Challenges of Hydrogen Propulsion for Transport Aviation

an Aerospace Engines Manufacturer's Perspective

3rd International Hydrogen Aviation Conference
IHAC 2022

"Hydrogen: makes you fly in the sky!"

https://www.hy-hybrid.com/ihac-2022

1st September 2022, Glasgow

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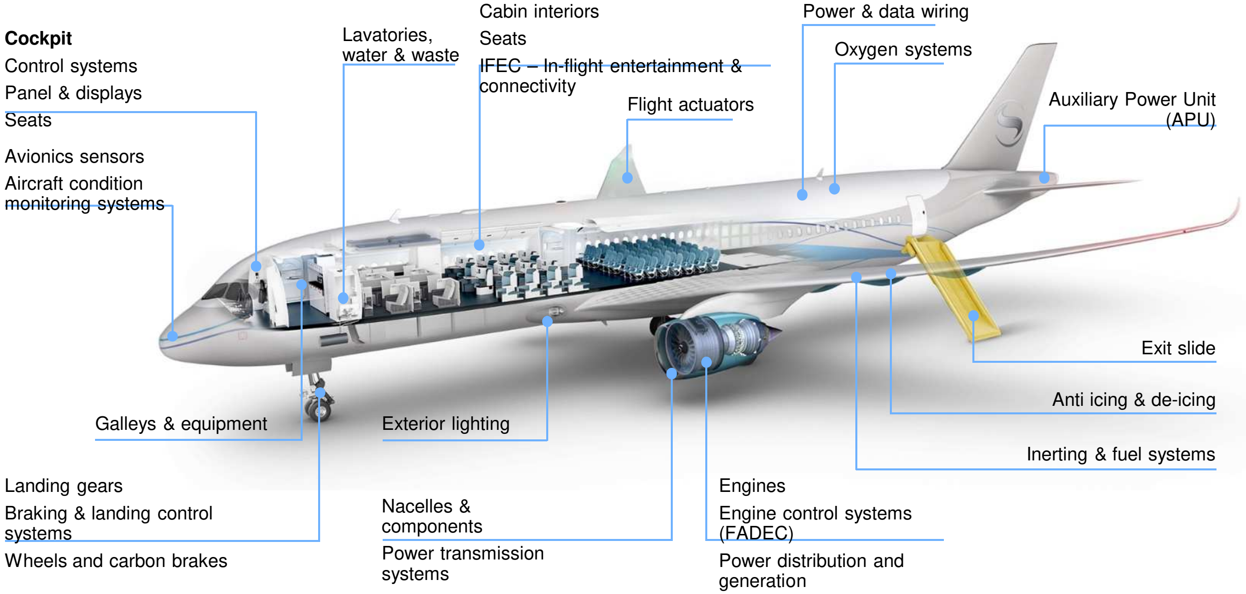
Safran at a glance



WORLD'S No.3 AEROSPACE COMPANY
(excluding aircraft manufacturers)

No. 1
WORLDWIDE FOR ENGINES POWERING SINGLE-AISLE MAINLINE COMMERCIAL JETS IN PARTNERSHIP WITH GE

No. 1
WORLDWIDE FOR HELICOPTER TURBINE ENGINES

No. 1
WORLDWIDE FOR LANDING GEAR

More than 76000 employees in 351 locations across 31 countries

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Ultra-low or Zero Carbon Energy Source Options for Aviation

Meeting Aviation specific constraints: WEIGHT SENSITIVITY + SAFETY

Sustainable alternative fuels

- Only available as short term option
- Up to -80% net CO_2 impact
- **Policies needed to develop supply and uptake**

Power to liquid (e-fuels)

- Better CO_2 reduction (-90%)
- Availability > 2030
- Renewable electricity intensive

« Drop-in » fuel solutions

Are a key contributor to any scenario until 2050

Aviation will develop specific technologies needed to overcome current 50% max blend ratio limitation

Liquid Hydrogen

- Zero CO_2 potential
- Radical changes on aircraft architecture
- Major safety challenges
- High investment for infrastructure change
- Impact of H_20 emissions to be assessed

« Non Drop-in » solutions

Longer term option for zero CO_2 with current low maturity / high risk

Aviation will assess feasibility and derisk gradually the technologies accordingly

Batteries

- Strong limitation due to weight, even with long term perspectives
- Potential for very short distance flight, or in hybrid configurations

« Batteries »

Not an option for longer distance flight, but a potential of hybrid configuration for short range configuration

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What is the fuel cell the real challenger of ?

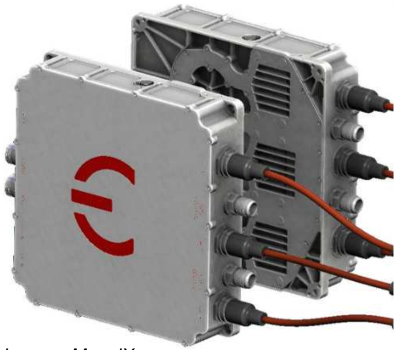
Image : MagniX

Battery


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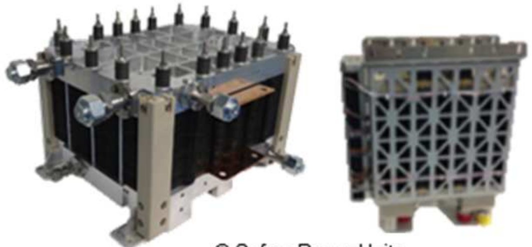
Gas Turbine

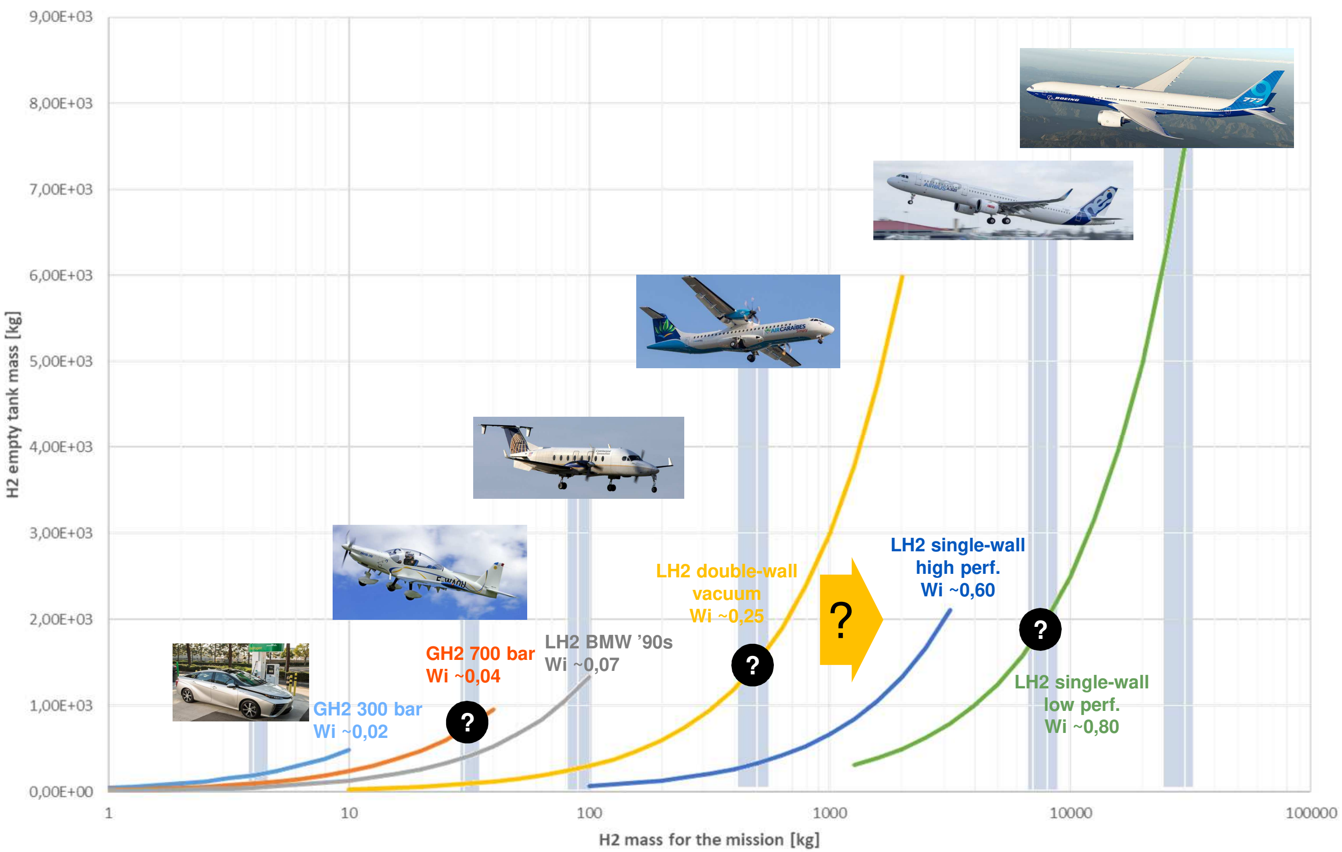

© Safran Power Units

Fuel Cell

~~Market Value/Operating Cost~~

~~Logistics~~

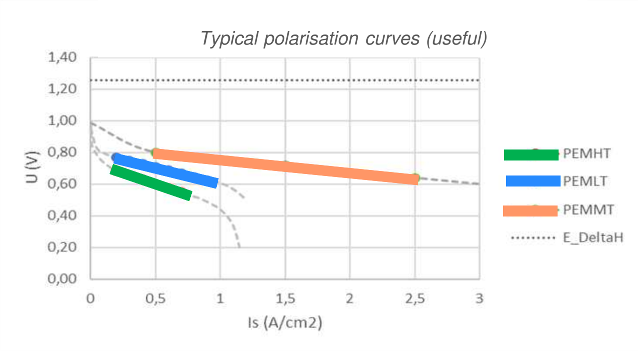
The Challenge of H2 Storage / Operating Empty Weight

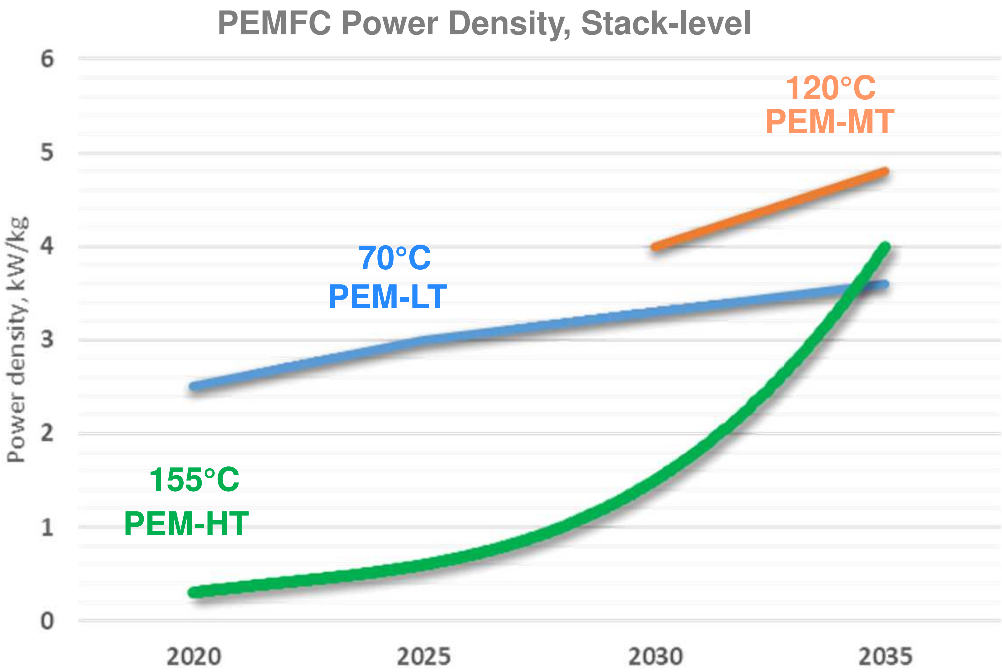


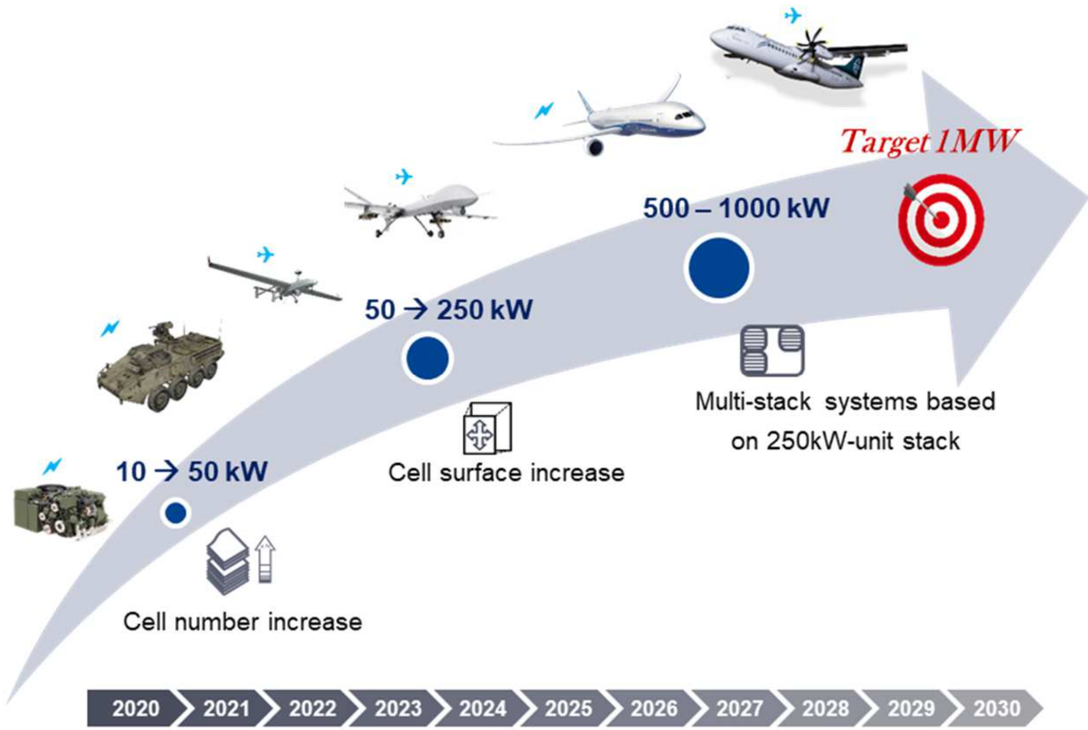
- Vacuum insulation for LH2 comes with a significant mass penalty for Regional segment and above

- Space-standard lighter designs have their issues (boil-off management, insulation life)

PEM Fuel Cells for Propulsion : SoA and Timeline





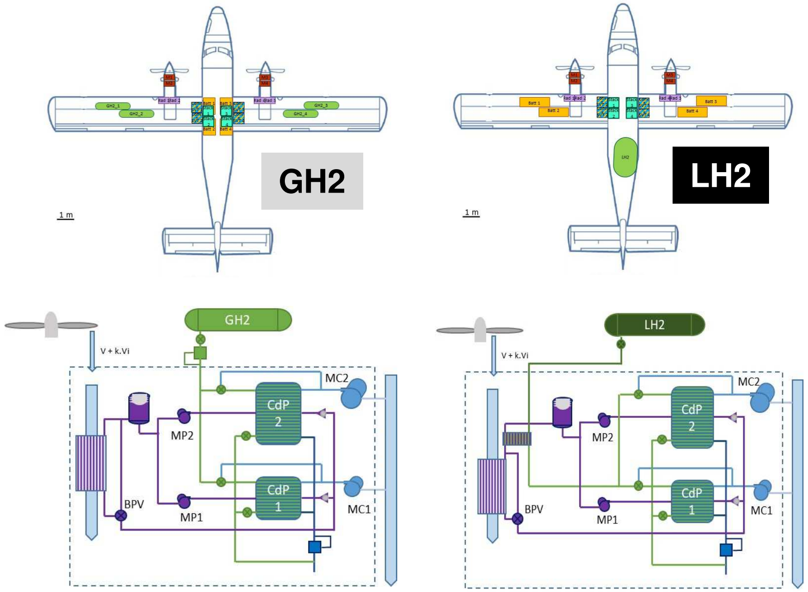


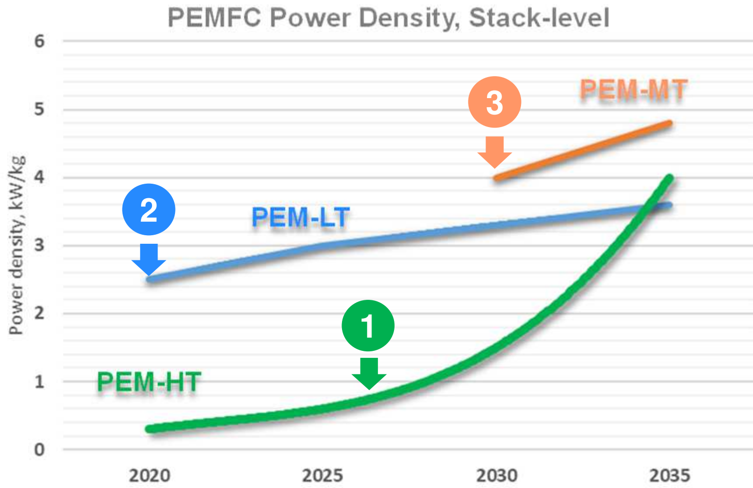
Exercise : Twin Otter Propulsion Retrofit @ Iso MTOW

Thoraval et al., 2021

Trade payload for fuel until aircraft is able to fly experimental mission range

100 NMi + 50 NMi diversion + 10 min Hold





	GH2	LH2		
	PEM-HT	PEM-HT	PEM-LT	PEM-MT
Stack Power Density, gross [kW/kg]	0,8	0,8	2,5	4
System Power Density [kW/kg]	0,42	0,42	0,64	0,76
Ratio	*53%*	*53%*	*27%*	*19%*
Max Useful Power, Cont. [kW]	112	111	143	115
Added Cooling Drag	+5,8%	+5,4%	+30%	+8 %
Allowable PAX	**4**	**11**	**13**	**16**

Gaseous H_2 is a no-go, even with 700 bar storage

PEM-LT Much higher specific power and better efficiency is completely obliterated by **cooling drag**, even with H2 heat sink

➔ Sizing of thermal management system linked to stack operating temperature (technology dependent)

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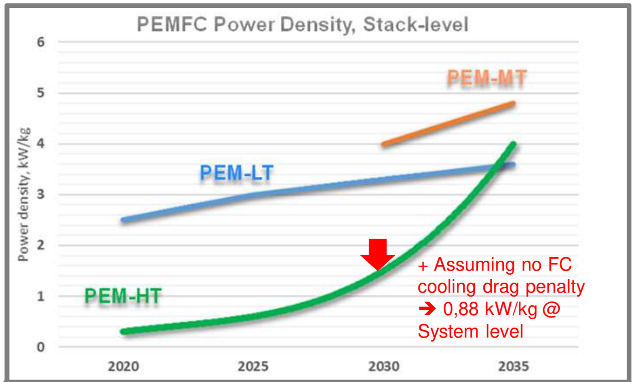
Broader Design Space Exploration for PEMFC Propulsion

Isikveren et al., 2021



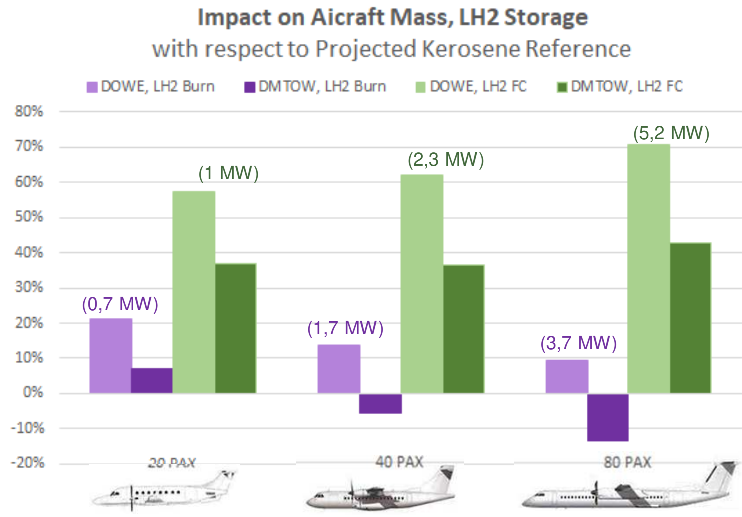
Gas Turbine SoA	
Overall Propulsion System Efficiency	26.3%
Overall Propulsion Gravimetric Power	0.861 kW/kg

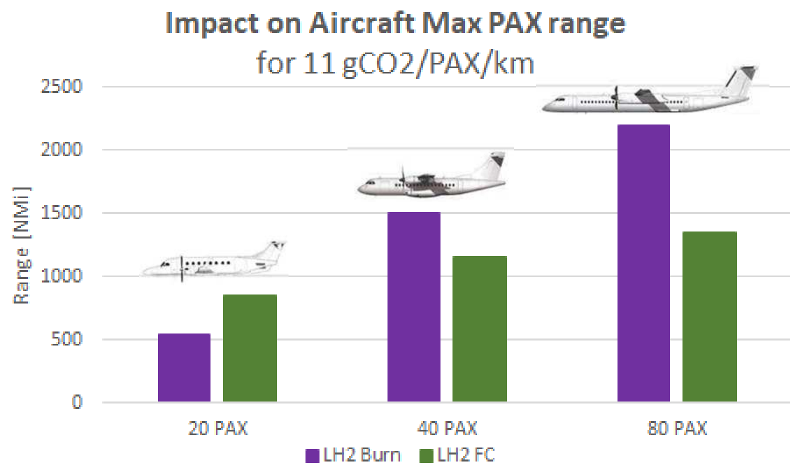
	H2	Electricity
Emissions Index, WtT [kgCO2/kg]	0,82-1,12 (Blue) ; 0.92-1.13 (Green) => Mean 1,13	-
Emissions Index, WtT [kgCO2/kWh]	0,034	0,017 - 0,276

PEM-FC

VS.

H2-Burn





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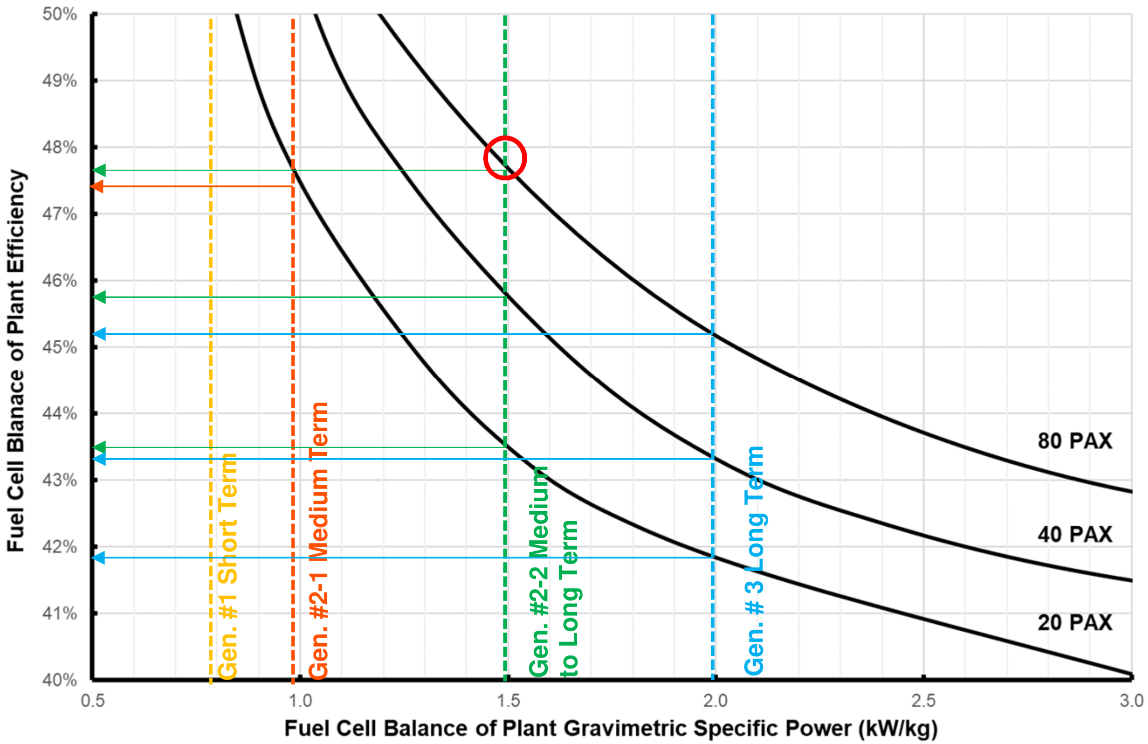
LH_2 PEMFC System Performance Targets to Compete With LH_2-Burn

Or :
How Do I Kill the Gas Turbine ?



	Gen. 1	Gen 2.1	Gen 2.2	Gen. 3
BoP Specific Power [kW/kg]	0,75	1	1,5	2
BoP Efficiency	N/A	0,48	0,43 - 0,48	0,42 - 0,45
Pax Allowable	None	20-40	20-80	20-80

- Assuming LH_2 tanks
- For a given PAX, identify targets for Balance-of-Plant level specific power (GSP) and overall efficiency that produces the same block energy and CO_2-emissions outcome to that of LH_2 combustion-based

Proposed target for Fuel Cell is
1.5 kW/kg
48% efficiency
at Balance-of-Plant level
with No Cooling Drag Penalty

Fuel cell life-time (20k hours min. for aircraft application)

- Automotive SoA is 5000h
- 10k-12k hours for heavy duty transportation using carbon bipolar-plates (non-compliant with an aggressive power-to-weight ratio)

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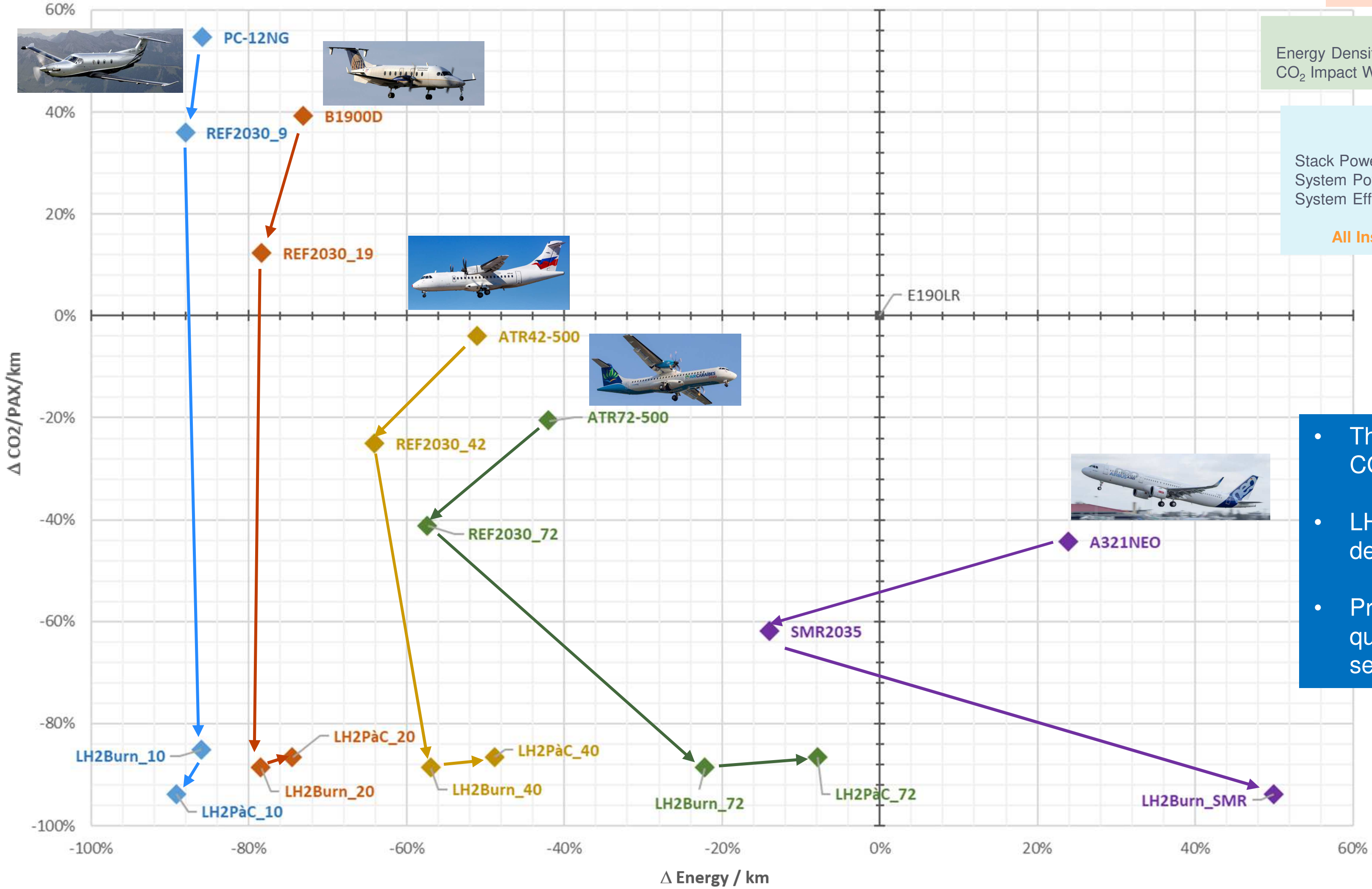
The Big Picture : Emissions & Energy Potential for H2 Aircraft



JET-A1
Energy Density: 11.89 kWh / kg_{JETA1}
CO_2 Impact WtW : 0.320 kg_{CO2} / kWh (CORSIA)
NO CREDIT FOR SAF

LH2
Energy Density: 32.94 kWh / kg_{LH2}
CO_2 Impact WtW : 0.034 kg_{CO2} / kWh (Mean SoA "Blue" – "Green")

Fuel Cell SoA, HT-PEM

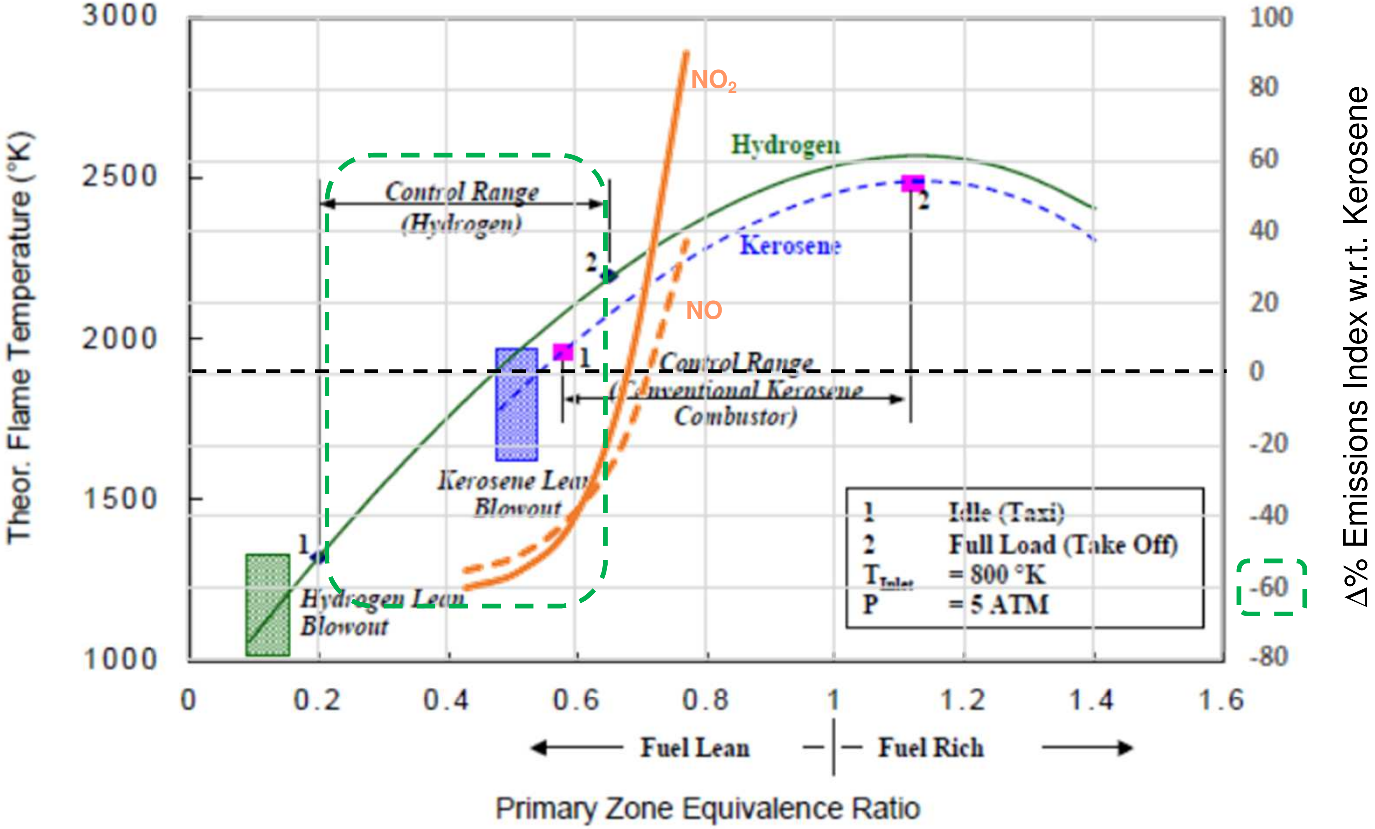
Stack Power Density: 0.88 kW/kg
System Power Density: 0.55 kW/kg
System Efficiency: 38%

All Installation Drag Impacts Considered Neutral

- The smaller the aircraft, the better the CO_2 gain of a LH_2 solution
- LH2-burn aircraft energy efficiency degrades when size increases
- Propulsive fuel cell interest is questionnable above Commuter segment

No Silver Bullet

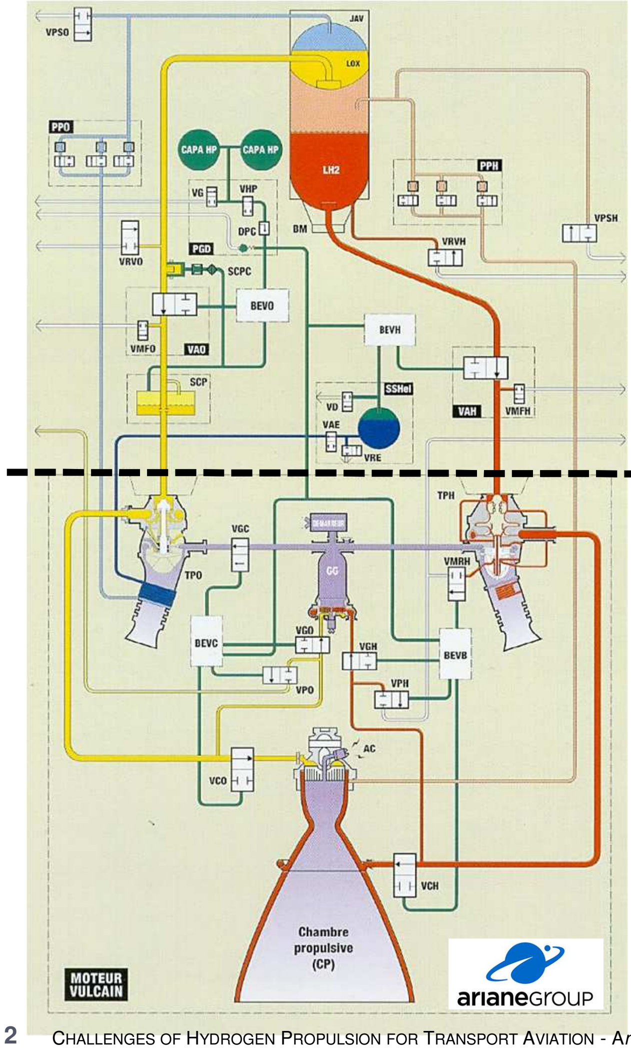
Airbreathing H2 Combustion – NOx is not Inevitable

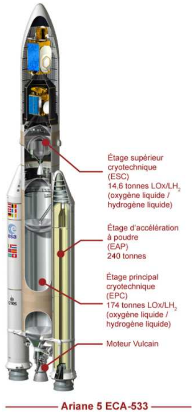


MICROMIX

LDI

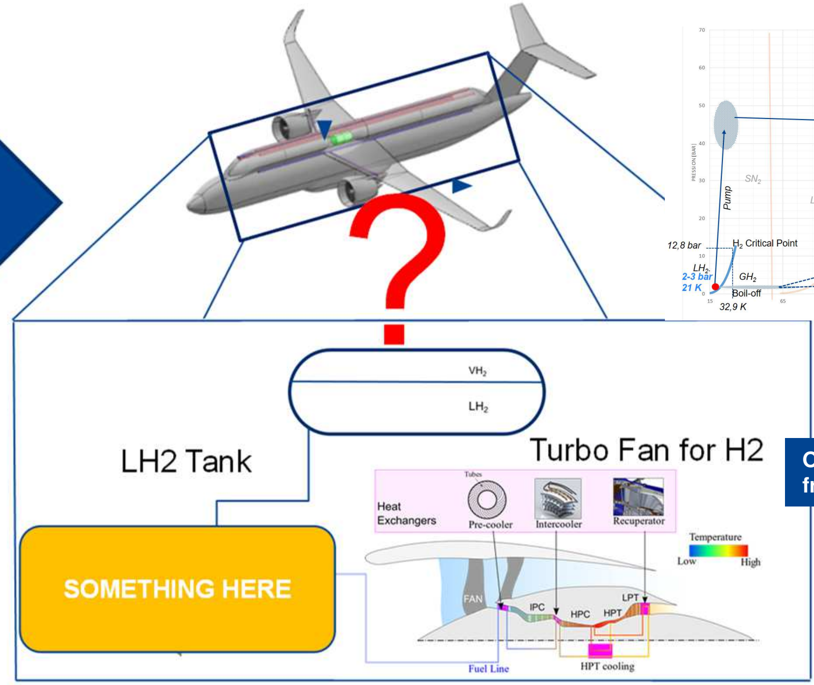
Legacy of Space Propulsion

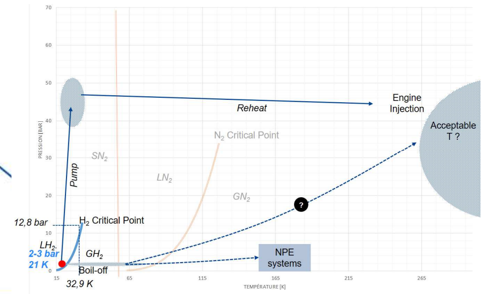




Stage

Engine





One whole Functional System from Tank to Engine

- **Multiple interactions between subsystems from tank to engine**
  - *Strong fluid & thermal interactions*
  - *Optimization opportunities*
- **Traditional aviation boundaries** between Airframer and Engine Provider may be modified accordingly
- **Multiple subsystems and components to develop or transpose for aviation use**
- **Without under-estimating transient operation**
  - *Chill-down*
  - *Altitude relight on TEFO*
  - *No Helium for purging/venting/dynamic seal barrier*

Which Safety Policy in front of H2 novelty ?
2 failures ➔ 3 failures before CAT event ?

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LH2-Burn Tech Acquisition – Engaging on all fronts

From light TP…

TURBOTECH

H2 Conditioning & Metering System

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Air Liquide

dgac **Project BEAUTHYFUEL**

arianeGROUP

Elixir Aircraft

DAHER

… to large scale flight test demonstration

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Concluding Remarks

- **Gaseous storage** of hydrogen does not appear to be a suitable option for commercial transports **; cryogenic storage,** even if more challenging, seems the way to go

- Preliminary scanning of commuter & regional design space allows **setting targets for PEM Fuel Cells** to compete with gas turbines
  - These targets remain **long-term objectives**; they will require **doubling the specific power of the integrated system** and not only improvements at stack level
  - Targets very dependent on Blue/Green Hydrogen Emissions Index
  - Preliminary systems analysis and design highlights the **critical issue of thermal management and its aero integration**, that can tremendously degrade specific power and efficiency if not tackled with caution

- **Gas turbines will remain the go-to technology for commercial transports** until at least the middle of the century
  - Low-NOx technology achievable
  - Space propulsion legacy, technology and infrastructures enable comprehensive and efficient Integrated Propulsion System

- **Airframer safety policy in front of novelies introduction** to be carefully taken into account when designing H2 propulsion systems (both CS-23 ad CS-25)

- Safran H2 propulsion roadmap targets **both high performance PEMFC systems and H2-Burn Gas Turbine** at end-20’s

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