

« Hydrogen as a Fuel is a Bad Idea. »

... or is it?

“I have not the smallest molecule of faith in aerial navigation (flight) other than ballooning.”

Lord Kelvin, ~1870.

“Fooling around with alternating currents is just a waste of time. Nobody will use it.”

Thomas Edison, ~1880.

“There is no future for the turbine engine in aircraft.”

William J. Stern, U.K. Air Ministry Laboratory, ~1920.

“The energy produced by the breaking down of atoms is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine.”

Ernest Rutherford, ~1930.



Flying to Sustainability with Hydrogen

Facts and Challenges

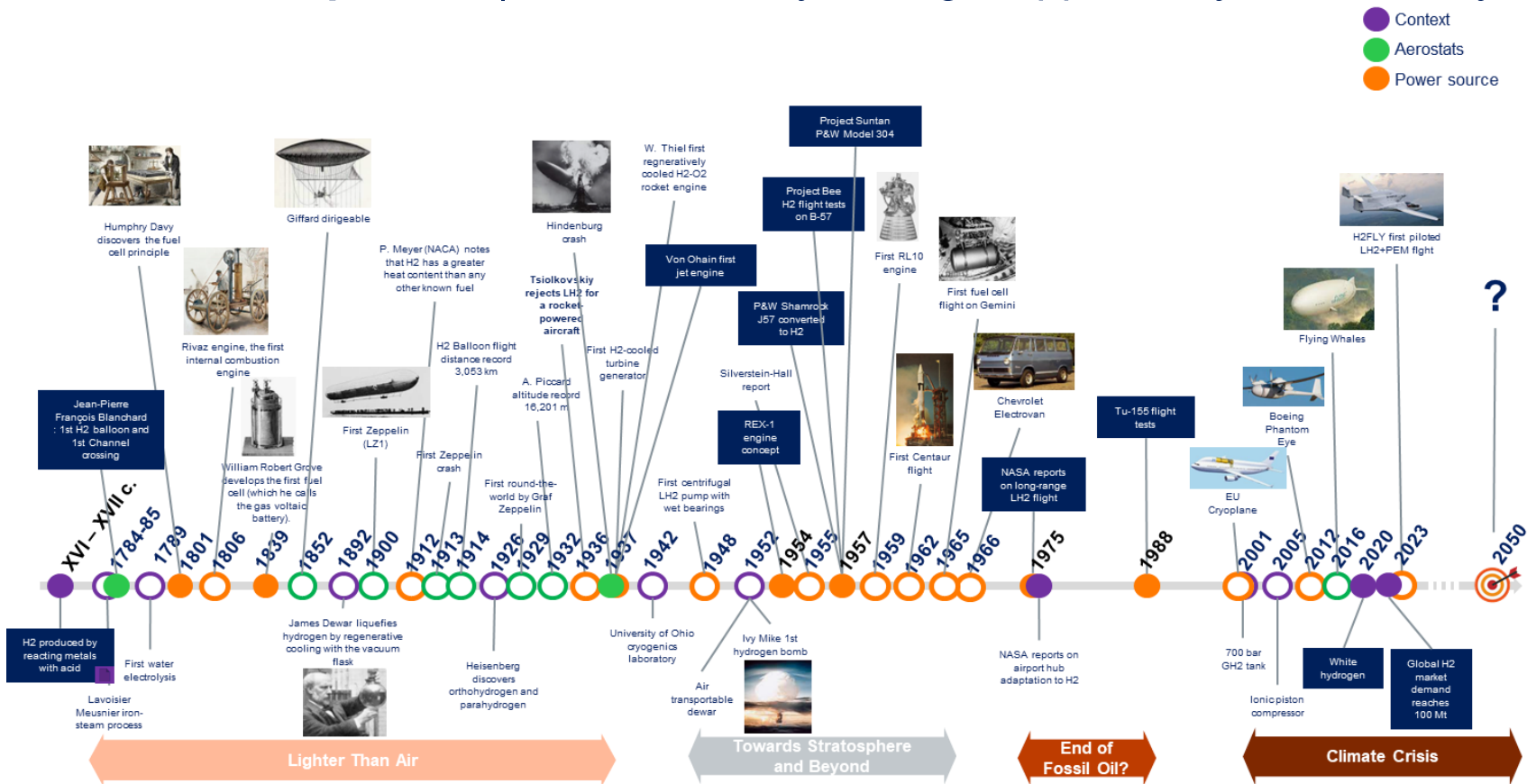
Dr. Pierre A. Lambert

EASN15th
International Conference
on "Innovation in Aviation & Space towards sustainability today and tomorrow"

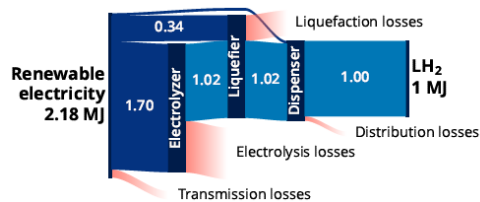
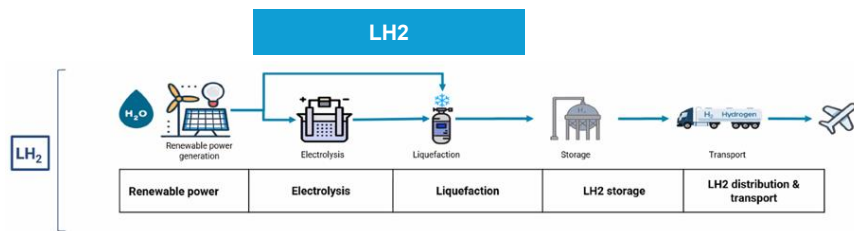
OCTOBER 14-17, 2025
MADRID, SPAIN



Historical Perspective | From Curiosity through Opportunity to Necessity

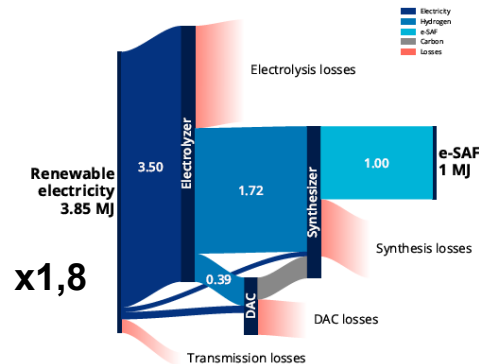
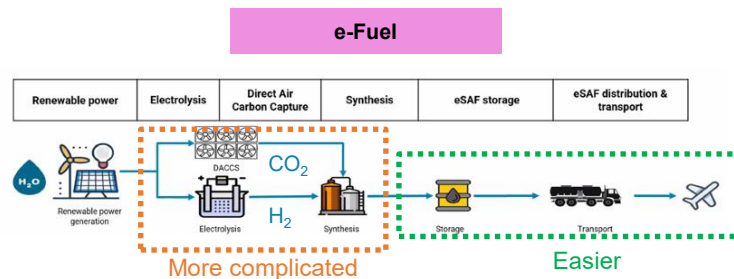


Direct Hydrogen or e-Fuel?



Production Processes Energy Expense

Eytan J. Adler and Joaquim R. R. A. Martins. Energy demand comparison for carbon-neutral flight. Progress in Aerospace Sciences. 2024.

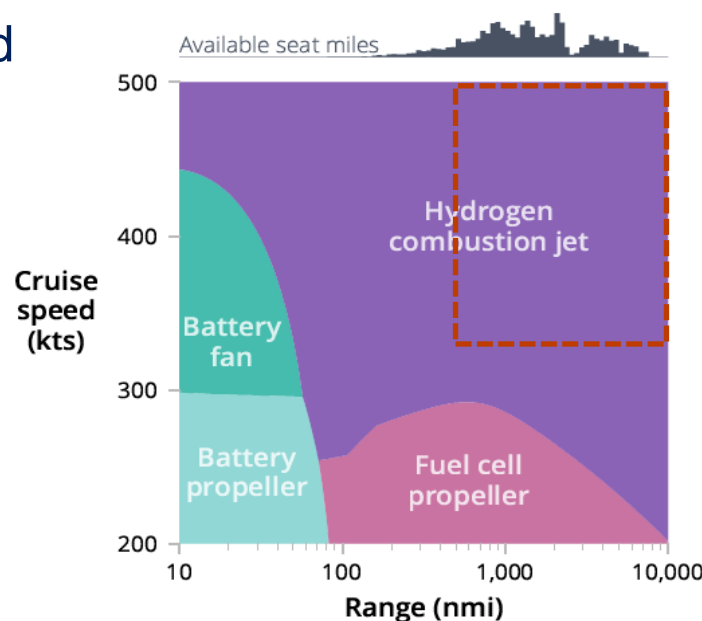
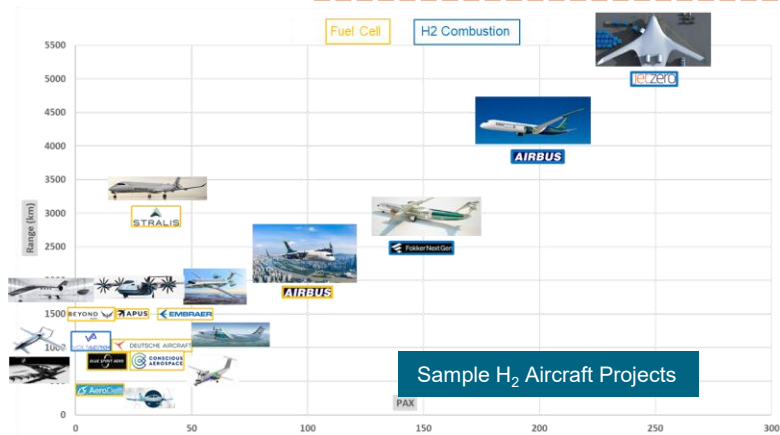
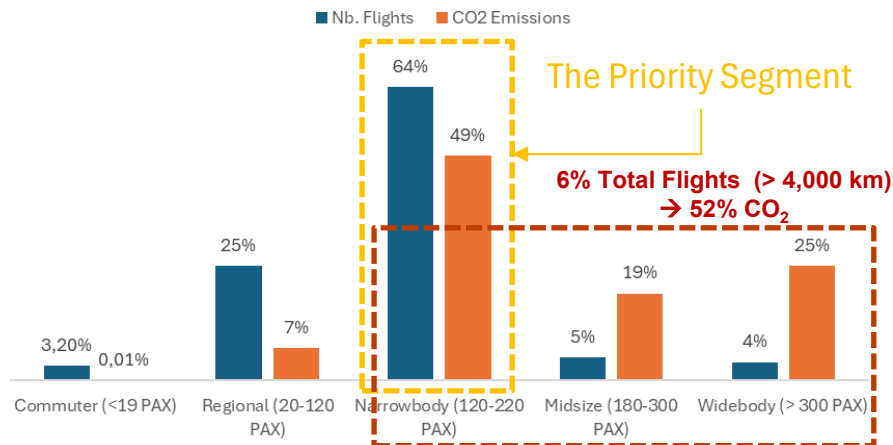


- ✓ Potentially carbon-free
- ✓ Wide possible industry uses
- ✓ H₂ storage + fuel cells could alleviate the intermittence of renewable electricity
- ✓ Gas pipelines could be competitive with HVDC newtorks
- ✗ H₂ leaks unavoidable
- ✗ Transport through H₂ carriers (e.g. NH₃) significantly decreases process efficiency

- ✓ « Business-as-usual » in the limits of the aviation sector
- ✗ Process efficiency
- ✗ Specific aviation formulation to cope with existing fleets may induce high prices
- ✗ Carbon-neutral at best

On either way, aviation sustainability in the 21st century completely relies on widespread access to affordable Hydrogen

Hydrogen-Fueled Aviation | The Playground



Eytan J. Adler and Joaquim R. R. A. Martins. Energy demand comparison for carbon-neutral flight. *Progress in Aerospace Sciences*. 2024

Sustainability of the world aviation market imposes to address scalability to Medium and Long Range from the onset

H₂ Propulsion | Two Technologies Competing?



PEM Fuel Cell

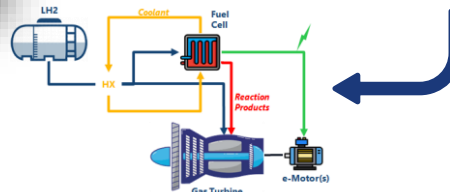
- ✓ Alleviates **battery limitations** for electrical propulsion
- ✓ **NOx free**
- ✓ **~50% efficiency**
- ✗ **Complex** system
- ✗ **Ageing** issues
- ✗ Durable **weight penalties** limiting growth potential
- ✗ No architecture standard, Cert referential to build
- ✗ High Temperature PEM needed
- ✗ Electrical distribution and motor hurdles for > MW



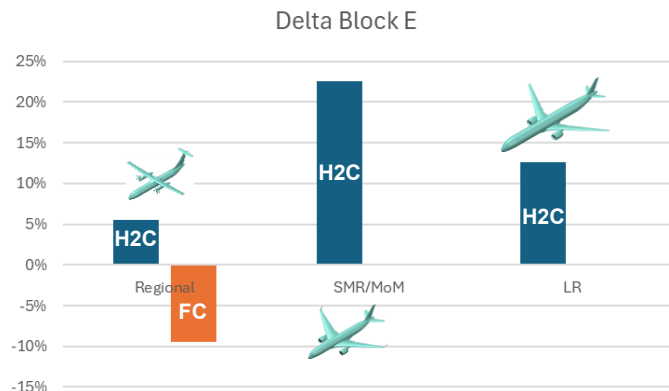
Towards the Best of Both Worlds
H2C/PEM Hybrid

H₂-Combustion

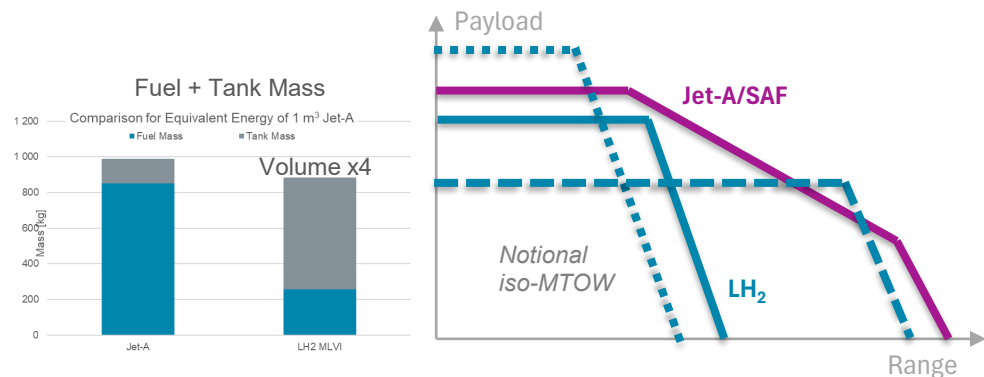
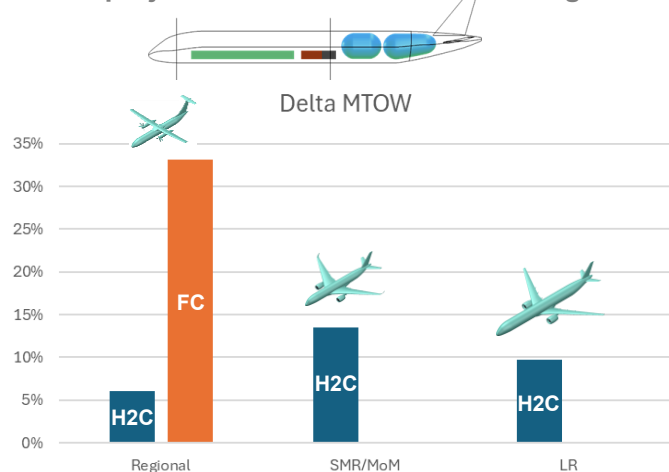
- ✓ Legacy gas turbine architectures **still valid**
- ✓ **Growth potential** across all segments
- ✓ NOx emissions **manageable** (-50% vs best JetA)
- ✓ Important **efficiency gains** achievable with LH2 cooling
- ✓ Existing **CS-E basis**
- ✗ More challenging LH2 **conditioning and control system**



LH₂ Aircraft | A Different Breed



Vs. projected EIS 2040 SAF Tube&Wing



LH₂ aircraft have less versatility
Cannot trade PAX for Fuel that easy

Lighter fuel, but huge LH₂ tanks, heavy fuel system impact both performance and operation profile

- Do not expect H₂ to be an energy saving solution in the medium term
- New market segmentation ?
- Very aggressive designs needed to alleviate MTOW issues, unlikely at large scale before 2050



-19% Block E
- 15% MTOW

LH₂ Fuel System Architecture & Technologies | A Major Challenge



Tank

- Liquid hydrogen storage -253°C
- MLV insulation
- Trade between subcooled/saturated



Pipes

- Low/high pressure LH₂ & GH₂
- Rigid/Flexible
- Easy & reliable disconnect



Hydrogen Cryo Pumps

- Low, Intermediate and High Pressure pump types
- LH₂ submerged e-motor



Heat Exchangers

- H₂/Air
- H₂/Coolant fluid
- Electrical

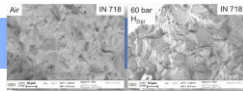


Valves

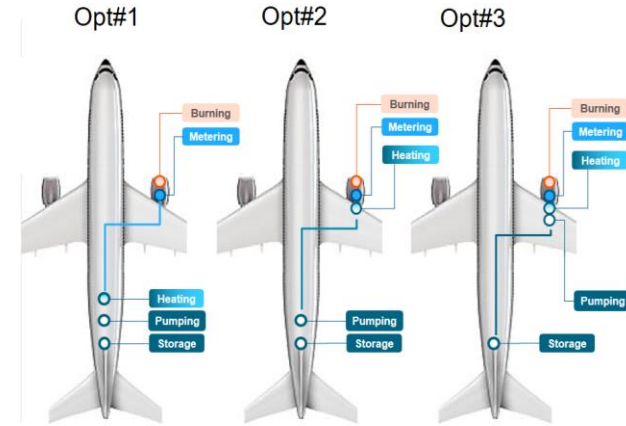
- GH₂ and/or LH₂
- Shut-Off Valves
- Control Valves (fuel metering)

H₂ Distribution and Conditioning

• Materials compatibility



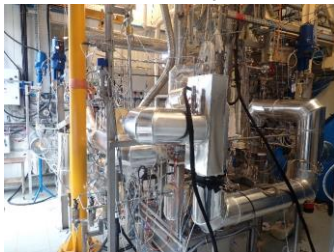
• Sensing & Control Systems



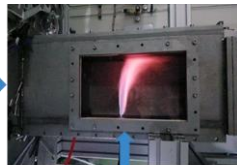
Peculiar thermodynamics induce strong coupling across the end-to-end propulsion system

Paramount importance of early system-level experimental learnings

LH₂ Conditioning & Metering System



Case Burn-Through



Contained Detonation



Air

H₂

Multiple architecture & installation options induce different technology challenges and risks

Overall architecture, aircraft / engine interfaces still blurred in front of the need for standards

Aviation will have to benefit from other sectors



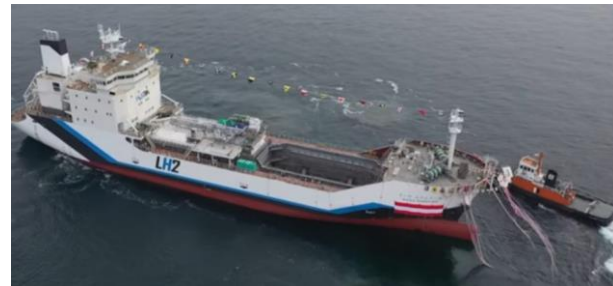
SPACE

Tackle the Extremes



LAND

De-Mistify Everyday Use

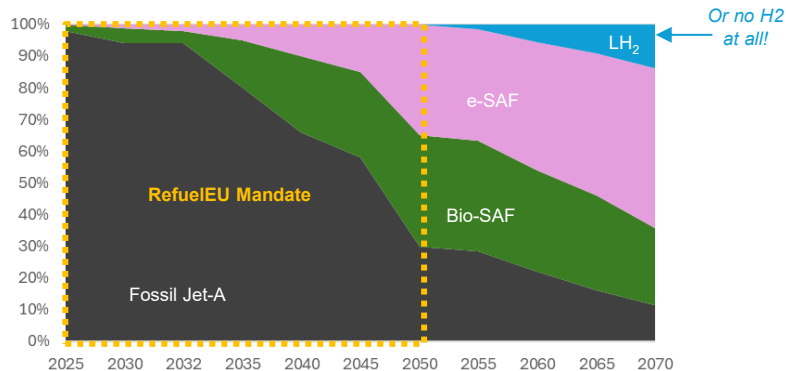


OIL&GAS

Handle Large Quantities

H₂ as a fuel | Timelines

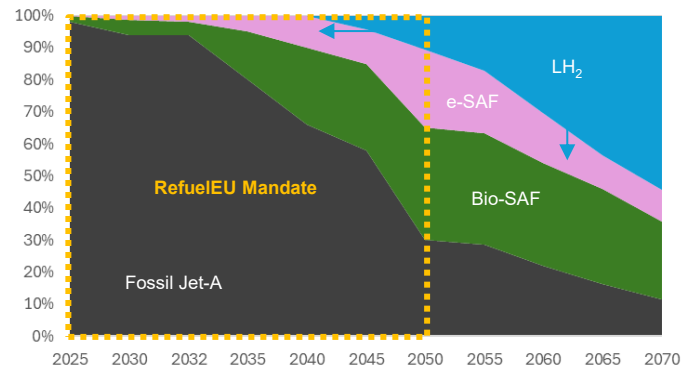
EU Aviation Fuel Share - Scenario A



If...

- H₂ production needs & costs are met
- Cost of Carbon Direct Air Capture (DAC) falls to level where eSAF is commercially attractive (but not so low as to make DAC + Fossil preferable)
- Wide e-SAF adoption outside of Aviation
- Delays in H₂ technology

EU Aviation Fuel Share - Scenario B



If...

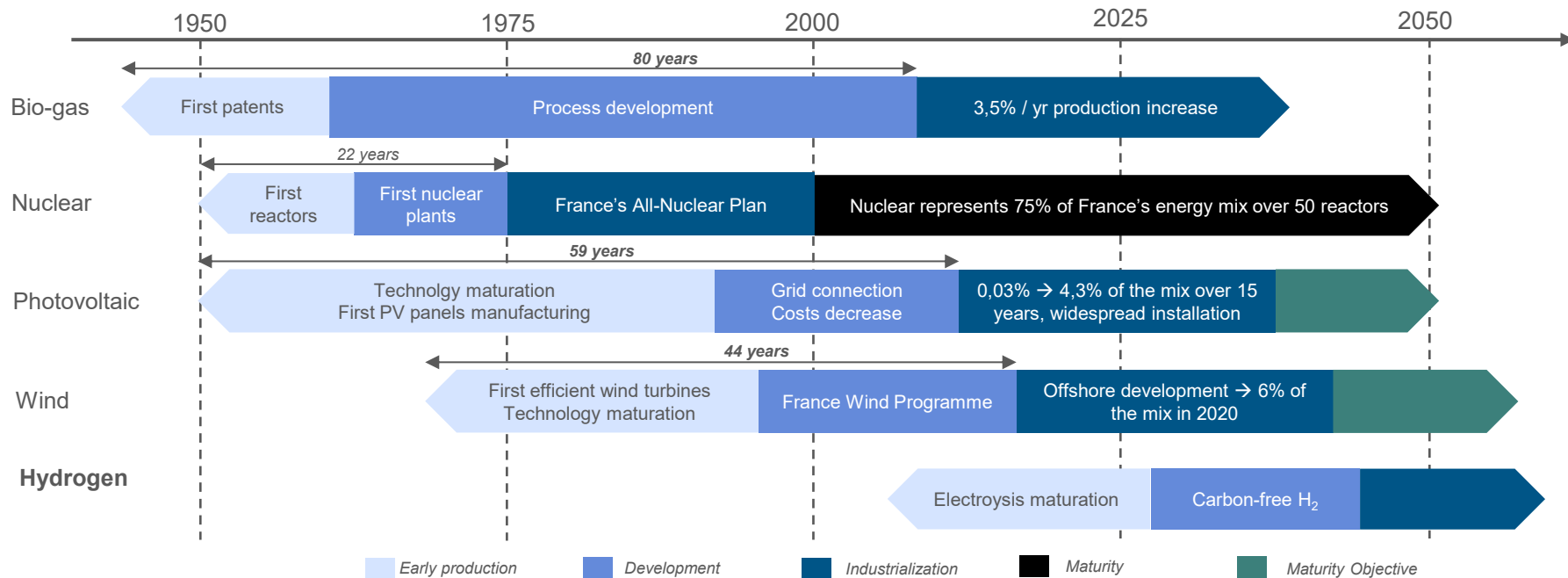
- H₂ production needs & costs are met
- H₂ propulsion contrail impact at least neutral
- Public sentiment rises against tailpipe CO₂ emissions
- H₂ aircraft mandate & government support
- H₂ becomes a commodity for other sectors and/or e-SAF becomes an aviation-specific market

The current hydrogen economy and SAF dynamics do not play in favour of widespread H₂ fuel introduction before the early 2050's
Building confidence takes time and would need strong local support for early scout « thin-haul » lines in the late 2030's



● Declared early adopters

Time is of the Essence

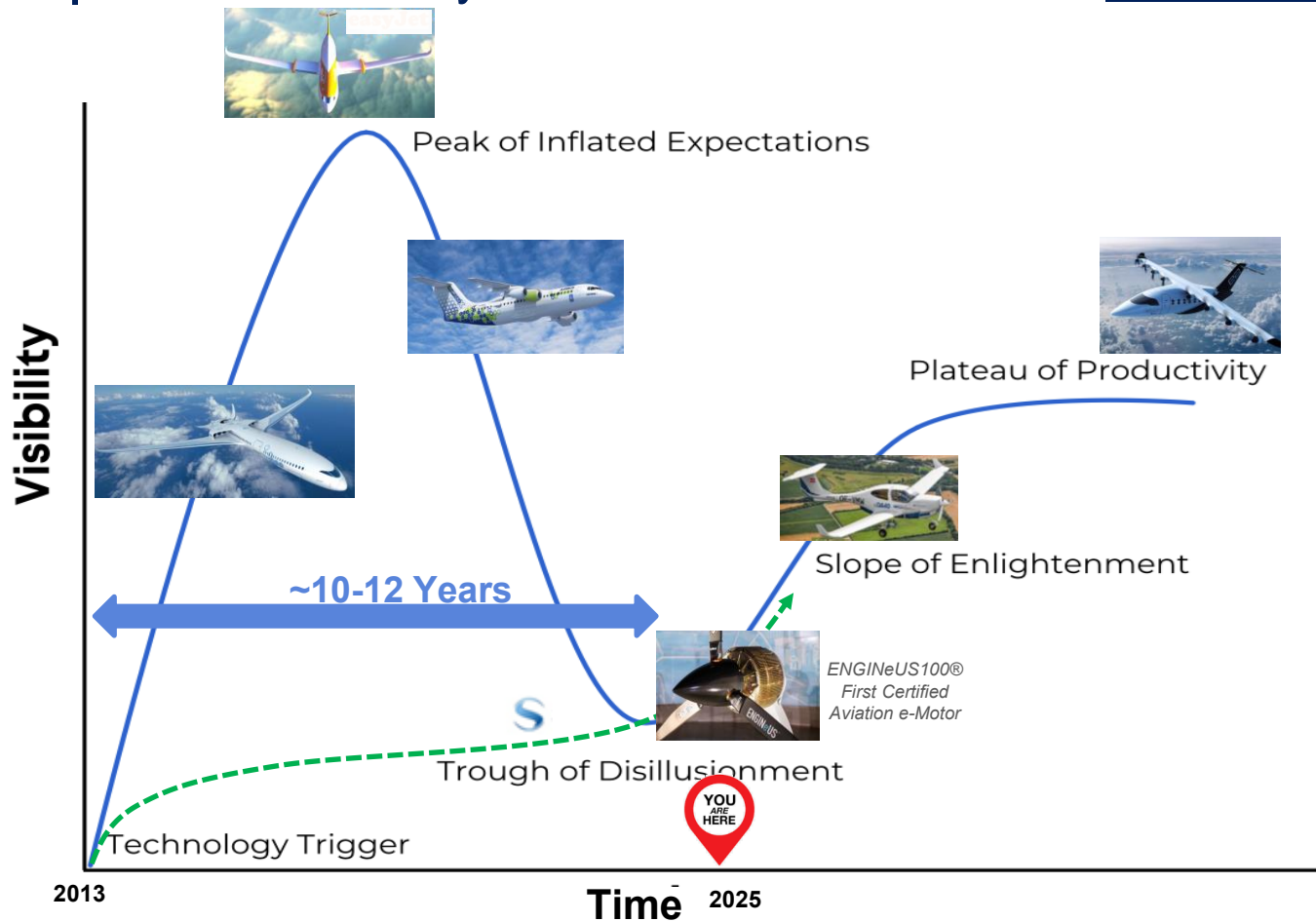


Source IPHE/Clean Hydrogen/Wavestone

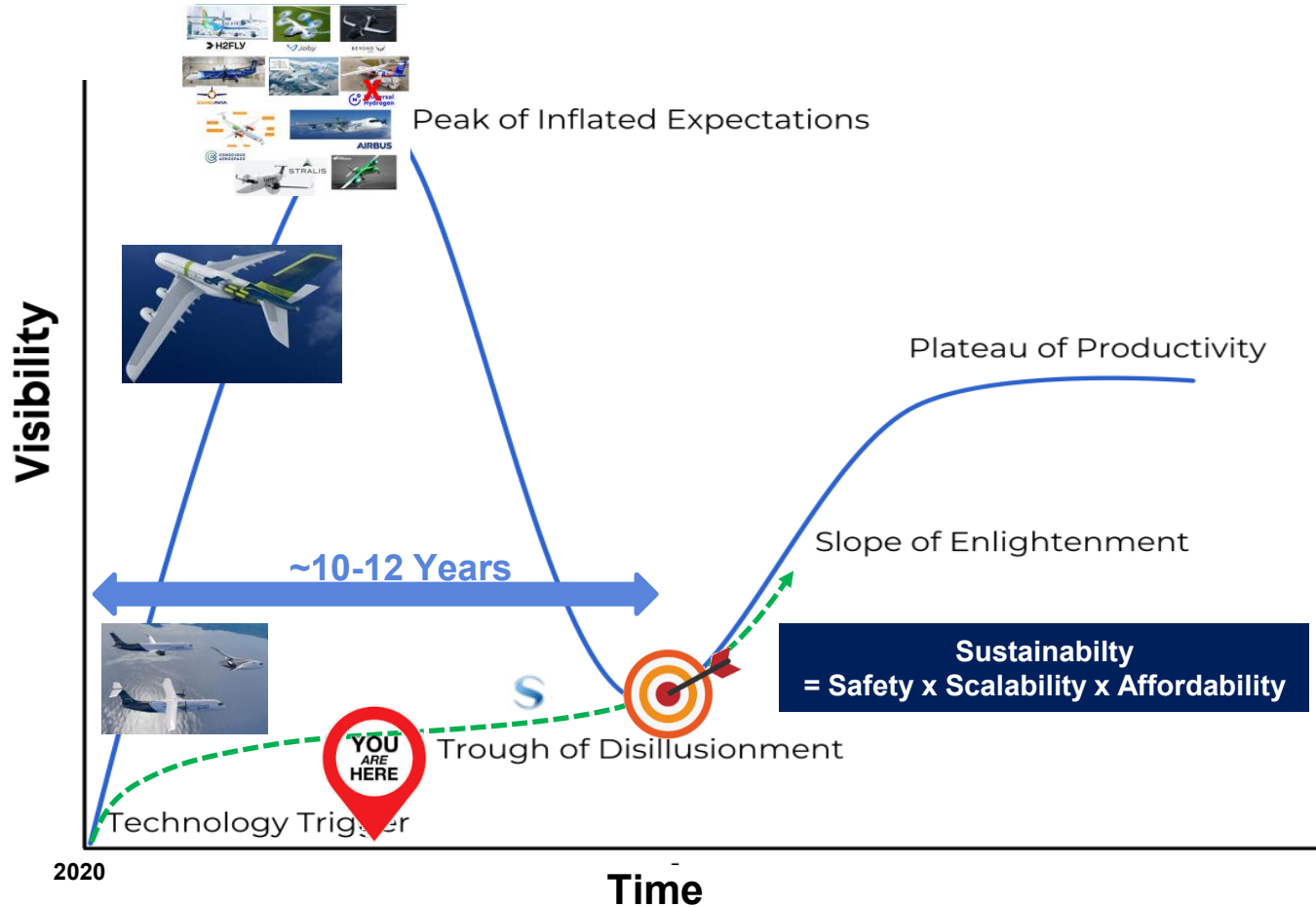
A new energy sector does not develop in 10 years
 Hydrogen will become a commodity, the question is not « when » but « at what speed »

High Hopes | We Have Already Been There

The 2010's All-Electric Promise



High Hopes | Aim Right





Patience. Consistency. Resilience.

POWERED BY TRUST

Yes, my friends, I believe that water will one day be used as fuel, that the hydrogen and oxygen which compose it, used either separately or together, will provide an inexhaustible source of heat and light, with an intensity that coal cannot achieve.

Jules Verne, *The Mystery Island* (1874)