Hydrogen for Aviation
Webinar

INNOVATE · ACCELERATE · CHALLENGE

Agenda & Presenter

PRESENTER

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AGENDA

1. Introduction
2. Comparison of low carbon solutions for aviation: battery, fuel-cell and hydrogen propulsion
3. Field of use of hydrogen propulsion in civil aviation
4. The 4 challenges for the large-scale deployment of 100% hydrogen civil aviation
5. Q&A

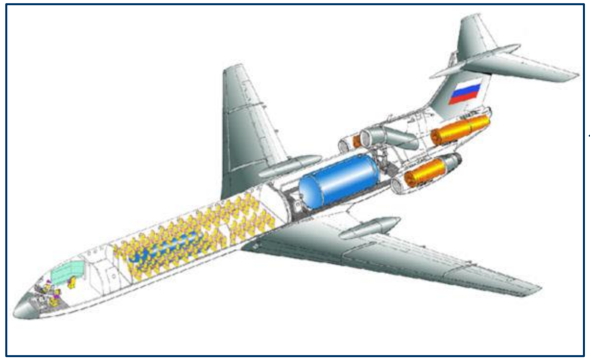
WHEN will the first H_2 mid-range aircraft appear ?

? **WHEN will an H_2 powered mid-range aircraft fly?**

H_2 aviation is not Sci-Fi and ecological transition puts it back in the spotlight…

TUPOLEV TU-155

- *Switch to a single LH2 engine during flight*
- *1st LH_2 flight: April 15th 1988*
- *Cancelled: 1994*



… But sector wide adoption of H_2 is a bigger challenge than flying a single aircraft

Hydrogen is the only viable low emission option for commercial aviation

Batteries
Li-ion

Unviable
Very small planes only

*"Assuming for a moment that we'd be able to rely on **batteries 30 times as energy dense as that** [from 100wh/kg to 3000], an A320 would be able to fly with **half of its payload for one-fifth of its current range**, 500nm max. So, assuming a battery which today does not exist … It doesn't work, purely electrical will not work."*

Grazia Vittadini,
Airbus, 2019

E-fuels

Viable mid term

kerosene-equivalent performance

Interoperable with kerosene, but limitations due to energy consumption during production :

- H2 production (electrolysis)
- CO2 capture systems
- Fuel synthesis systems

→ High OPEX

Fuel Cells with LH2

Viable for limited range and performances

*For an E175 aircraft (78 PAX) "With experimental fuel cell densities potentially as high as only 2.2 kW/kg, the fuel cell system would require about **19,800 kg of equipment to generate the 43.7 MW of power** output during the climb phase of the flight, **compared to the 2364 kg total for two CF34-8E turbine engines** on the aircraft today"*

Ahmed F Ghoneim
MIT: Center for Energy & Propulsion Research, 2019

LH2 as propellant

Viable High ranges and performances

Increased aircraft weight and volumes:
For same energy

Fuel Weight / 2.8 vs kerosene
Fuel Volume x 4 vs kerosene

High autonomy requires a significant increase in the aircraft volume for LH2 storage.

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The interest of hydrogen & its use cases across its application segments

Technology Readiness Levels:			Industry Feedstock and applications	Grid balance	Heating	Mobility
			Feedstock for production of ammonia fertilizers & steel	A **gap-filler** between variable production & demand	A progressive **substitute** to fossil fuels used for heating	A **new energy vector** for mobility applications
System Ready	**9**	Qualified system with **proof of successful use** – product	Petrochemical	Storage	Heating	Buses, Cars, Forklifts
	8	Qualified system with **proof of functional capability** in area of use – product				Trains, Trucks
Prototype in work	**7**	Prototype in use – **demonstration almost to scale in the operational environment**				
	6	Prototype in operational environment – **technical feasibility demonstrated** in the area of application				Propeller aircraft
Experimental Tests	**5**	Experimental setup in operational environment – **key technology elements tested** in a relevant environment				
	4	Experimental setup in **lab** environment – **key technology elements tested**				Jet

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Major public investments in H2 projects across the world

	Germany	France	United Kingdom	South Korea	China	United States
Date	**June 10th 2020**	**June 9th 2020**	**September 2019**	**June 2018**	**June 2019**	
Budget	**€9 billion**	**€1.5 billion**	**£12 billion**	**$22 billion**	**$17 billion**	***No major public announcement so far :*** *$64 million announcement for green hydrogen production (2020).*
Goal	Ramp up **Hydrogen production** capacity to **5 GW by 2030** and **10 GW by 2040**	Development of a **carbon-neutral aircraft** by **2035 (Prototype** between **2026 & 2028)**	Deployment of a **4GW floating wind farm** for **hydrogen production** in the **early 2030s.**	Develop private-public **Industry ecosystem for Hydrogen fueled vehicles** by **2022.**	Develop **fuel cell industry** and **H2 mobility supply chain** by **2023**.	*Private sector (such as Nikola) is investing massively in H2*

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3 steps to reduce CO_2 emission using H_2

2025 - 2030 | **2030s** | **2040s**

Synthesis Kerosene – E-Fuels

Synthesized from CO2 and Hydrogen

No impact on the aircraft design

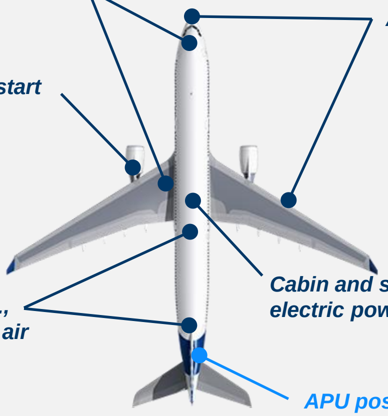
Compatible with current engines

Higher fuel cost than H_2

Lower CAPEX, Higher OPEX

Fuel cells as auxiliary power unit

Electrification of auxiliary systems by **Hydrogen based fuel cells:**



Hydrogen fuel cells as propulsion

Existing small planes prototypes

ZeroAvia 6 seaters

Radical rethink of the design for small aircraft
(e.g. distributed electric propulsion)

Higher CAPEX, Lower OPEX

LH2 for propulsion

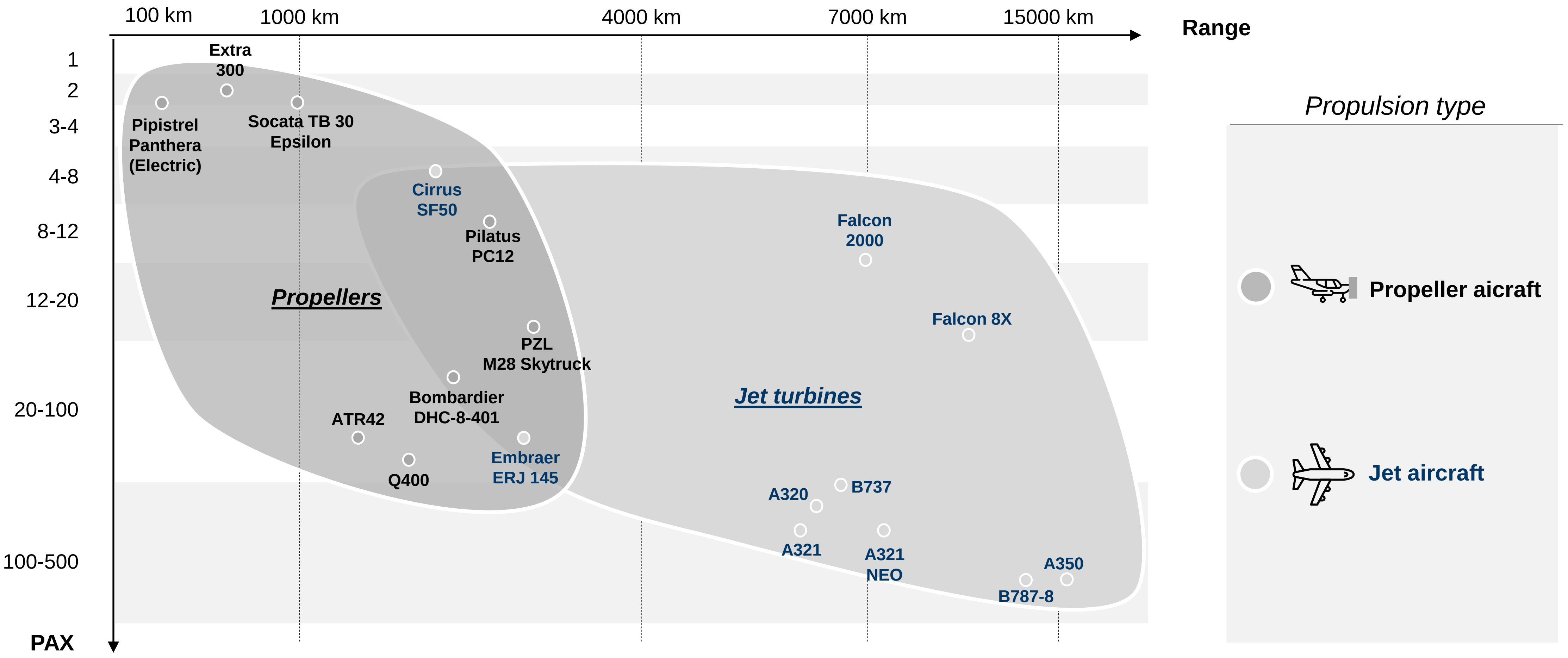
Re-design of jet aircrafts

Early 2000 Cryoplane project

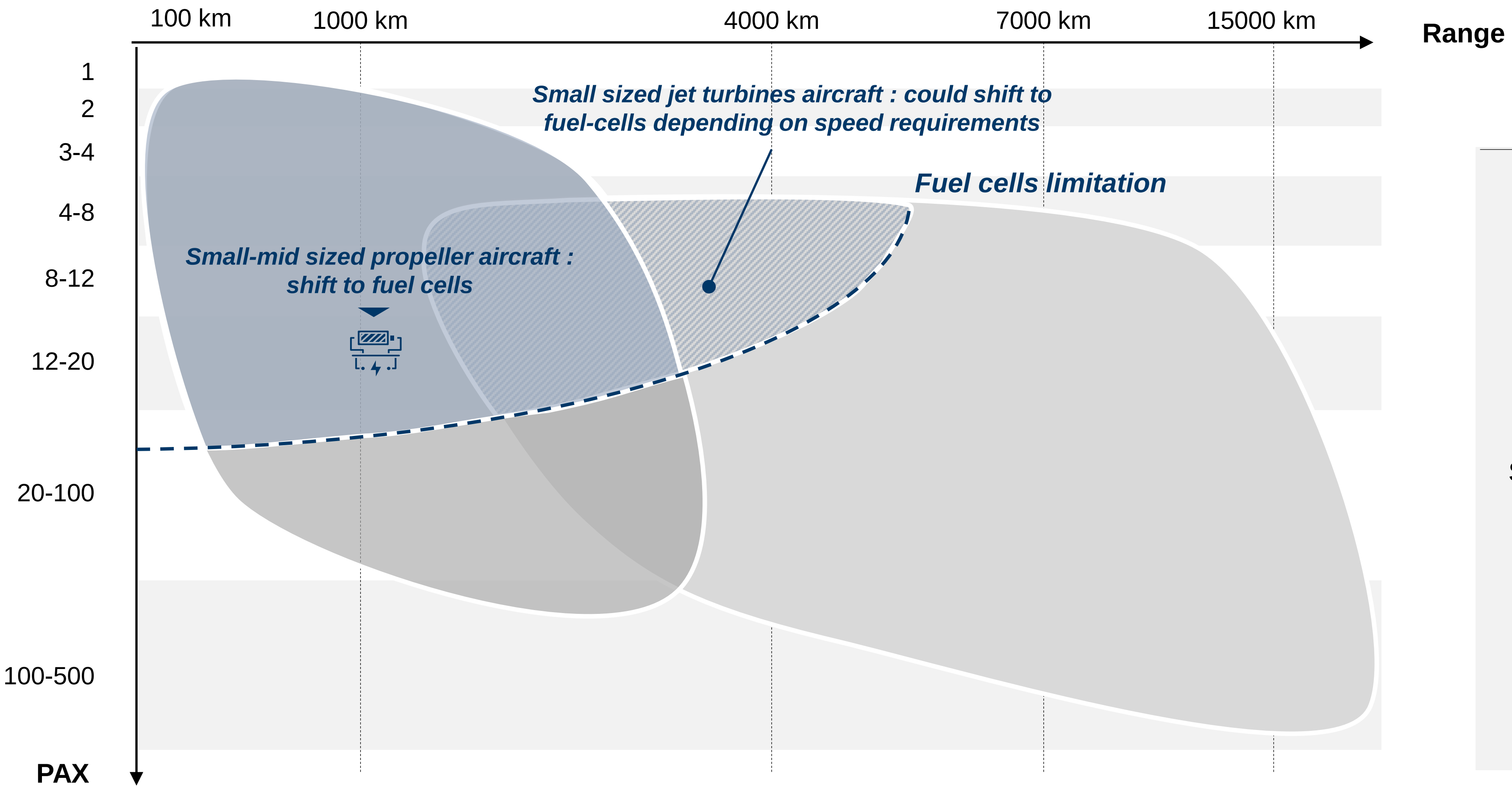
Could appear earlier than fuel cells for mid-size carriers

Higher CAPEX, Lower OPEX

Mapping of civil aviation



Fuel cells are relevant to replace within a certain load and performance limit

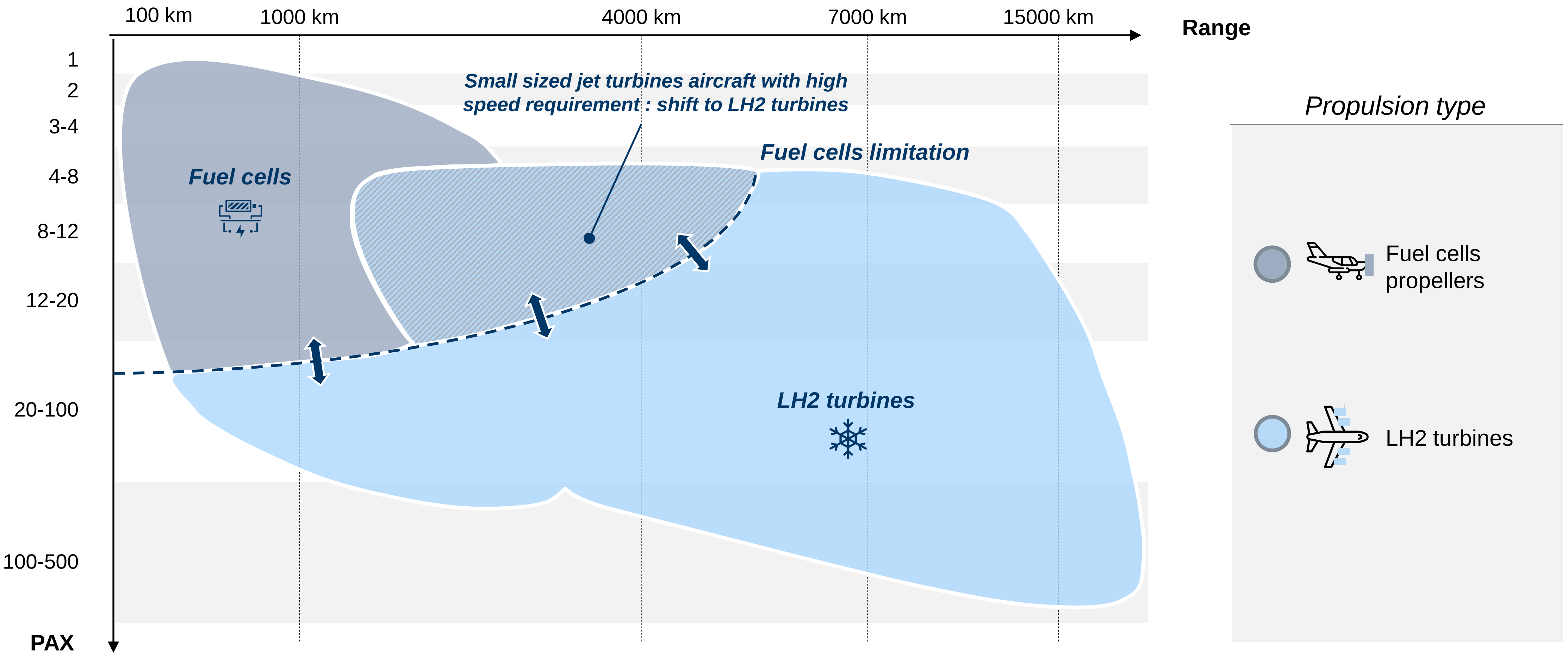


Propulsion type

Light propellers and **jet turbines**

Shift to fuel cells propellers

LH2 jet turbines are suited for larger aircraft and longer ranges



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4 key challenges of large scale H2 aviation

H_2 aircraft → New aircrafts have to be designed and certified

New, safe and robust solutions have to be developed including Storage tank, distribution, Venting, dispensing and purging

Cost impact → Lower emissions come at a higher price

Cost increase has to be offset either by carbon taxes of ~500€/ton of CO_2 or supported by the passenger

Electricity production → Widespread and sustainable H_2 requires more electricity supply

Full electrolyzed H_2 scenario requires a 35% increase of current global electricity generation

Supply chain→ Massive H_2 storage & delivery capacities must be developed

40,000 airports have to go through a major overhaul of their infrastructure while maintaining dual capabilities during a 30-year transition period

LH2 Aircraft

What does the Liquid H_2 aircraft look like?

Current design

LH2 concept

System

- **New Fuel System**: Tanks, Pipes, Valves, Pumps, Vents
- **New Fuel Control System**: Sensors, Control Box
- **Fire Protection featu**res: Sensors, Ventilation , Control Box

Engine

- **High pressure Pump**
- **Heat Exchanger**
- **Fuel Flow Control Valve**
- **Combustion Chamber**
- **Control Box**
- **Oil Cooler**

Airframe

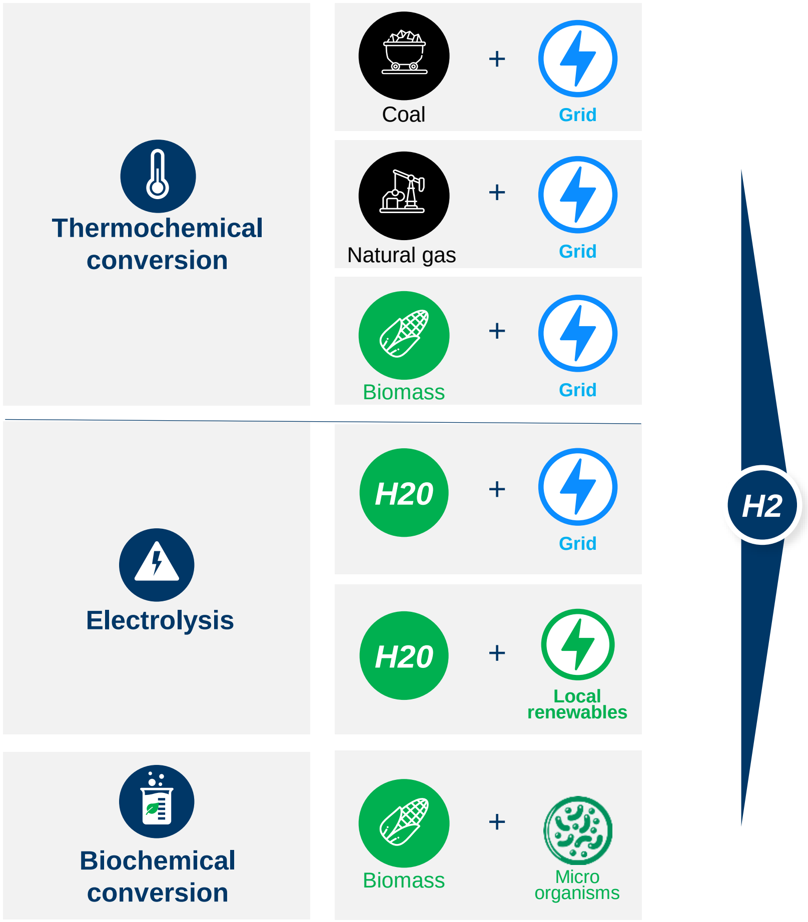
- **Tank support**
- **Local strengthening fuselage**
- **Fairings fuselage stretch to accommodate increased payload strengthening of wing structure**

Configuration

- **Integration of large cylindrical tanks, preferably above the passenger cabin**

Cost Impact

First of all, 3 colors of Hydrogen



Different "shades of green"

CO_2 emissions from hydrogen production depends on technology and energy mix

GREY H_2 – Fossil Fuel

- *Gasification – coal / lignite*
- *Steam methane reforming*

BLUE H_2 – Grey with CCS* or Grid electrolysis

- *Fossil fuel production with Carbon Capture & Storage*
- *Electrolysis from grid yet not renewable sources*

GREEN H_2 – From renewable energies

- *Electrolysis from low-carbon renewables source*

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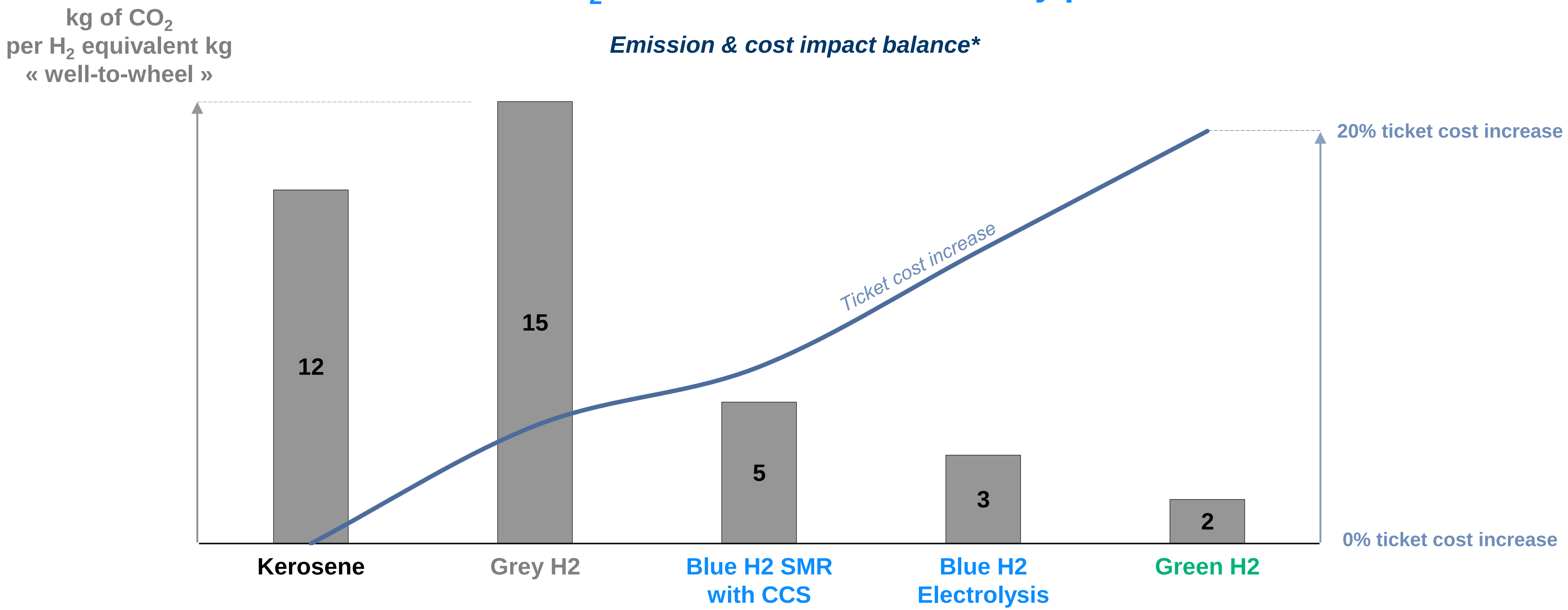
** Carbon Capture and Storage*

Cost Impact

Finding the right balance between emissions and cost

Almost CO_2-free aviation is technically possible



- *Calculation based on the French energy mix with 58 gCO2/ kwh*
- *Cost impact on a Boeing 737 or A320 block-hour cost for a 3000km flight*

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Electricity Production

Paris CDG airport turned 100% H_2 with state of the art technology

Paris Charles de Gaulle Airport

700
Take-offs / day

Kerosene	H2 Propulsion
4 200 t *Kerosene need by day*	**1 500 t** *H_2 need by day* → **4 GW** *Power needed to produce H_2 by electrolysis*

What do these 4 GW represent?

NUCLEAR

EPR Flamanville 3: 1,65 GW

2.5
EPR reactors

€9 bn
*Capex Cost**

WIND POWER

Wind farm: 3 200 turbines spread over 2 000 km²

3 200
5MW-25% load factor Wind turbines

€16 bn
Capex Cost

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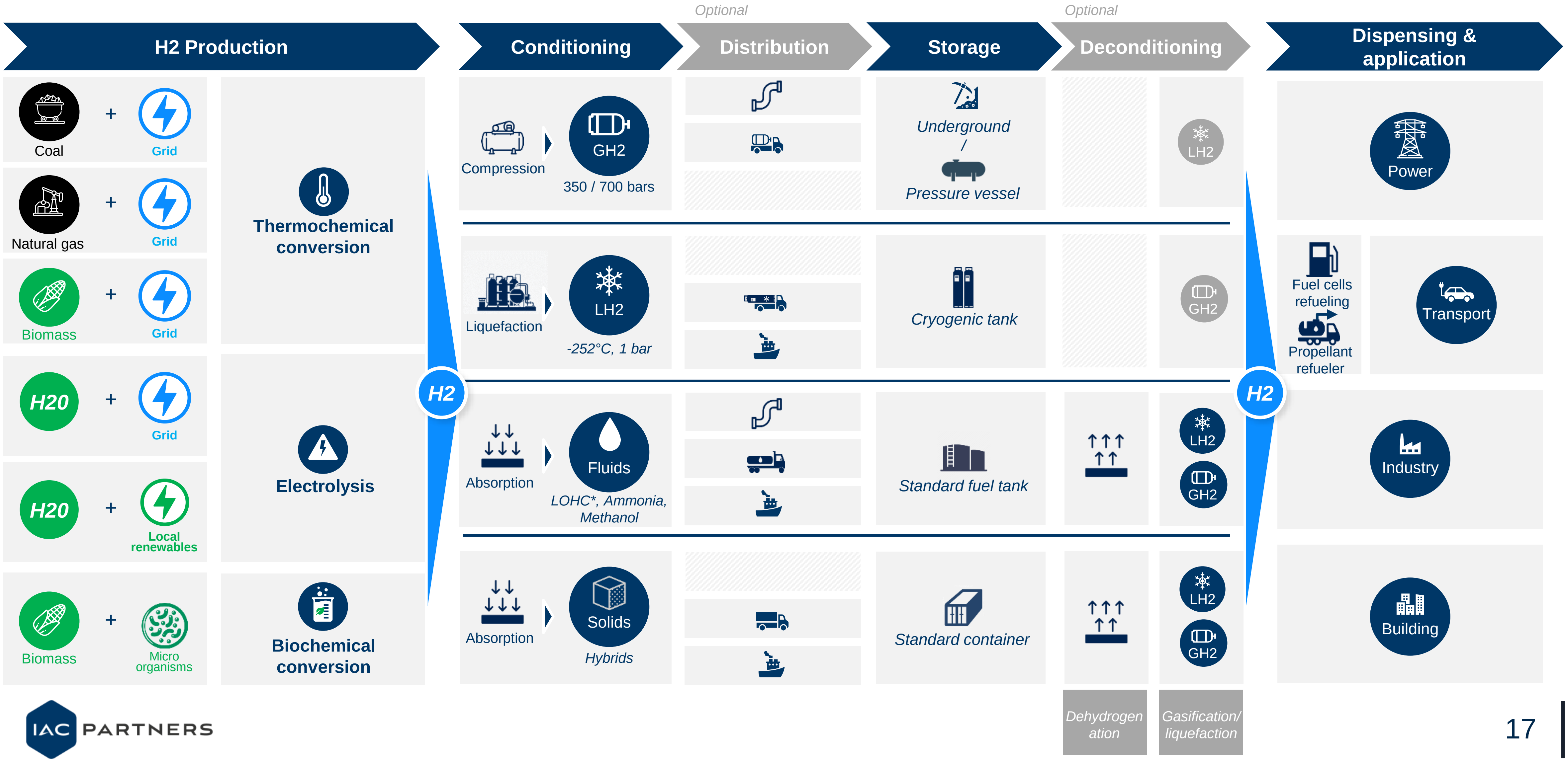
**Based on initial cost estimation of €3.5 bn*

Hydrogen value chain – Multiple production and supply patterns

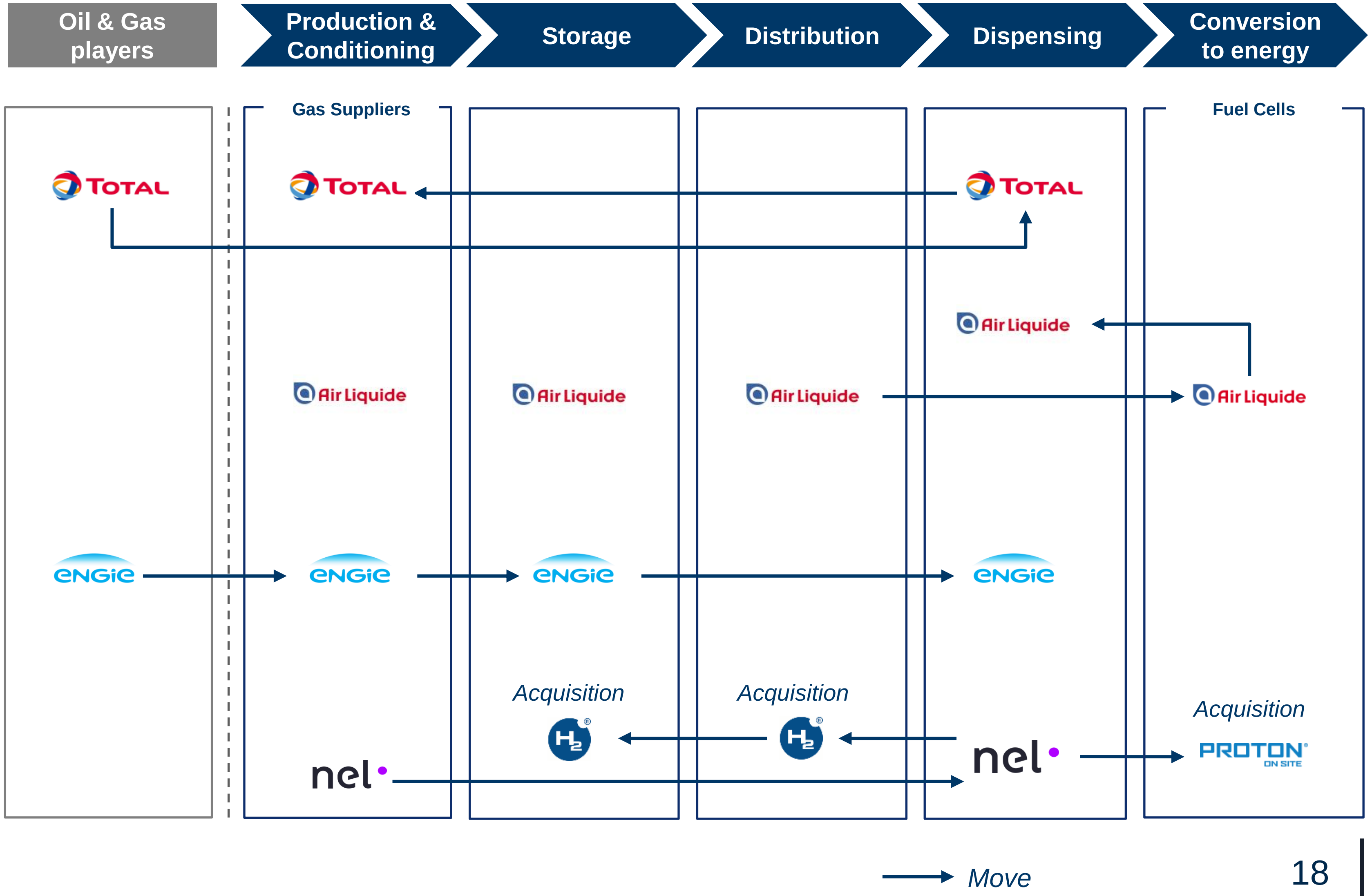


*Liquid Organic Hydrogen carrier

Supply Chain

Positioning of the main actors in H2 supply chain is beginning to take shape

Key player	Their vision of hydrogen
TOTAL	*TOTAL sees hydrogen as a green fuel (potential threat to the fossil fuel market)*
Air Liquide	*AIR LIQUIDE sees hydrogen as a molecule and wants to remain a world leader in gaseous/liquid molecules production & distribution*
ENGIE	*ENGIE considers hydrogen as a clean source of electricity / a useful buffer for renewable energy production*
nel	*NEL sees itself as an hydrogen conversion specialists*



Take aways, Q&A

1. H_2 **aircraft** has proved to be **feasible,** however a **long development and certification** phase is to be expected

2. **Zero-carbon aviation is technically achievable with H_2.** Today, its production is mostly “grey” and more polluting than burning kerosene

3. **Immediate focus** should be **on infrastructures and supply.** An **H2 airplane without refueling capabilities is useless**

4. **H2** for aviation will **benefit from a scale effect** as many regions and industries are investing heavily

5. **Production ramp up** will be a massive **challenge** since a large amount of energy will be needed to generate H_2**: full H_2 scenario** would **need 35% of current worldwide electricity generation capacity**

6. **E-fuels might play a role as a short-mid term solution,** esp. for the already existing fleet, despite **significant production costs**

Q & A