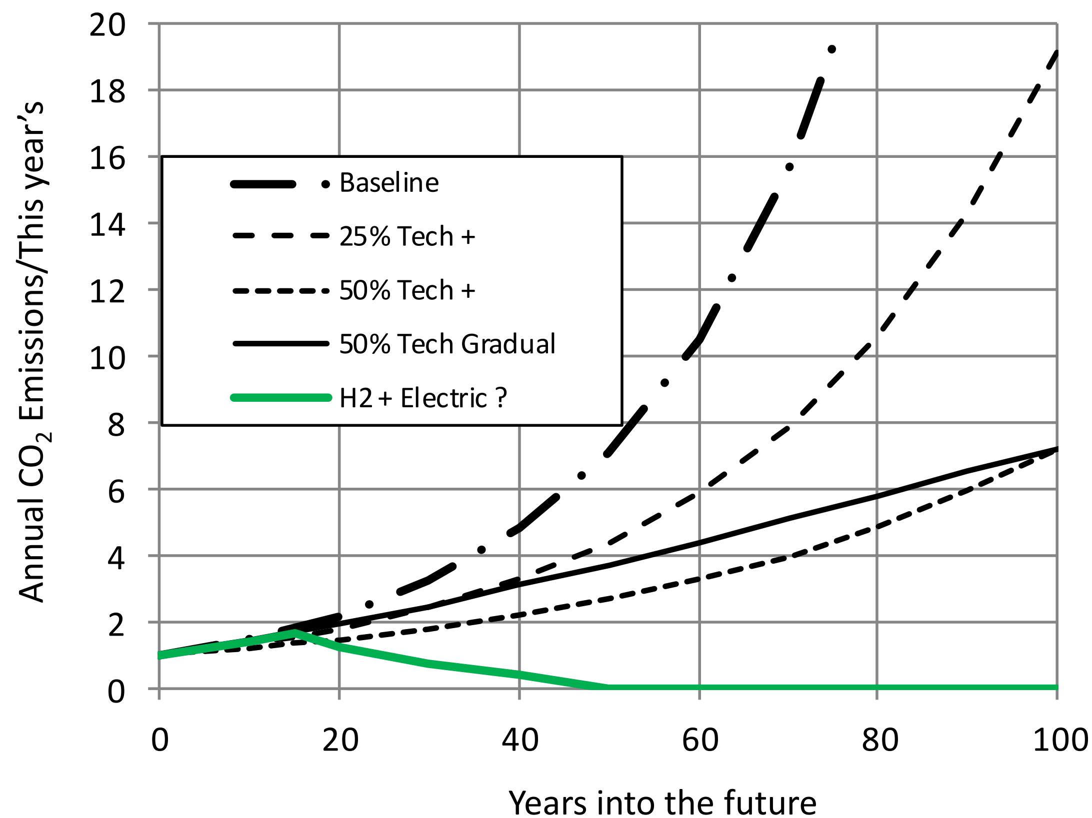
How could H_2 Gas Turbine Propulsion change the World?

ISABE 2022 OTTAWA
September 25th -30th

Sustainability =
Environment + Economy

Philosophical views
and some studies

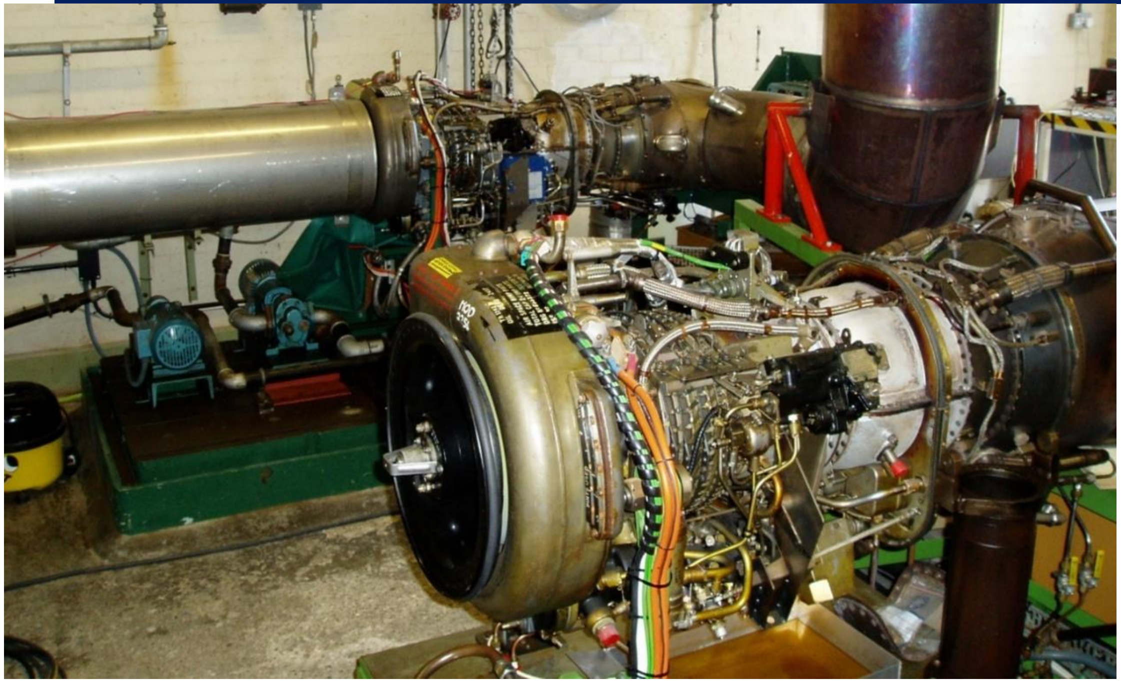


Pericles Pilidis - Director Thermal Power MSc,
FRAeS, UK Representative ISABE
Cranfield University - Thermal Power & Propulsion

Acknowledging support of many colleagues

GAS TURBINES FOR AIR LAND AND SEA:

A CORE ACTIVITY AT CRANFIELD



1946 - Cranfield College of Aeronautics
One of the 4 units was Aircraft Propulsion

1969 - Cranfield Inst of Technology (University)

1993 - Cranfield University (change of name)

H_2, Electrical and Gas Turbines at Cranfield

1994 – Hydrogen for GTs

2000 Cryoplane

2010 – NASA Project

2017 – Hybrid Electric Propulsion Group

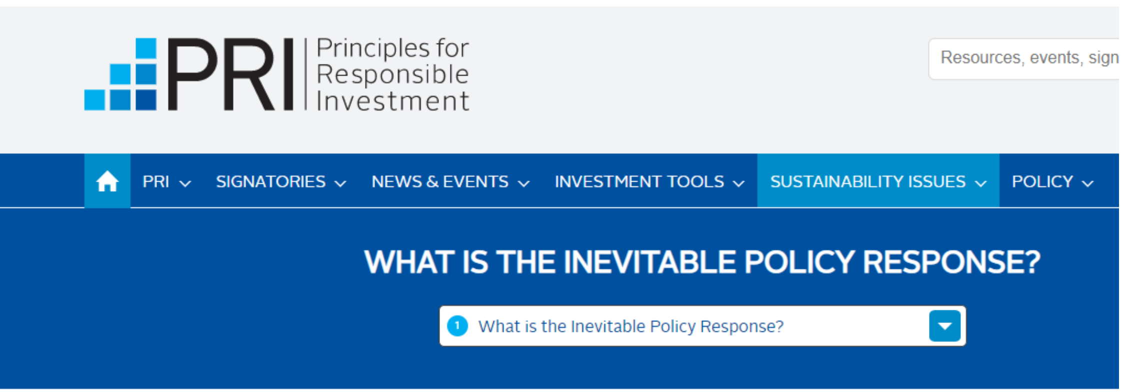
Now: ENABLEH2
Airbus/ATI + 3 x Fly Zero
ENABEL, Industrial projects
+ + + +

+ + + Cranfield Own Projects

H_2 to Protect Aviation Socioeconomic Benefits

Good Long Term Economic Case for Aircraft
Very Strong Environmental Case
Very Strong Economic Case for Civil Aviation
Very Strong Economic Case for Society

https://www.unpri.org/inevitable-policy-response/what-is-the-inevitable-policy-response/4787.article



https://www.theguardian.com/commentisfree/2020/jan/17/the-guardian-view-on-flight-shaming-face-it-life-must-change

It started in Sweden, where the term *flygskam* (flight shame) was coined in 2018 to describe the unease about flying experienced by environmentally conscious travellers. The hashtag *#jagstannarpåmarken* (which translates as #stayontheground) came into use around the same time, as groups sprang up to share tips.

Other wealthy countries are not immune from such trends: a recent survey of 6,000 people in Germany, France, the UK and the US found 21% had cut back. Such a shift in attitudes makes it all the more disturbing that members of the current government, including the health secretary, Matt Hancock, have yet to catch up. Asked twice on the radio this week whether people should reduce the number of flights they take, the minister said they should not.

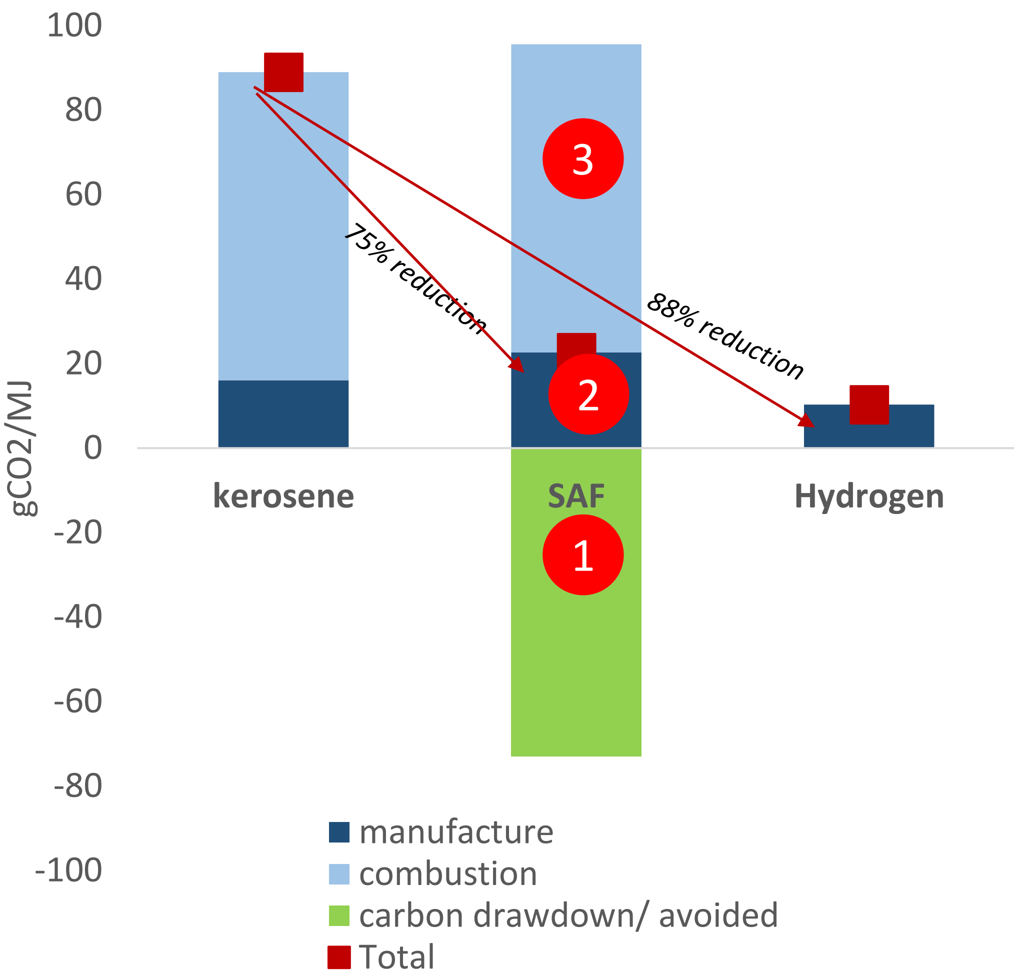
Acceleration of regulation and High Transition Cost

H_2 & Electric

No CO2
No CO, UHCs, aromatics, soot, SOx
Much lower potential NOx than Hydrocarbons
Cirrus avoidance?

Why Hydrogen

The SAF Cycle



1 - Remove CO2 from the air

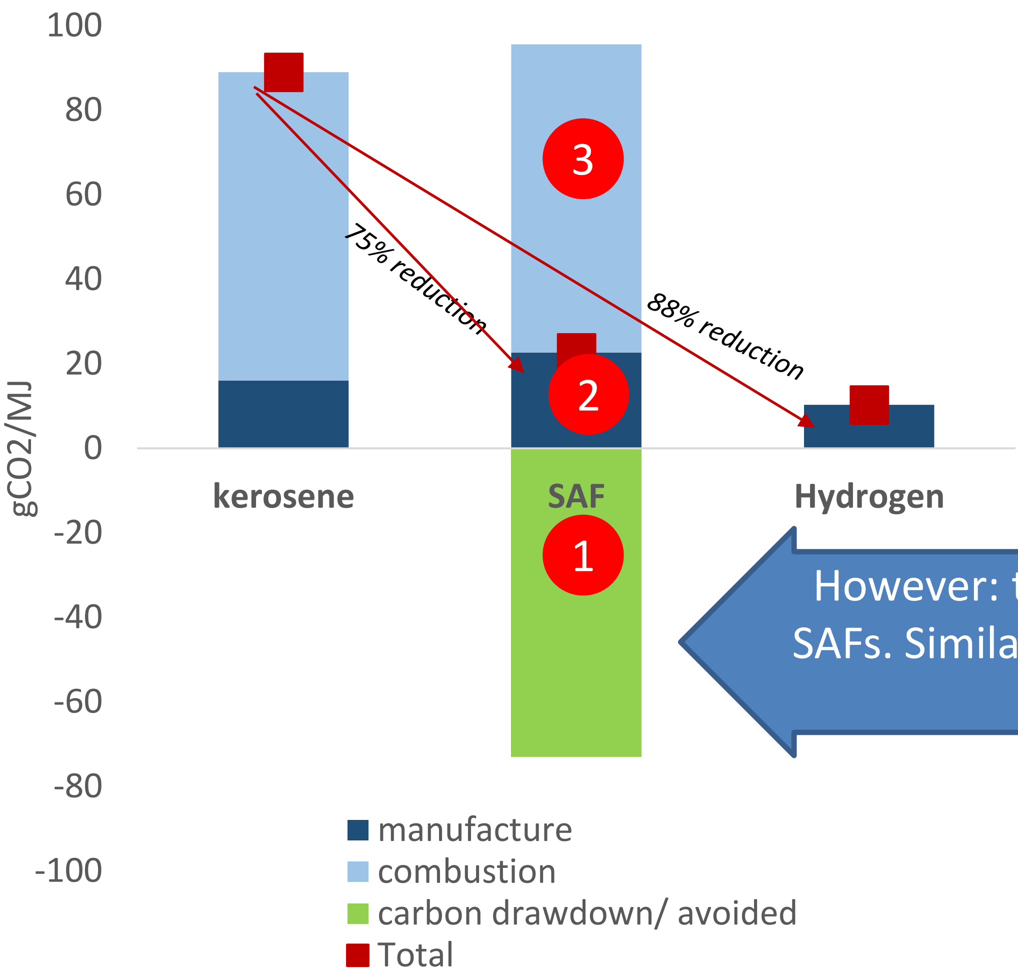
2 – Process into JetA 'lookalike' fuel

3 – Burn in the jet engine

Based on ATI Insight Publication
Aviation emissions: Modelling the road to Net Zero 2050

Why Hydrogen

The SAF Cycle



1 - Remove CO_2 from the air

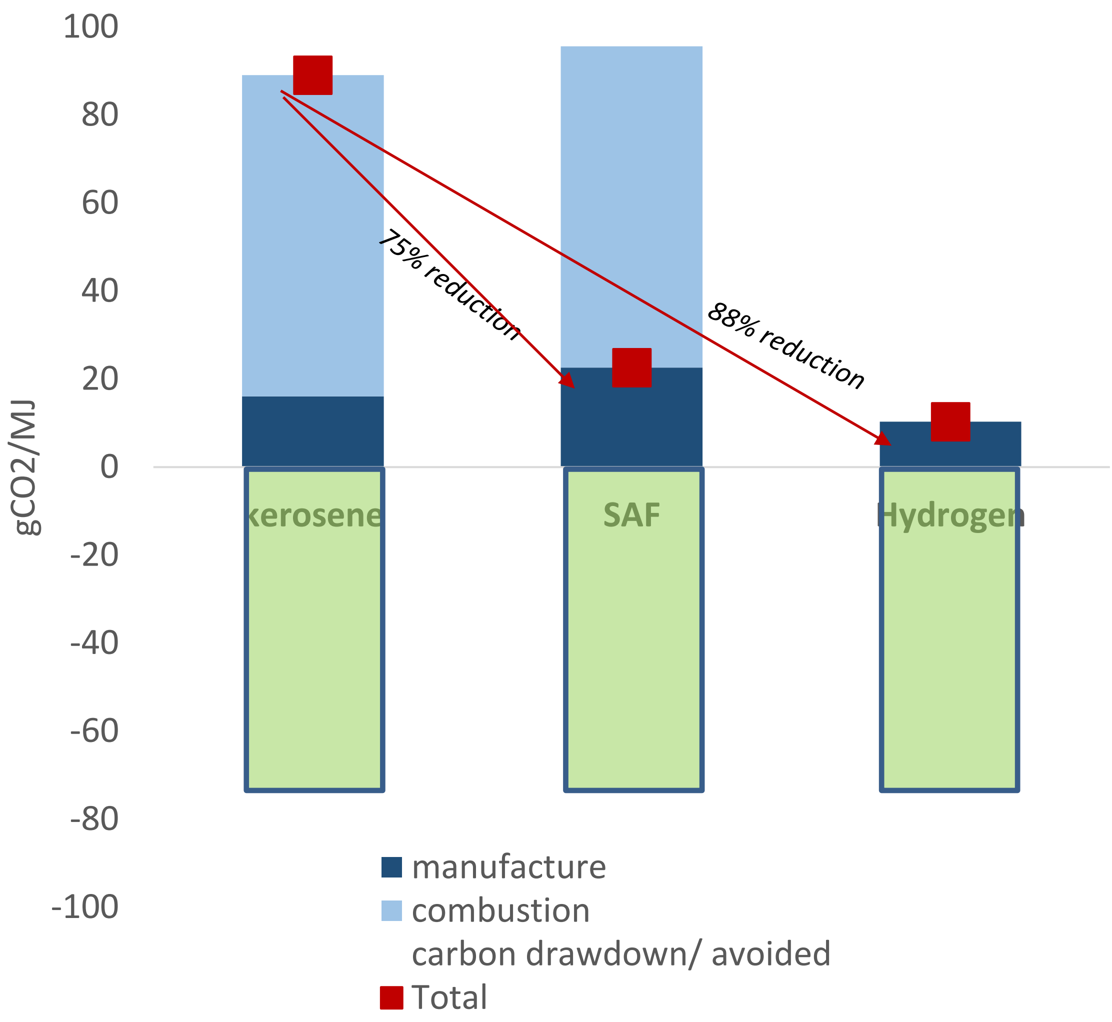
2 – Process into JetA 'lookalike' fuel

3 – Burn in the jet engine

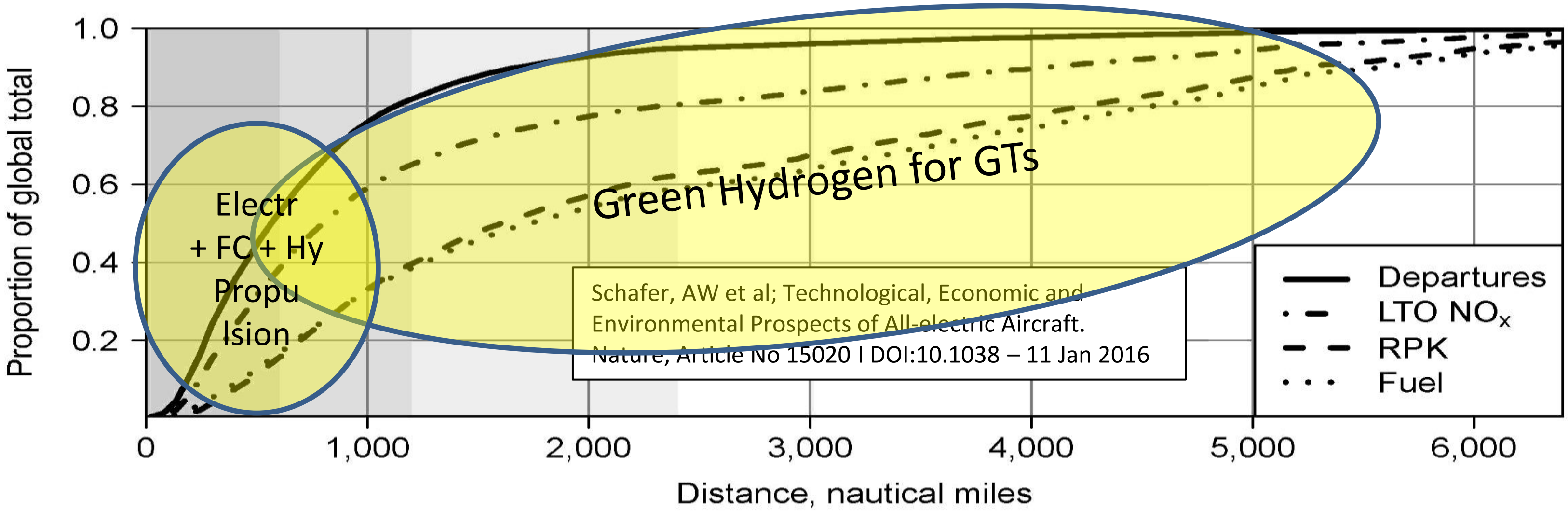
However: this 'shadow' is independent of SAFs. Similar one can be applied to all three columns

Based on ATI Insight Publication
Aviation emissions: Modelling the road to Net Zero 2050

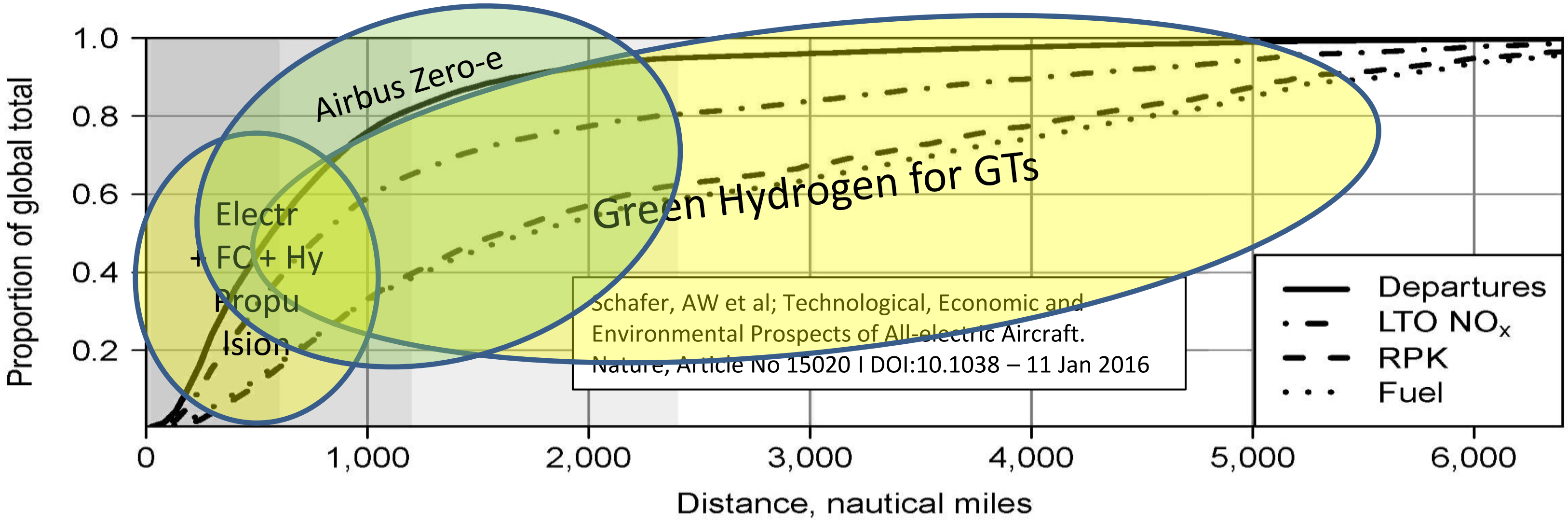
A More Realistic Picture?

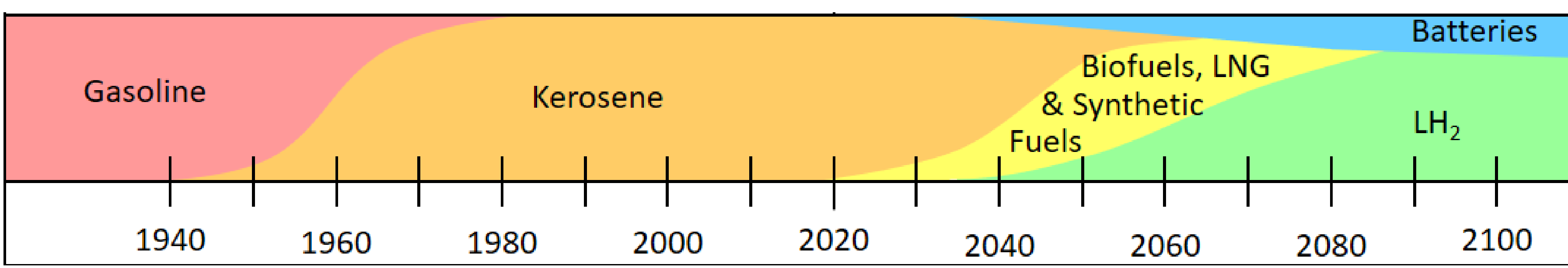


Decarbonisation Portfolio



Decarbonisation Portfolio





H_2 : VOLUME IS THE MAIN DRIVER, NOT WEIGHT

WEIGHT: Gravimetric Efficiency

$$\eta_{grav} = M_{fuel} / (M_{fuel} + M_{tank})$$

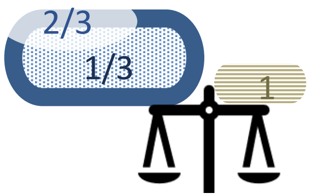
SAME ENERGY CONTENT (approx)

$Vol_{LH2} = 4 \times Vol_{Ker}$ and $M_{LH2} = 0.36 \times M_{Ker}$

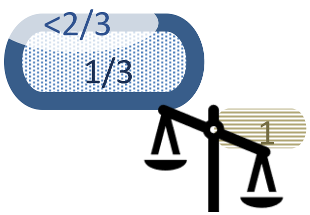
14kg Jet-A1 → 44kg CO_2 + 18 kg H_2O

5 kg H_2 → 45 kg H_2O

LH2 *JET-A*



$\eta_{grav} = 0.33$

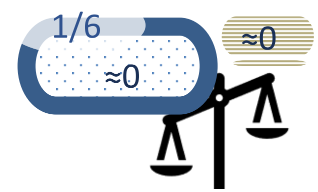


$\eta_{grav} > 0.33$

Take-Off

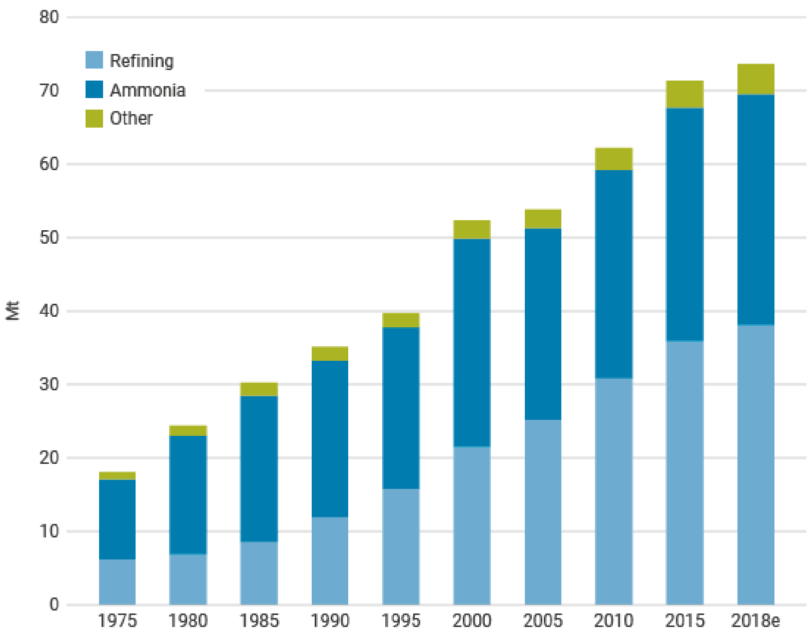
Take-Off

$\eta_{grav} = 0.667$

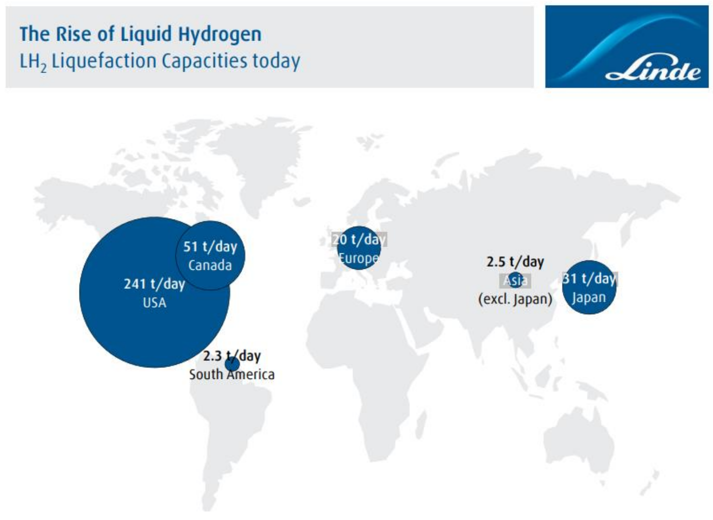


Landing

Hydrogen technology R&D needed



Global annual demand for pure hydrogen (source: IEA)



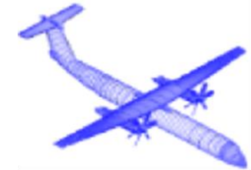
2020 LH_2 capacity (source Linde) ~ 100 kt pa

In service: Pumps, Pipes, Electrolysers, storage, etc - ie the components implied here. Need extensive R&D to meet aerospace certification requirements and economies of experience & scale.

Innovation Waves – H_2 and Electric in Synergy
A Cranfield Perspective

Innovation Wave I
10-15 yrs
Focus: Certification

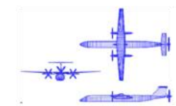




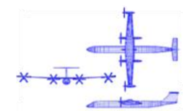
Conventional Airframe

Innovation Wave IIa
20+ yrs
Focus: Efficiency

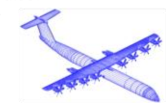




BLI Propulsor



Wing Tip Propulsor



Distributed Propulsion

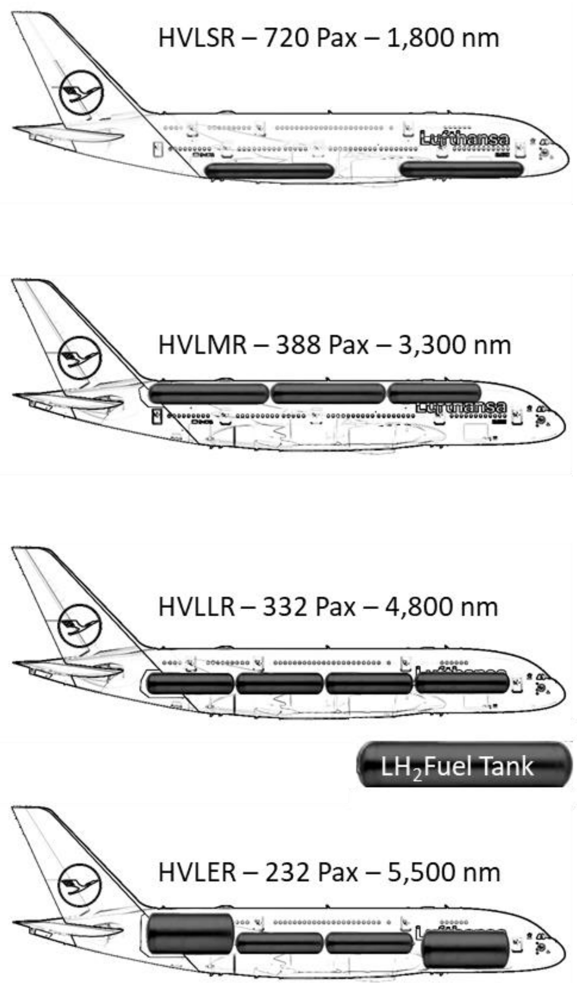
Innovation Wave IIb
20+ yrs
Focus: FC Certification


Innovation Wave III
30 + yrs
Focus: Turbocryoelectric



HVLMR From a family of 1st generation H_2 airliners

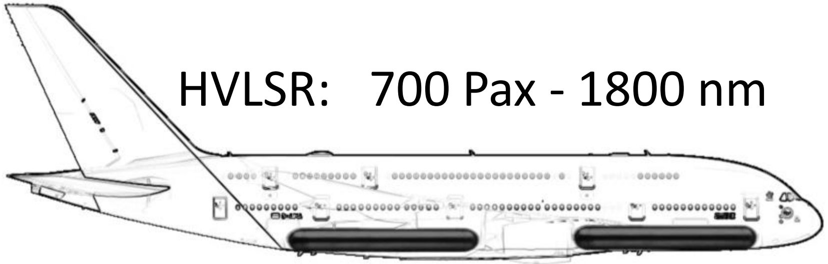
Design Derivative & Vast Integration Challenge – NOT a retrofit!

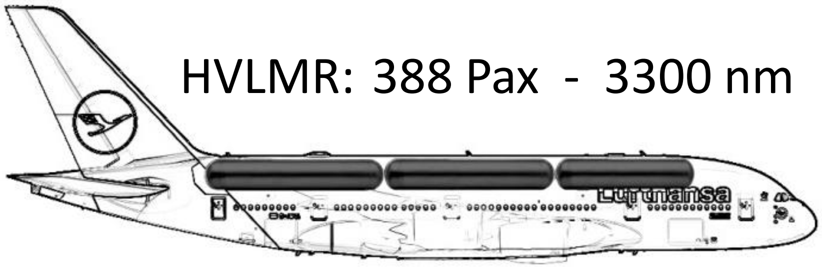


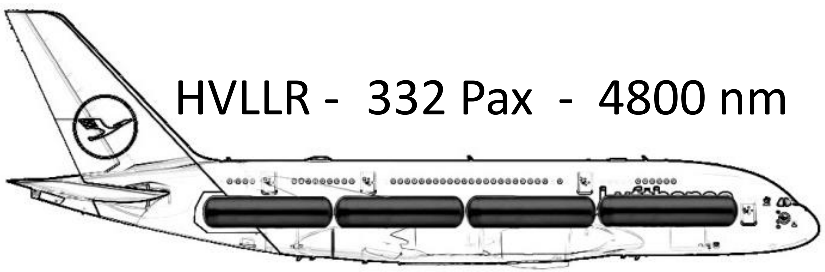
	AIRBUS A350-1000	AIRBUS A380-800	HVLSR	HVLMR	HVLLR	HVLER
Mass (tonnes)						
Ramp	317	577	288	274	304	310
Max. take-off	316	575	287	273	303	309
Max. landing	236	394	275	251	275	276
Max. payload	68	83	80	50	45	36
Operational empty	155	276	194	200	229	238
H2 Tank: grav eff. 0.45			20	33	51	59
Engines	2	4	2	2	2	2
Cruise thrust/engine (kN)	87	81	84	81	88	90
Static thrust/engine (kN)	432	374	421	406	441	448
Range (nm)	8700	8000	1800	3300	4800	5600
Pax (2 class)	315	555	720	388	332	232

Huete, J., Nalianda, D., & Pilidis, P. (2022). Impact of tank gravimetric efficiency on propulsion system integration for a first-generation hydrogen civil airliner. *The Aeronautical Journal,* 1-9. doi:10.1017/aer.2022.60

1st Innovation Wave H_2 Airliners







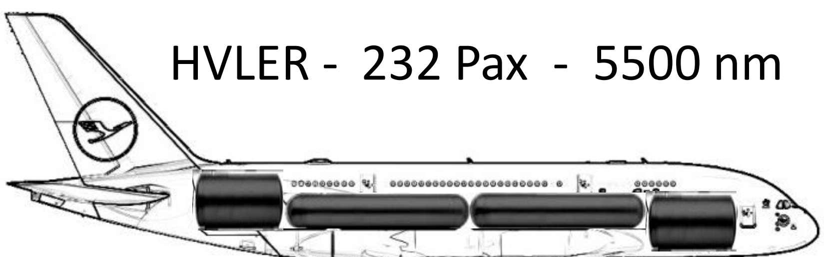


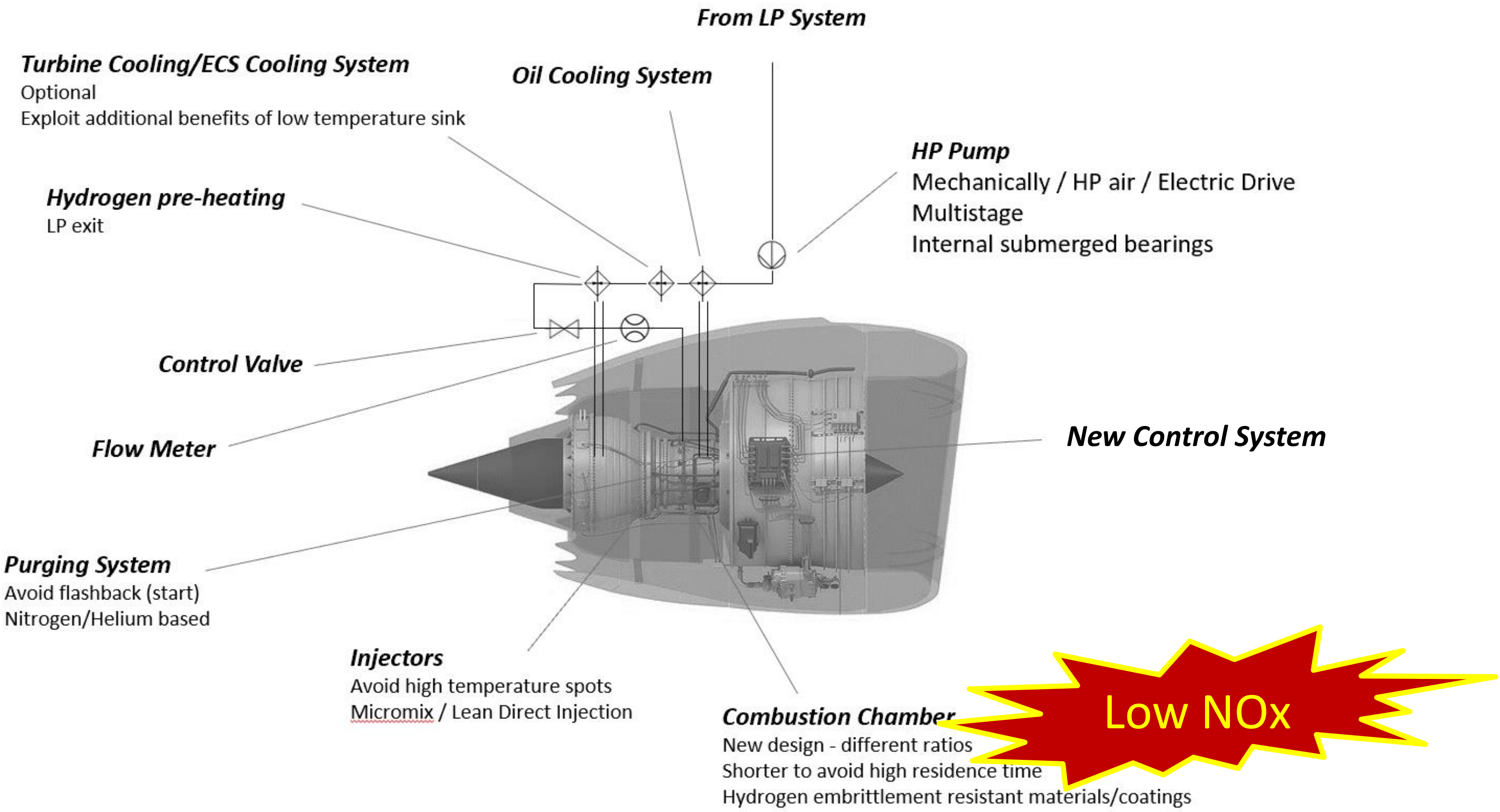
Table of Distances	nm	km
Ottawa - Miami	1193	2210
Ottawa - LA	2063	3820
Ottawa - London	2897	5365
Ottawa - Toulouse	3175	5880
Ottawa - Dakar	3467	6420
Ottawa - Athens	4195	7770
Ottawa - Honolulu	4195	7770
Honolulu -Sydney	4417	8180
Ottawa -Dakar	4457	8255
Ottawa -Rio	4460	8260
Ottawa - Recife	4536	8400
Ottawa - Cairo	4795	8880
Cairo - Singapore	4590	8500
Ottawa -Kuwait	5373	9950
Ottawa - Tokyo	5586	10345

Images Courtesy Lufthansa, amended by the authors

The Trent XWBH

Some GT modifications to burn hydrogen.

Engine image courtesy of Rolls-Royce modified by the authors.



Hydrogen Low NOx Combustion

No Carbon

No CO_2/CO/UHC/Soot

Less Luminous Radiation

Better liner durability

Wider stability limits

Leaner combustion

Lower flame temperature

Higher burning velocity

Higher reaction rate

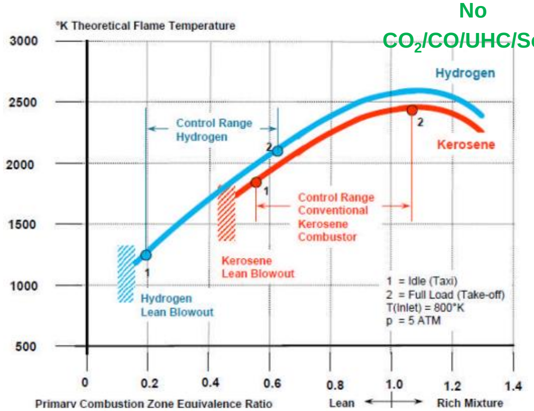
Lower residence time

Higher diffusivity

Faster mixing

Lower thermal NOx

Shorter combustor



Ziemann J, Mayr A, Anagnostou A, Suttrop F, Lowe M, Bagheri SA, et al. Potential use of hydrogen in air propulsion. EQHHPP, Phase III.0-3. Final report, submitted to European Union (contract no. 5077-92-11 EL ISPD).

LH2 Tanks

Insulation & Sealing

MAOP

'To Vent or Not to Vent'?

Materials

Additive Manufacture

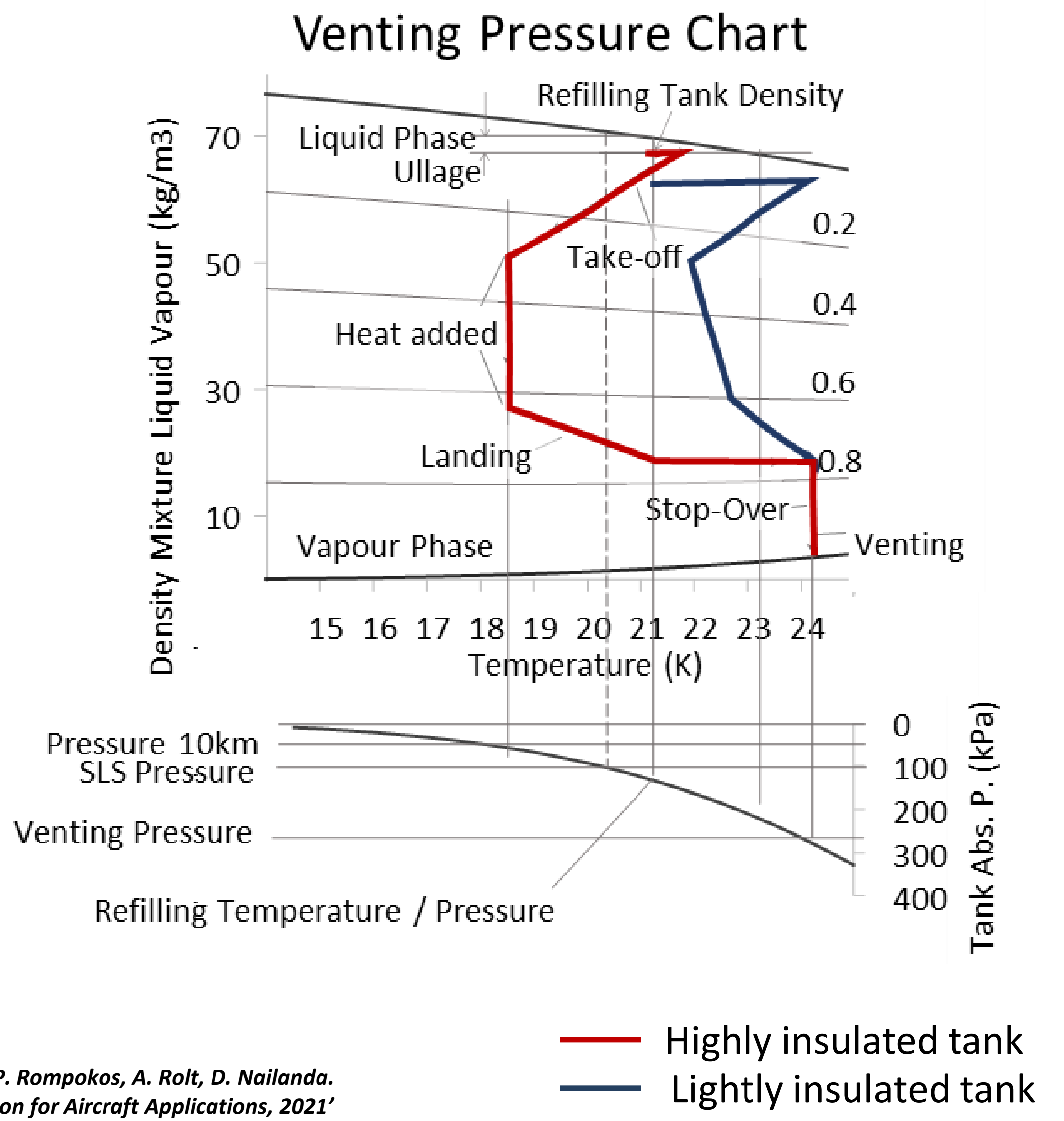
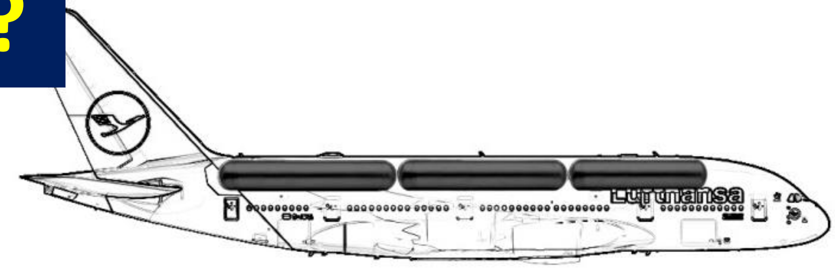


Figure: Adapted from P. Rompokos, A. Rolt, D. Nailanda. 'Cryogenic Fuel Storage Modelling and Optimisation for Aircraft Applications, 2021' And from J. Huete, P. Pilidis, 'Parametric study on tank integration for hydrogen civil aviation propulsion, 2021'

Certification accelerators?



Images Courtesy Lufthansa, amended by the authors

First Innovation Wave

Yr 0 agree R&D of 100 b for 10 yrs (~HS2 or 1% of EU tourist industry)

Yr 1-5 fly kerosene prototype for flight qualities

Yr 1-9 fly conventional 4 Engine testbed
($2H_2$ + 2Ker) tech & certification update

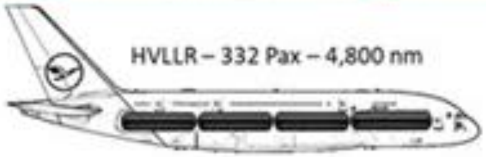
Yr 5 -10 develop & fly hydrogen prototypes - tech & certification update

Yr 11 cargo version in service

Yr 13 pax versions in service

Introducing H_2 early in very few hubs for a much faster introduction: allows very gradual airport development

Pioneering One Hub Scenario with 1st generation HVLLR

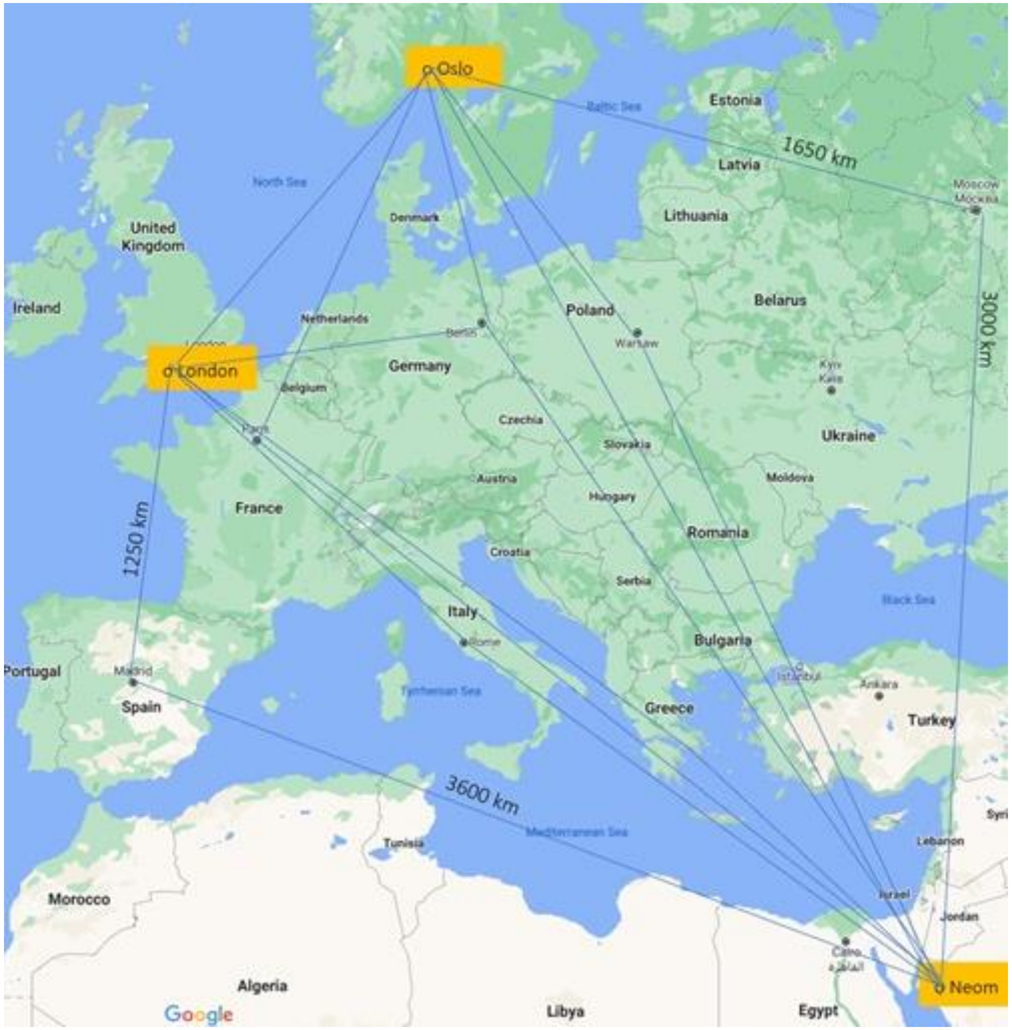


Return trip unrefuelled to important destinations within 4250 km

Almaty 4000 km	Lagos 4200 km
London 3900 km	Mumbai 4100 km
Nairobi 3600 km	Oslo 4000 km
Stockholm 3800 km	St Petersburg 3600 km

London – 3900 km – 14.3t LH_2 one way daily flight for a year needs PV of , 6.79k m^2 (2025) 1.558 km^2 (2050).

Three hub scenario. opportunity for indirect flights with larger capacity shorter range 1st generation HVLMR



Tankering – better with H_2
London – Madrid – Neom
Tankering costs ~ 250 kg H_2 on 18t

Decarbonising the UK – H2 & Electricity – A Cranfield Study

Hydrogen: 35-40 % of electricity supply (use seawater electrolysis)

Aviation > 50% of Hydrogen supply

International trade

Mainly CCGT and/or Nuclear offer nearly constant power grid scenario

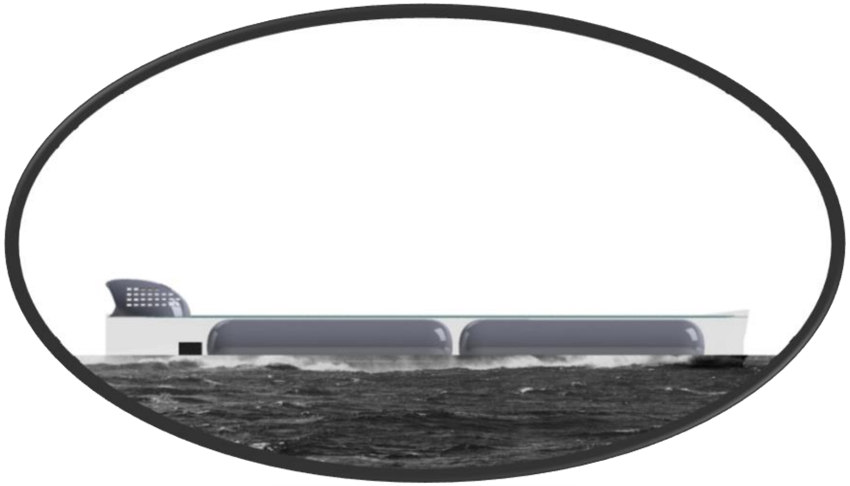
Benefits of Thermal plant and better heat use in colder countries (like UK)

Start with Scenario 4 (Short Term) and progress to 1 (LT) with international grids?

Cost ~ 2% of GDP-

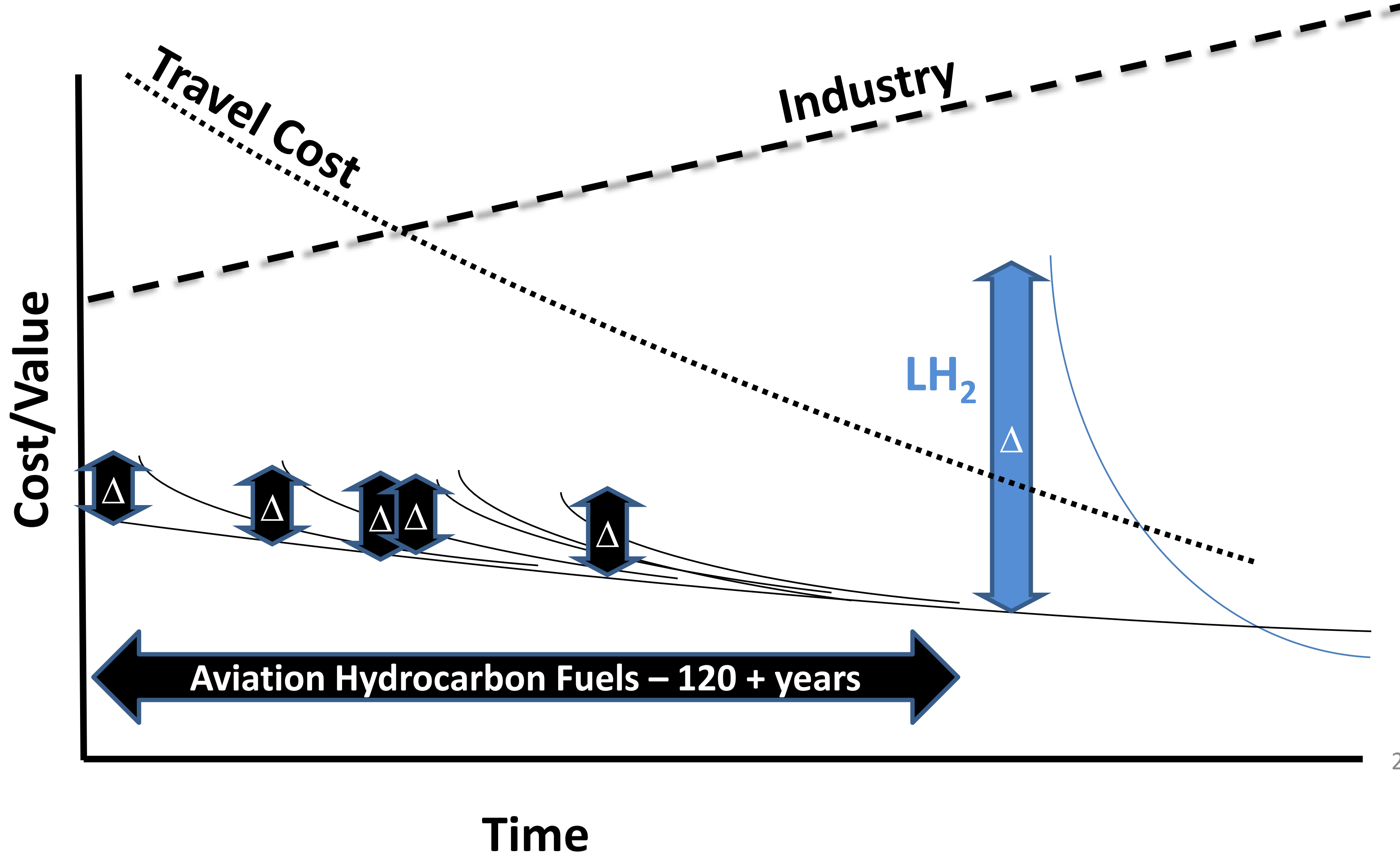
Scenario	Electricity Supply TJ	Peak GW	Installed Capacity GW
Baseline	1,165,320	80	97
S1 - Emphasis on Renewable	5,093,538	110	391
S2 - Emphasis on Nuclear	4,175,280	83	175
S3 - Emphasis on Nuclear and Renewables	4,193,820	83	216
S4 - Emphasis on Gas Turbines and Renewables	4,185,720	83	214
S5 - Similar to 4 low heat	4,786,380	109	235
S6 - Emphasis on Gas Turbines	4,193,280	83	176

A Liquid Hydrogen Tanker

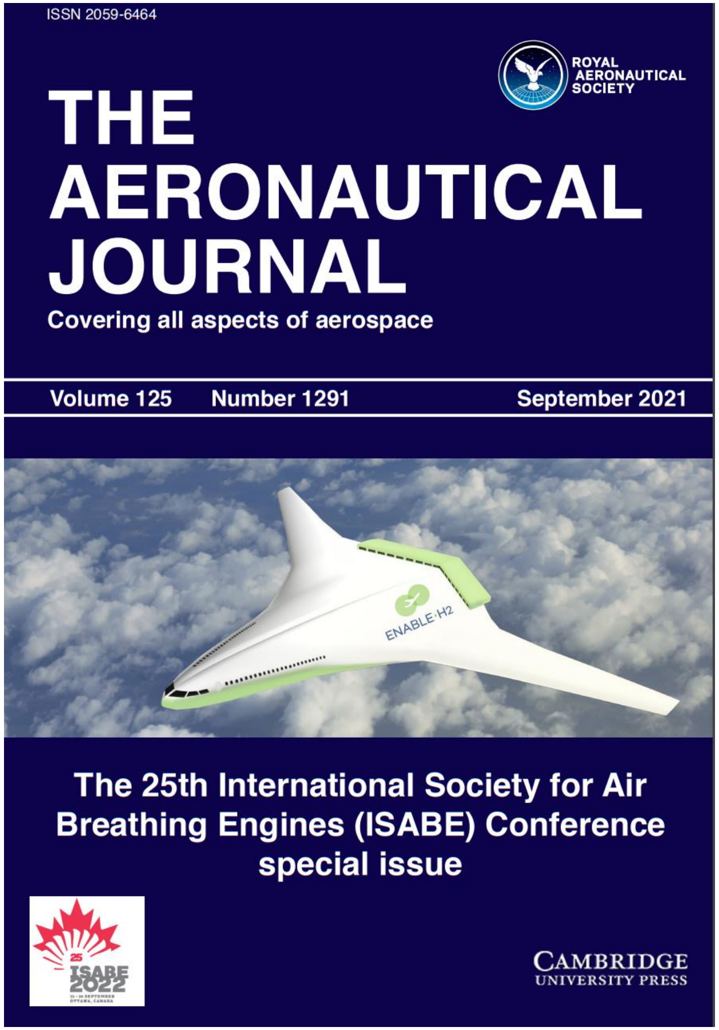


	LH_2 Tanker	Ore Brasil
Length OA	375m	362m
Draft FL	10.11m	23m
Depth	35m	30m
DW (000 t)	20	402
Speed (knots)	15.8	15.4
Power (MW)	30	29

Investment Pattern Comparison



The Light Beyond the Clouds



Your Homework

1 Share socio-economic benefits of aviation. Worth the cost of this transition.

2 Success is dependent on young, talented individuals to deliver the analysis, research, development and products for ‘green’ aviation

Rewards: Environment, jobs, travel, tourism, business, growth, careers, etc.