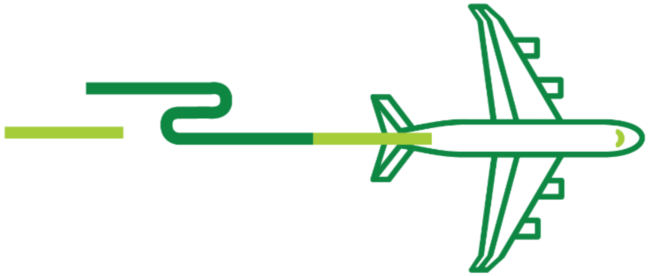
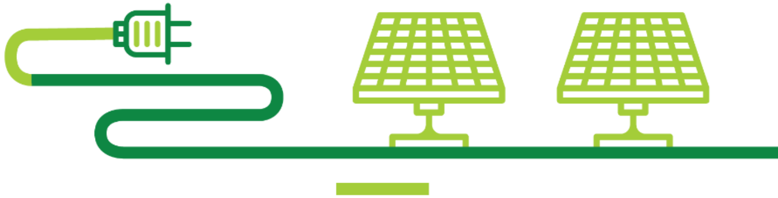


# AVIATION $CO_2$ REDUCTIONS



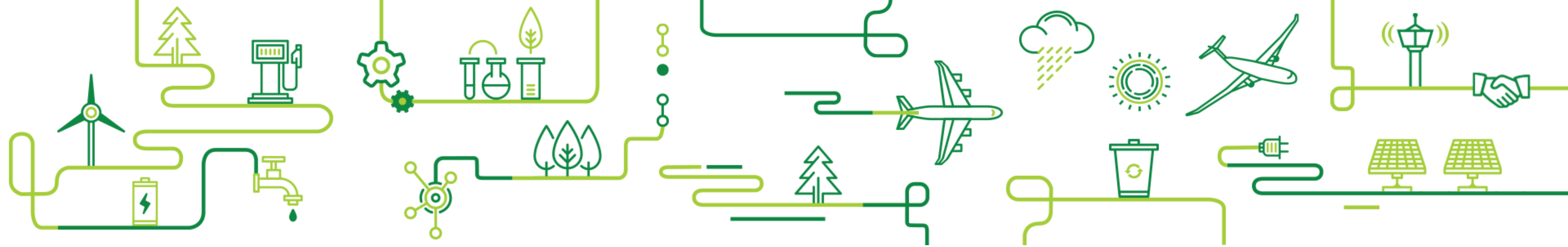
## STOCKTAKING SEMINAR

TECHNOLOGY · OPERATIONS · SUSTAINABLE AVIATION FUELS

# High-level roundtable: a new vision for the future

**Jean-Francois Brouckaert,**

Chief Scientific Officer – Clean Sky Joint Undertaking (www.cleansky.eu)



# Hydrogen Powered Aviation by 2050

## Project team

FCH

McKinsey & Company

Clean Sky 2

## Contributors

AIRBUS

LIEGE AIRPORT

SAFRAN

Air Liquide

equinor

GROUPE ADP

Linde

Schiphol Group

Bauhaus Luftfahrt Neue Wege.

easyJet

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arianeGroup

## Study focus

Evaluation of **potential**, **technical and economical feasibility** of hydrogen for aviation

Modeling of implications on **aircraft design**, **airport infrastructure** and **fuel supply chains**

**Recommendation** of a R&I roadmap

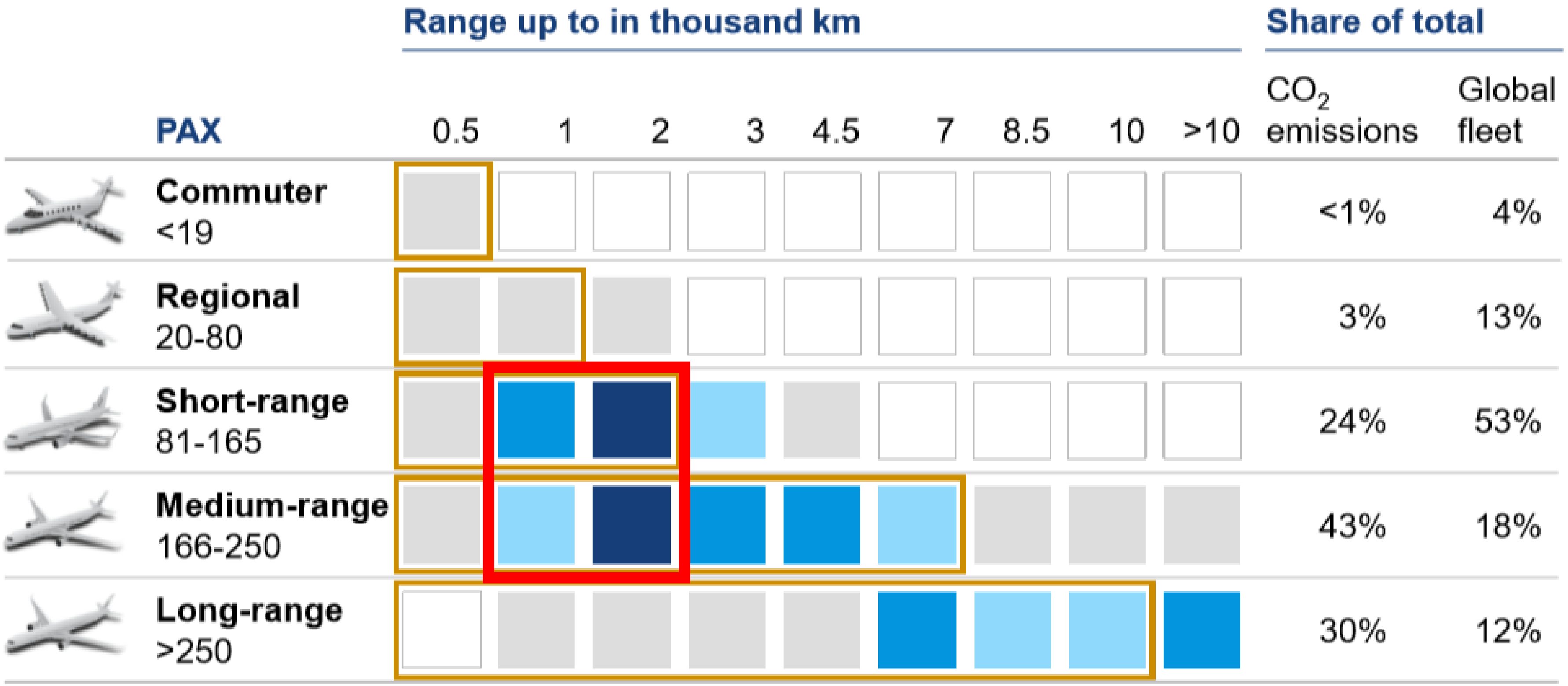
Hydrogen-powered aviation

A fact-based study of hydrogen technology, economics, and climate impact by 2050

**Full report** available on www.cleansky.eu / www.fch.europa.eu

# Methodology

Potential of hydrogen propulsion evaluated in 5 fleet segments



| | **Range up to in thousand km** | | | | | | | | | **Share of total** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **PAX** | 0.5 | 1 | 2 | 3 | 4.5 | 7 | 8.5 | 10 | >10 | $CO_2$ emissions | Global fleet |
| **Commuter** <19 | ░ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | <1% | 4% |
| **Regional** 20-80 | ░ | ░ | ░ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | 3% | 13% |
| **Short-range** 81-165 | ░ | ▓ | █ | ▒ | ░ | ☐ | ☐ | ☐ | ☐ | 24% | 53% |
| **Medium-range** 166-250 | ░ | ▒ | █ | ▓ | ▓ | ▒ | ░ | ░ | ░ | 43% | 18% |
| **Long-range** >250 | ☐ | ░ | ░ | ░ | ░ | ▓ | ▒ | ▒ | ▓ | 30% | 12% |

***5 segments defined for evaluation, covering ~90% of total emissions***

Share of total $CO_2$ emissions ☐ < 0.1% ░ 0.1-2% ▒ 2-5% ▓ 5-10% █ 10-15%

**Dimensions of evaluation**

- **Climate impact**
- **Technical feasibility:** Aircraft design Infrastructure
- **Economics**

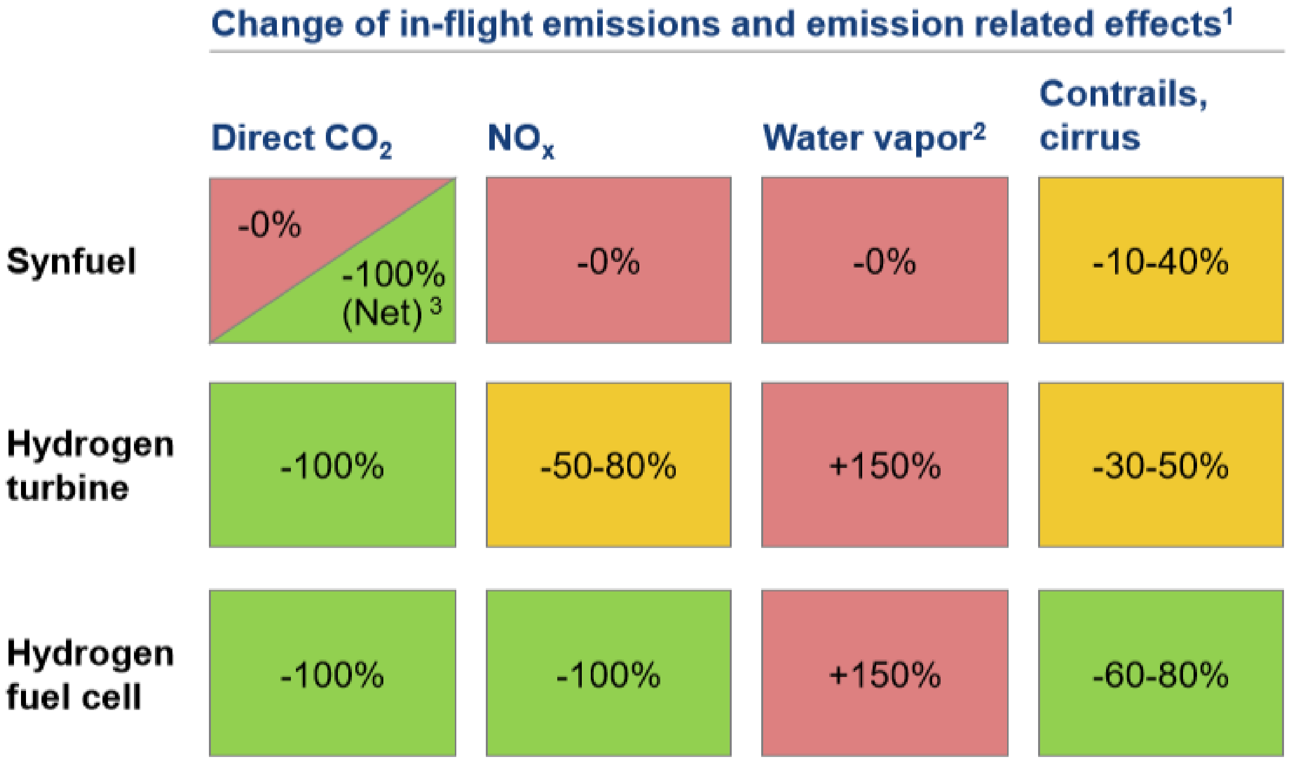
# Climate Impact

H2 propulsion has no CO2 emissions and biggest potential to reduce climate impact*

**Ongoing scientific debate** about **full climate** impact, in particular:

- Contrail/cirrus formation
- Aggregate measure

**Total climate impact could be 2 to 4 times** compared to $CO_2$ emissions alone



**Change of in-flight emissions and emission related effects[1]**

| | Direct $CO_2$ | $NO_x$ | Water vapor[2] | Contrails, cirrus |
|---|---|---|---|---|
| **Synfuel** | -0%<br>-100% (Net)[3] | -0% | -0% | -10-40% |
| **Hydrogen turbine** | -100% | -50-80% | +150% | -30-50% |
| **Hydrogen fuel cell** | -100% | -100% | +150% | -60-80% |

**Climate impact reduction potential[4]**

**-30-60%[3]**

**-50-75%**

**-75-90%**

1. No full LCA considered, but assuming decarbonized production and transportation of fuels in 2050
2. 10 times lower climate impact than from $CO_2$ emissions
3. Net $CO_2$ neutral if produced with $CO_2$ captured from the air
4. Measured in $CO_2$ equivalent compared to full climate impact of kerosene-powered aviation

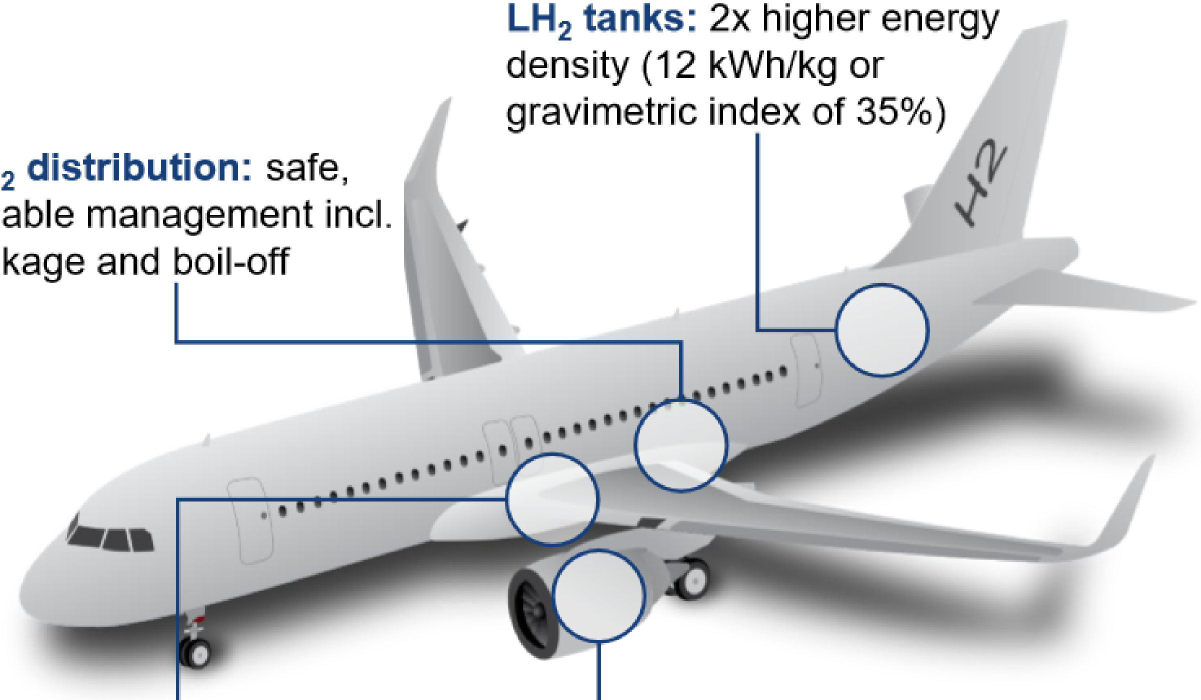
* High Uncertainty on non-CO2 effects!

# Aircraft Design

## 4 Technology Improvements could enable H2-aircraft

**TIMEFRAME 2035**

EXEMPLARY PICTURE



**$LH_2$ tanks:** 2x higher energy density (12 kWh/kg or gravimetric index of 35%)

**$LH_2$ distribution:** safe, reliable management incl. leakage and boil-off

**Fuel cell system:** 2-3x higher power density (2kW/kg), high life-time

**$H_2$ turbines:** high efficiency and low NOx emissions

### Example result of simulation of H2-powered short-range aircraft

**Mission:** 2,000 km, 165 PAX, Mach 0.72

**Propulsion:** parallel hybrid of $H_2$ turbines and fuel cell system

**Evolutionary design:** adjusted for $LH_2$ systems, **+10% longer fuselage**

**100%** decarbonization

**75%** climate impact reduction

**-5% energy** demand

**15 years** to entry-into-service

# Three major infrastructure challenges

## Refueling challenge most significant – Significant investment required

- ⬜ Can be accommodated in prevailing infrastructure
- 🟦 Updates of infrastructure / operations required
- ■ Full overhaul of infrastructure / operations required

| | | **Until 2040 (hydrogen 15% of fleet)** | **From 2040 to 2050 (hydrogen 40% of fleet)** |
|---|---|---|---|
| 1 | **$H_2$ production and distribution for aviation** | ⬜ **5% of global hydrogen** demand<br>Can be **served with $LH_2$ trucks** from central production sites or on-site | 🟦 **10% of global hydrogen** demand<br>At-scale distribution **requires pipelines** to airport |
| 2 | **Required $LH_2$ airport infrastructure** | ⬜ **Centralized liquefaction** (unless on-site production)<br>**Truck-based** refueling<br>**No** major infrastructure updates | 🟦 **Onsite liquefaction**<br>**At-scale** refueling systems<br>**Larger** gate sizes and on-ground traffic changes |
| 3 | **Refueling times** | 🟦 **Within usual turnaround times** for shorter range flights<br>**New safety regulations required** for parallel operations | ■ **Extends beyond usual turnaround times** for longer range flights[1] |
| | | **No major roadblocks in early ramp-up years** | **Significant but manageable challenges in scale-up years** |

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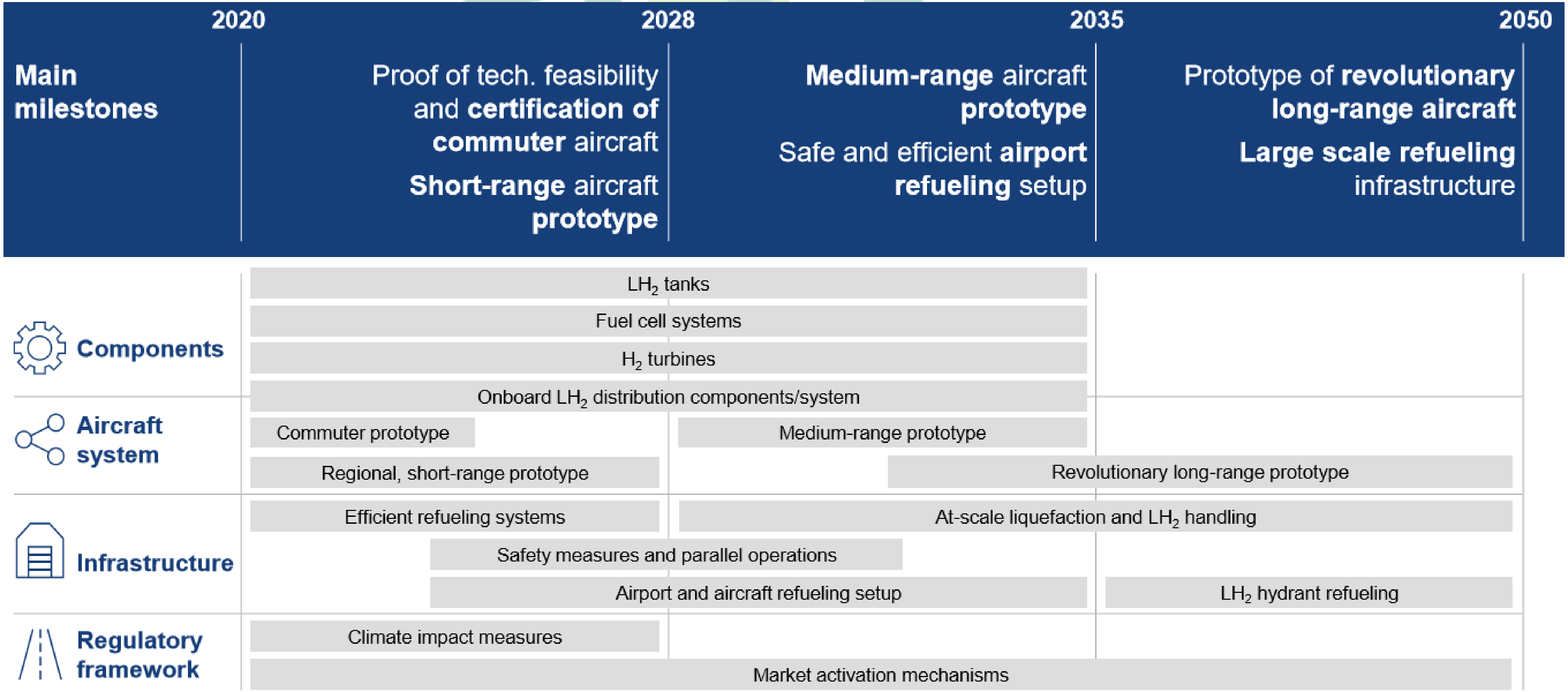
[1] Considering similar flow rates like kerosene and double the amount of refuelling points

# Significant Research & Innovation required : $H_2$-Agenda

4 main research areas for roadmap



| | 2020 | 2028 | 2035 | 2050 |
|---|---|---|---|---|
| **Main milestones** | | Proof of tech. feasibility and **certification of commuter** aircraft<br>**Short-range** aircraft **prototype** | **Medium-range** aircraft **prototype**<br>Safe and efficient **airport refueling** setup | Prototype of **revolutionary long-range aircraft**<br>**Large scale refueling** infrastructure |

**Components**

- $LH_2$ tanks
- Fuel cell systems
- $H_2$ turbines
- Onboard $LH_2$ distribution components/system

**Aircraft system**

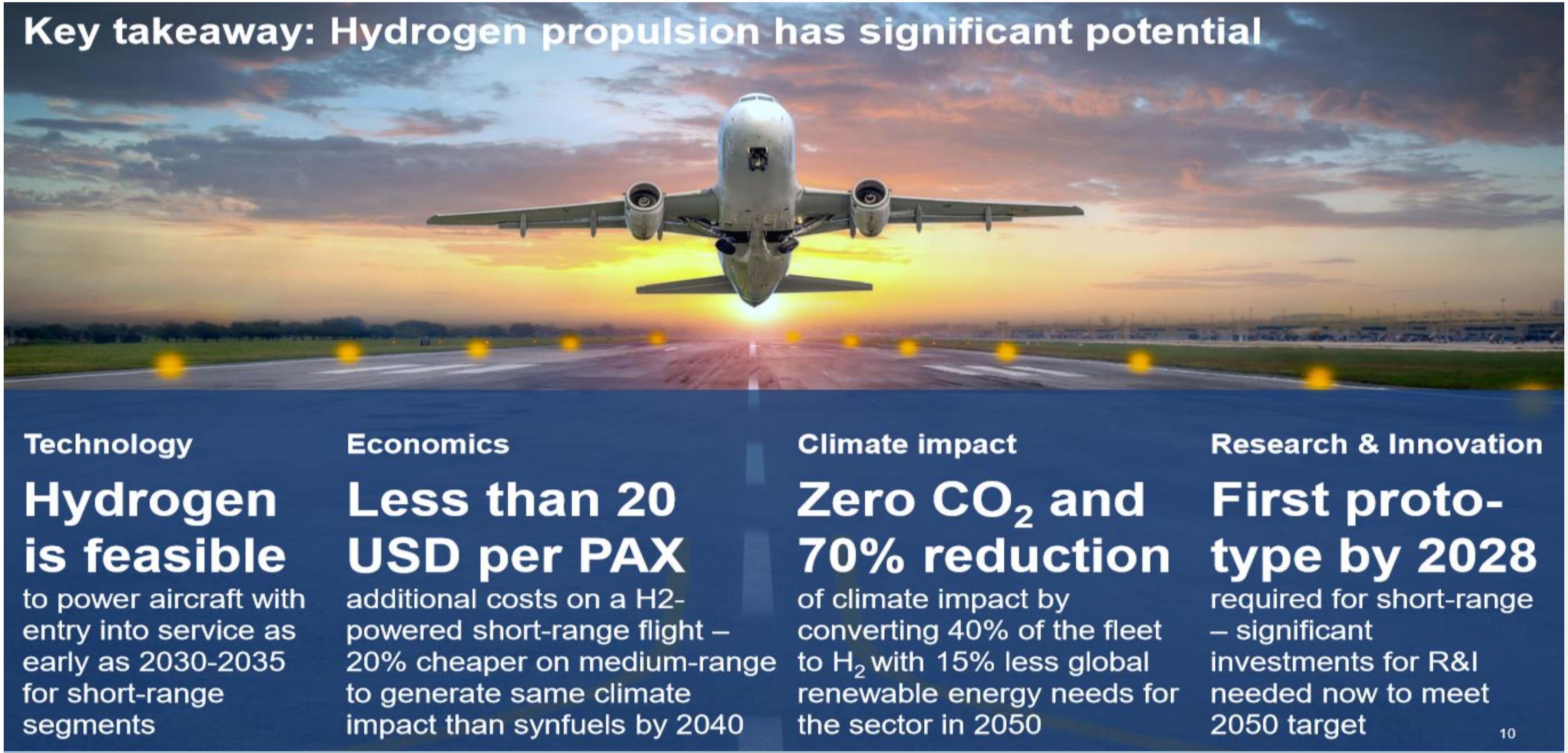
- Commuter prototype
- Medium-range prototype
- Regional, short-range prototype
- Revolutionary long-range prototype

**Infrastructure**

- Efficient refueling systems
- At-scale liquefaction and $LH_2$ handling
- Safety measures and parallel operations
- Airport and aircraft refueling setup
- $LH_2$ hydrant refueling

**Regulatory framework**

- Climate impact measures
- Market activation mechanisms



## Key takeaway: Hydrogen propulsion has significant potential

**Technology**

**Hydrogen is feasible**
to power aircraft with entry into service as early as 2030-2035 for short-range segments

**Economics**

**Less than 20 USD per PAX**
additional costs on a H2-powered short-range flight – 20% cheaper on medium-range to generate same climate impact than synfuels by 2040

**Climate impact**

**Zero $CO_2$ and 70% reduction**
of climate impact by converting 40% of the fleet to $H_2$ with 15% less global renewable energy needs for the sector in 2050

**Research & Innovation**

**First proto-type by 2028**
required for short-range – significant investments for R&I needed now to meet 2050 target

10

**High risk / High reward**
opportunity
for a game changing
impact

**$H_2$ not the single fuel of the future**
synfuels are likely remain the preferred solution for Long Range even beyond 2050

**High uncertainty on climate impact**
particularly
for **non-CO2 effects**

**Research, Demonstration and Investments needed now !**

# Thank You

ICAO