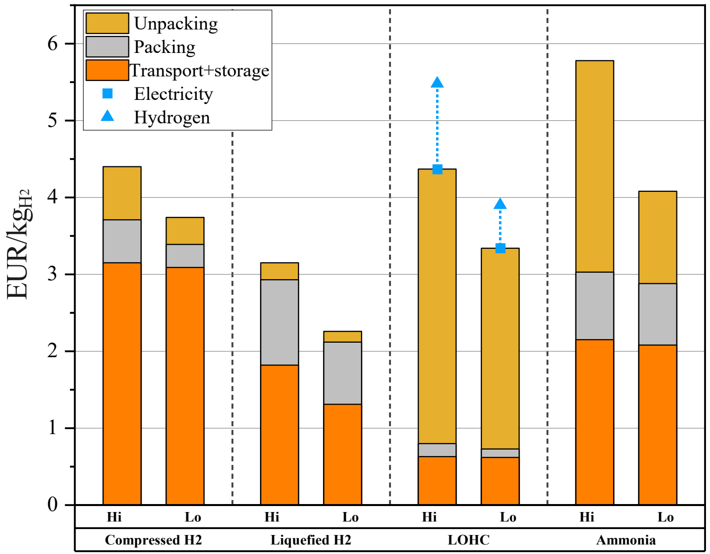
Transportation method	Transportation distance	Pressure	Hydrogen amount	Tank volume	BOG formation (per day)	Application examples or projections
Road	**Mid-range distance**	**≤ 7 bar**	**4 ton per truck**	**≤ 64 m^3**	**0.5 vol%**	**Air Products** transports liquid hydrogen via liquid semi- trailers with a capacity of 12,000 to 17,000 gallons (45-64 m^3).
Railway	**>1000 km**	**≤ 7 bar**	**7 ton per rail car**	**105 m^3**	**0.2 vol%**	**National Renewable Energy Laboratory** estimated that LH_2 rail delivery cost is likely to be lower than that of CGH_2 and LH_2 trucks/ pipelines delivery for long-distance and large-scale application.
Maritime	**Transoceanic delivery**	**≤7 bar**	**60 ton per tank**	**1,250-40,000 m^3**	**<0.2 vol%**	A pilot-scale liquid hydrogen supply chain **between Australia and Japan** (HySTRA Project, 1250 m^3 ship) has been completed in 2022.

Economic aspects of liquid hydrogen
Long-distance transportation

Projected costs (2030-2035) of green hydrogen delivery with different storage methods for a transporting distance of 2500 km



Delivering green hydrogen to a single customer - 1 MtH_2 per year



Delivering green hydrogen to a network of 270 hydrogen refuelling stations - 500 km distribution distance & 0.1 MtH_2 per year

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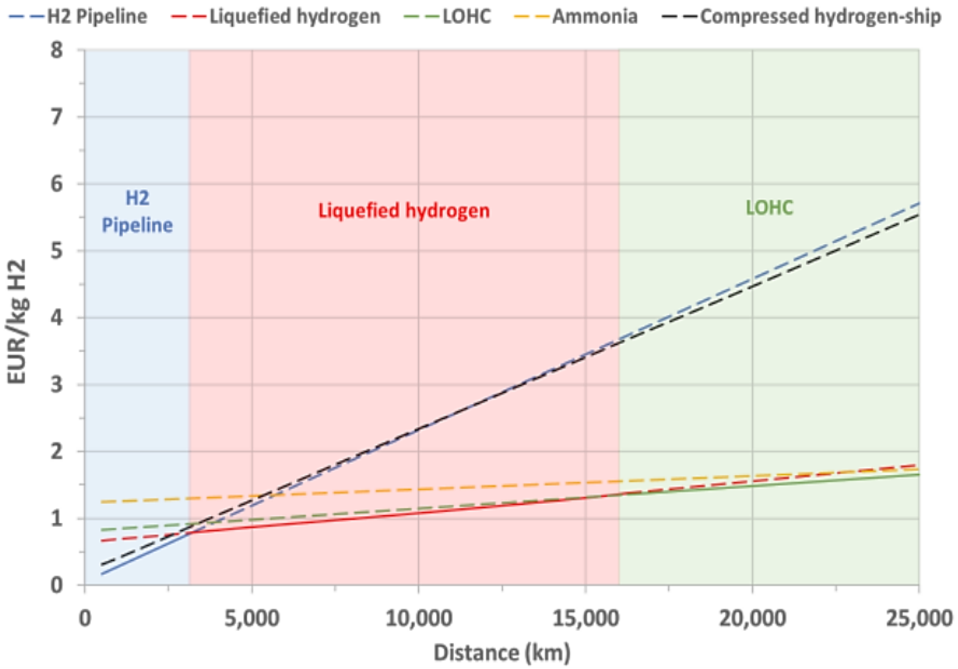
Assessment of Hydrogen Delivery Options. The European Commission's science and knowledge service (joint research centre); 2021.

Economic aspects of liquid hydrogen - long-distance transportation

Projected costs (2030–2035) of clean hydrogen delivery for different storage methods vs transport distance in single end-user scenario (1 Mt/H_2 per year)



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Liquid hydrogen provides an opportunity for long-distance energy transmission (e.g., intercontinental trade)

Assessment of Hydrogen Delivery Options. The European Commission's science and knowledge service (joint research centre); 2021.

Hydrogen Capabilities in the UK

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Zero Boil-off Hydrogen Storage and Energy Efficient Liquefaction

Prof Kumar Patchigolla (Teeside University)

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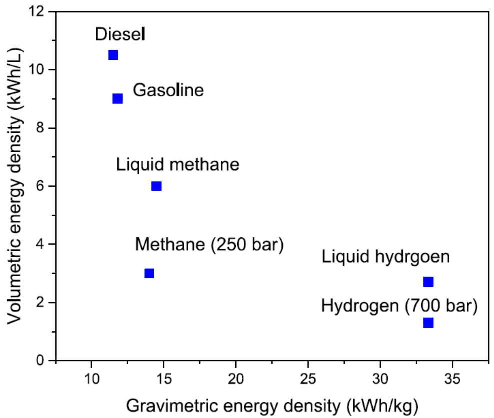
Zero Boil-off Hydrogen storage and energy efficient liquefaction

part of Growing Teesside's Hydrogen Economy and Catalysing a Just Transition to Net Zero]

The energy density of hydrogen compared to other common gases/ liquids[Zhang et al]



Two main objectives

H_2 Liquefaction

To develop modelling and design of liquefaction system with mixture working fluids for effective liquefaction of H_2 with specific energy consumption < 6 kWh/kgLH_2

LH_2 storage

Developing a lab scale 2 to 3 kg capacity LH_2 storage tank and reducing the boil-off rate to < 0.5% per day.

Main challenges in liquefaction and storage of LH2

1. **Formation of boil-off hydrogen**
2. **Very high specific energy consumption of liquefaction**

Hydrogen Capabilities in the UK

East Midlands Airport Green Futures Study

East Midland Airport (EMA) decarbonisation: towards a hydrogen-enabled ecosystem

Dr. Nahid Yazdani (University of Nottingham)

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Key Partners and Stakeholders

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Key Partners

- University of Nottingham (Energy Institute, Business School)
- Midlands Connect (reporting directly to the UK Dept for Transport)
- Midlands Net Zero Hub (reporting directly to the UK Dept for Business Energy and Industrial Strategy and the UK Dept for Levelling Up, Housing and Communities)
- EPRI (Electric Power Research Institute)

Key Stakeholders

- East Midlands Freeport
- East Midlands Development Corporation
- Local Enterprise Partnerships such as D2N2 and LLEP
- The community of distribution and logistics comprising the airport ecosystem including DHL, UPS, Royal Mail
- The rail freight sector including Maritime Transport, Alstom, DB Cargo
- Energy infrastructure companies such as National Grid, National Gas, Cadent, Uniper
- East Midlands Chamber of Commerce representing the SME community

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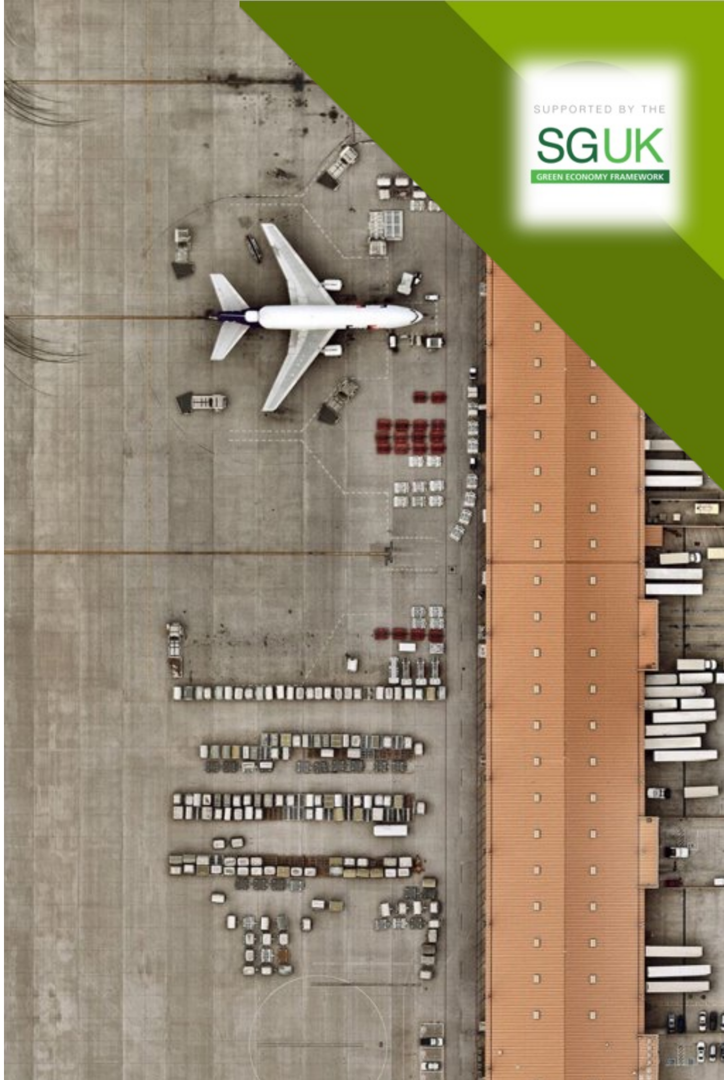
Context

- EMA is the UK's busiest 'pure cargo airport' and second only to LHR for total cargo handled
- Major global hub for DHL, UPS, FedEx, and Royal Mail
- Key economic hub, supporting 6000+ jobs and £300m for the region
- The aviation sector is a growing contributor to global GHG emissions
- UK's 6^{th} carbon budget will include aviation-related emissions

The current approach to decarbonising transport is fragmented, focusing on individual technical solutions!

Focusing on this airport ecosystem is ideal as it is small enough to be studied in detail and, at the same time, has sufficiently diverse transport modes (air, road and rail at/around the airport) to shed essential insights on a wide range of energy and infrastructure issues on the way to achieving net-zero targets!



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Aims

Aims of the study are to develop a vision (2030-2050 timeline snapshots) for zero-emission ground and air vehicles operating at and near major airports*. The scope will look at EMA as the case study and will include:

- Define a baseline scenario, with options for the adoption of electrification and hydrogen technologies
- Derive hydrogen infrastructure needs and costs under each scenario
- Calculate relative emissions (CO_2 and NOx) under each scenario
- Engage with external stakeholder groups representing government agencies, aviation companies, airport operators, energy infrastructure, distribution/freight

* In collaboration with ADL, we are expanding a pioneering Ontario Airport Hydrogen Enabled Ecosystem Study in California to a UK context.

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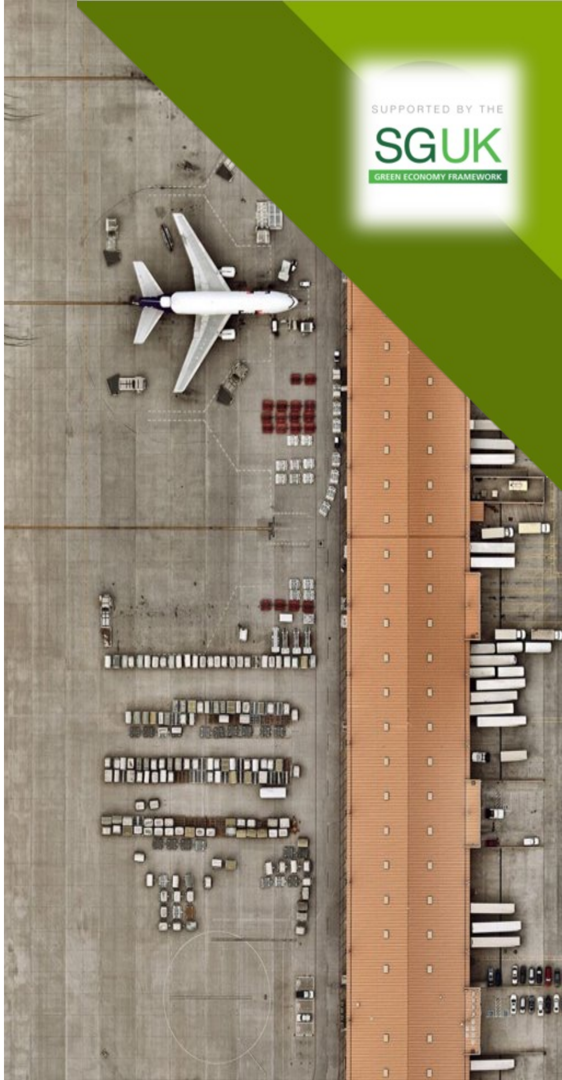
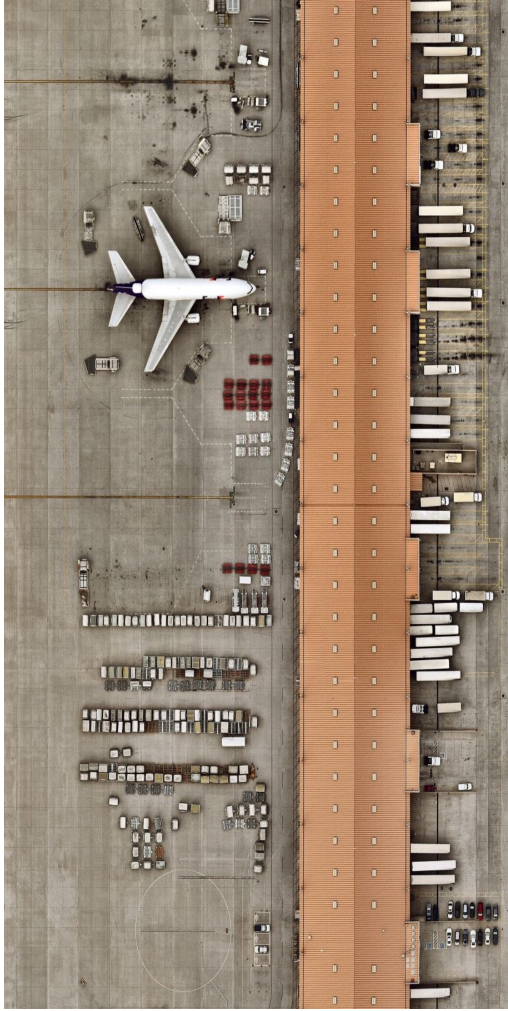


Ecosystem Boundaries

	Transportation of passengers and goods to/from EMA	Passengers: air transport, buses/coaches, individual cars and taxis, rail Goods: air transport, rail, HGVs and delivery vehicles
	Airport operations	Aeroplane movements (airliners, air taxis) Ground support equipment, maintenance vehicles and other airside vehicles EMA services
	Energy infrastructure to support EMA and its ecosystem	E.g., DNO, fuel suppliers, microgrid etc.

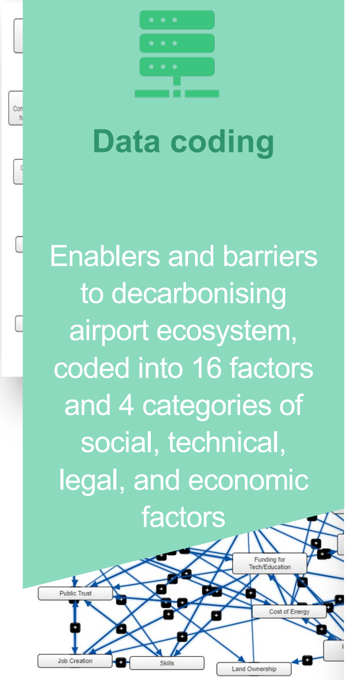


Technical study – ecosystem segment energy use/emissions

Methodology | Aircrafts – Passenger

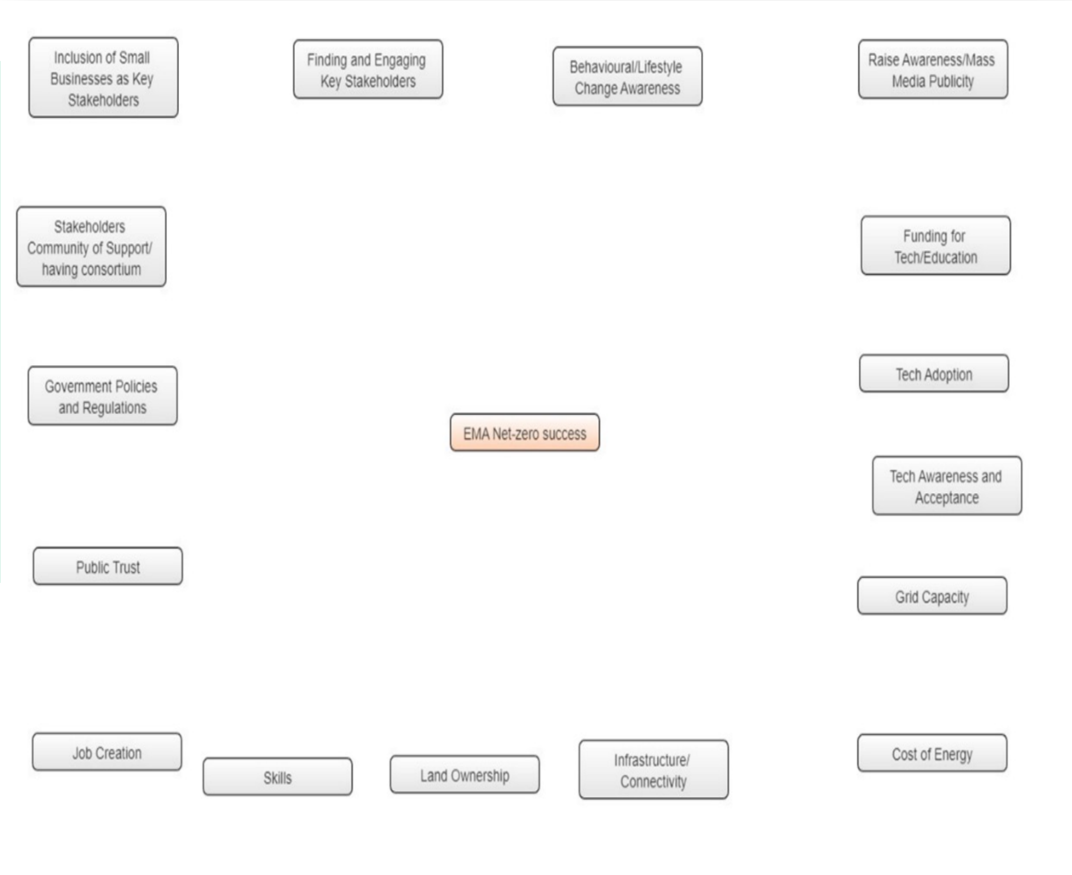
ADL

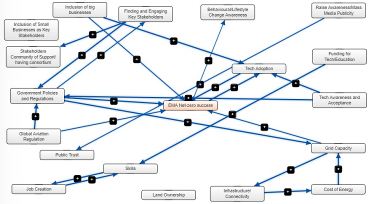
Social science- FCM and Knowledge map

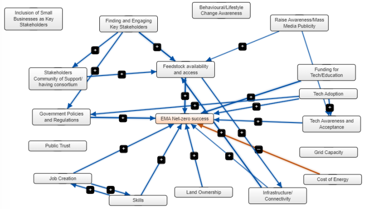


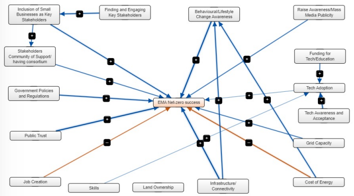
Data coding

Enablers and barriers to decarbonising airport ecosystem, coded into 16 factors and 4 categories of social, technical, legal, and economic factors





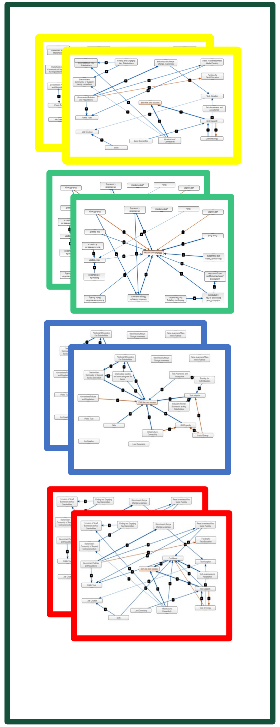




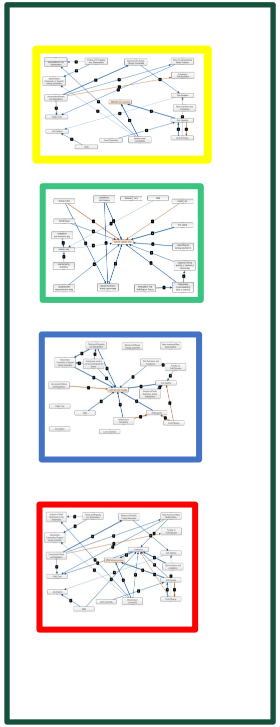
Multi-level Cognitive Map

Multi-level Data analysis

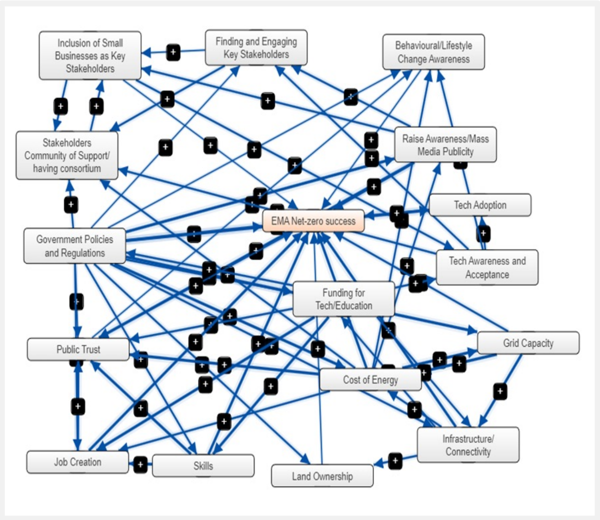
The individual maps are used to develop multi-level cognitive maps to find the patterns in different groups.



Micro level



Meso level



Macro level

Next steps

Social Stakeholders element

- Engaging social stakeholders, including industrial gas companies, automobile manufacturers and other companies with the hydrogen energy industry is vital. The transition to a hydrogen economy is a vast and systematic project that requires the full cooperation of governments, enterprises, scientific research institutions and the public.
  …In the data analysis process

Public Stakeholders element

- Studies globally reveal that societal acceptance significantly influences the success of hydrogen technologies. To address potential hesitations, particularly in the early adoption stages, providing transparent risk information, information dissemination, educating individuals, and dispelling misconceptions about the hydrogen technologies can foster positive attitudes towards its adoption.
  ….We are developing follow-up projects on Hydrogen storage and integration, and end-user awareness

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Singapore Presentation on Hydrogen

UKRI
Research
England

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Hydrogen research at NTU

Dr. Paul Liu (Nanyang Technological University)

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

This presentation has covered the following topics, but details on these slides have been omitted at the speaker‘s request.

- ✓ Snapshot of H2FC Research @ NTU over the last ~30 years
- ✓ Promotion of Hydrogen Economy
- ✓ Hydrogen and Fuel Cell Technologies
- ✓ Liquid Organic Hydrogen Carrier (LOHC)
- ✓ Catalyst and Reactor Demonstration for LOHC Technology, PSA
- ✓ Ammonia as Energy/Hydrogen Carrier
- ✓ Catalytic Methane Cracking for Turquoise Hydrogen Production
- ✓ Polymer Electrolyte Membrane Fuel Cells
- ✓ Proton Exchange Membrane Fuel Cells
- ✓ PEMFC System Development
- ✓ H2-fueled Harbor Tug and NH3-fueled Ocean-going Vessel
- ✓ Power-to-X
- ✓ Flue Gas Electrolysis
- ✓ Wet Air Electrolysis
- ✓ Complete Hydrogen Value Chain in REIDS, Semakau Island
- ✓ New Research Areas

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Thank You

ISCE^2

Initiatives on Sustainable Aviation Fuel (SAF) and Low-Carbon Hydrogen

Dr Wong Roong Jien

Institute of Sustainability for Chemicals, Energy and Environment

ISCE²

A*STAR and ISCE^2

A*STAR:

The Agency for Science, Technology and Research (A*STAR) is a statutory board under the Ministry of Trade and Industry of Singapore

ISCE^2:

ISCE^2 is one of 17 Research Institutes (RI) under A*STAR. We develop innovative sustainable technologies and partner with the ecosystem to catalyse the transformation and growth in green energy and chemicals

Our Approach

1. **Balanced Portfolio** of technologies
2. Platforms and infrastructure as **critical enablers** to accelerate innovation
3. Bridge the valley-of-death with partners towards **industrial scale-up**

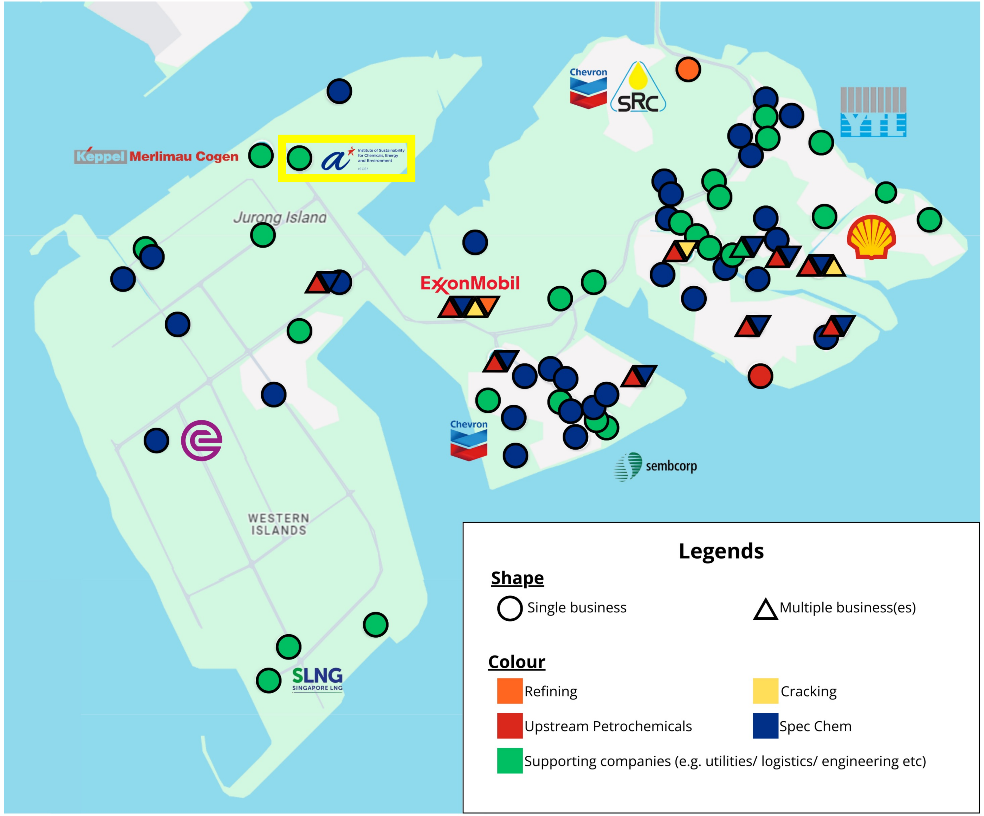
CREATING GROWTH, ENHANCING LIVES

Jurong Island contributes to 54%[1] of Singapore's total carbon emissions

Non-renewable raw materials (petroleum)

Carbon-intensive fossil fuels (natural gas, petroleum) as energy source

High capex > 100 MNCs; 3rd party utilities, waste treatment, storage & terminalling



The government invested S$7 billion to reclaim Jurong Island to develop an integrated refining, petrochemical and specialty chemical hub

Naphtha, aviation, automotive fuels, etc.

Petrochemical and specialty chemical products

[1]Hon, C.L., et al. *Energies*, **2021**, 14(20):6455

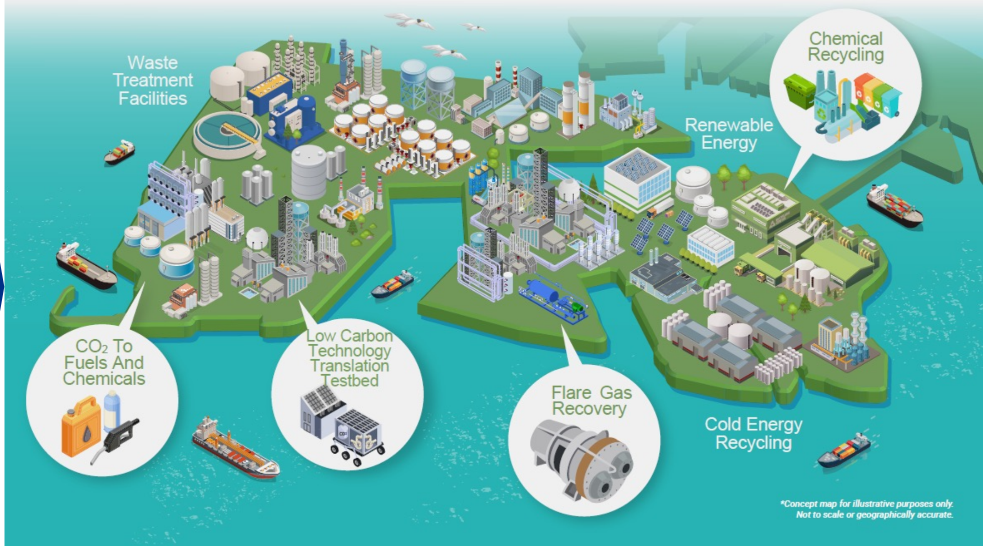
CREATING GROWTH, ENHANCING LIVES

Greening Jurong Island - the future direction of E&C is to reduce dependency on fossil fuels

Alternative raw materials (e.g. CO_2, biomass, waste)

New energy mix to support the clean energy transition (e.g. H_2/NH_3, green electricity)

Emergence of climate-tech companies with sustainable technologies



Jurong Island is envisioned to transform into a sustainable energy and chemicals park

Methanol, Biofuels, Sustainable Aviation Fuel (SAF), Hydrogen

New circular materials

CREATING GROWTH, ENHANCING LIVES

Image source: Sustainable Jurong Island Report, 2021

ISCE² Technology Development

CREATING GROWTH, ENHANCING LIVES

CO_2 to X (X = fuels, chemicals, materials)

Develop carbon-neutral/carbon-negative processes (at lab scale up to TRL ~4; with further scale-up (up to TRL ~8) to demonstrate the technology)

- **CO_2 methanation** technology developed and commercialised with **IHI**

- **CO_2 to SAF**: *Active collaboration with industry to establish larger scale demonstration unit*

- **CO_2 to methanol**: *Preparing proposal for government funding*

Accelerated Catalyst Development Platform (ACDP)

Accelerated discovery and develop heterogeneous catalytic processes by 5x, to TRL ~4

- 16 parallel catalyst syntheses; Flexible 16 reactor system
- Mimics industrial temperatures, pressures & reaction feeds; leverages automation, ML and high-performance computing

ASEAN Outstanding Engineering Achievement Award 2023

IES Sustainability Awards 2023 - *Innovative Solutions for Sustainability*

Low Carbon Technology Translation Testbed (LCT3)

Bridging the translational gap by rapidly piloting and scaling-up new CCU tech to TRL 4 - 8

- Reduce test-bedding time by 2x (from 2 years to <12 months)

- Future state Modularisation + Digital Twin for CCU

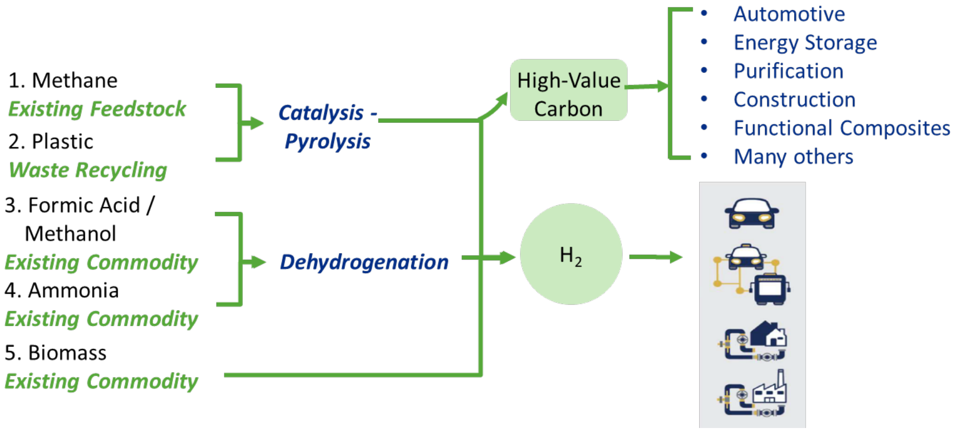
- Expected to be ready by 2026

In partnership with >20 ecosystem partners including E&C companies, technology adopters, solution providers, IHLs and A*STAR RIs

ISCE² Technology Portfolio

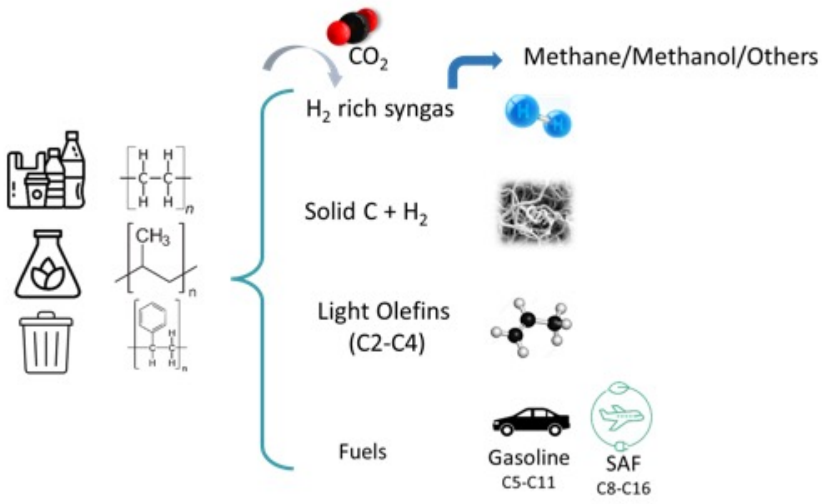
Low Carbon Future

Low-Carbon H_2



Circular Economy

Waste to Chemicals/Fuels/Materials



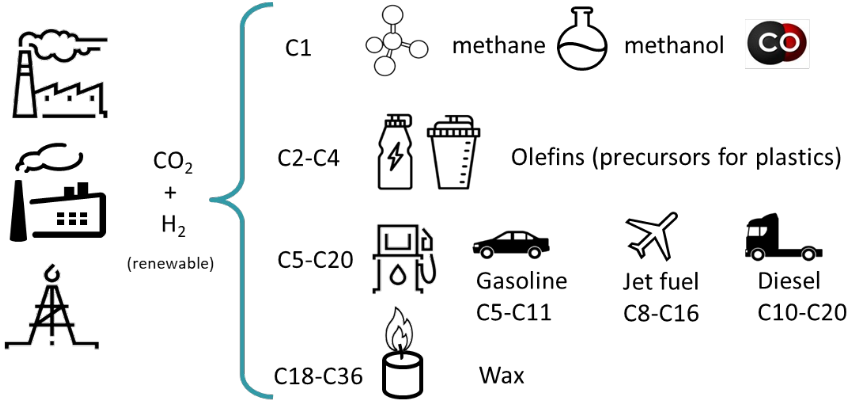
TOWARDS ZERO WASTE

GREEN PLAN

ISCE² Technology Portfolio

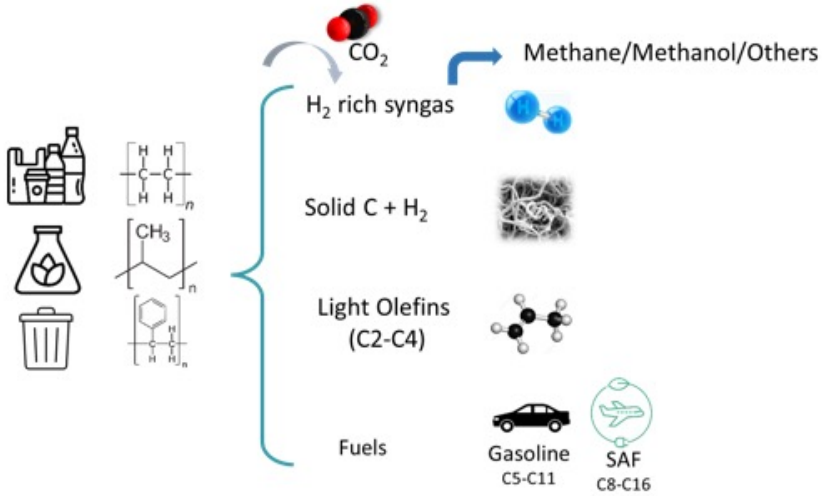
Low Carbon Future

CO_2 to X



Circular Economy

Waste to Chemicals/Fuels/Materials



TOWARDS ZERO WASTE

Sustainable Singapore

SG GREEN PLAN

CREATING GROWTH, ENHANCING LIVES

Agency for Science, Technology and Research
SINGAPORE

CREATING GROWTH, ENHANCING LIVES

Lunch Break

- Please join the conversation about today's event on social media:
  - #UKSGEF
  - #UKSingaporeJetZero
  - @HyDEXMidlands
  - @CranfieldUniversity

Roundtable Discussion

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Q1:
Will Hydrogen be a dominant fuel for the aviation sector?

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Q2:
Which of the following Hydrogen types is more suited for sustainable aviation and why?

- Green
- Turquoise
- Blue
- LH2
- Pink
- Grey…

Colours of Hydrogen

GREEN	Electrolysis from renewable technology
BLUE	Steam reforming of natural gas With Carbon storage and sequestration
GREY	Steam reforming of natural gas without Carbon storage and sequestration
BLACK/BROWN	Production from coal
PINK	Electrolysis from nuclear energy
TURQUOISE	Methane pyrolysis producing hydrogen and solid carbon
YELLOW	Electrolysis using solar
WHITE	Methane pyrolysis with solid carbon byproduct, **or** naturally occurring hydrogen
GOLD	Hydrogen from geological sources

Q3: Where are the opportunities for feedstocks for Hydrogen production to supply the aviation sector?

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Q4:
How can we support the airports (UK and Singapore) to develop the Hydrogen infrastructure?

Q5:
What are the opportunities for research collaboration in the Hydrogen supply chain?

Coffee Break – 15 mins!

Workshop Feedback