Renewable Energy and Hydrogen in Commercial Aviation

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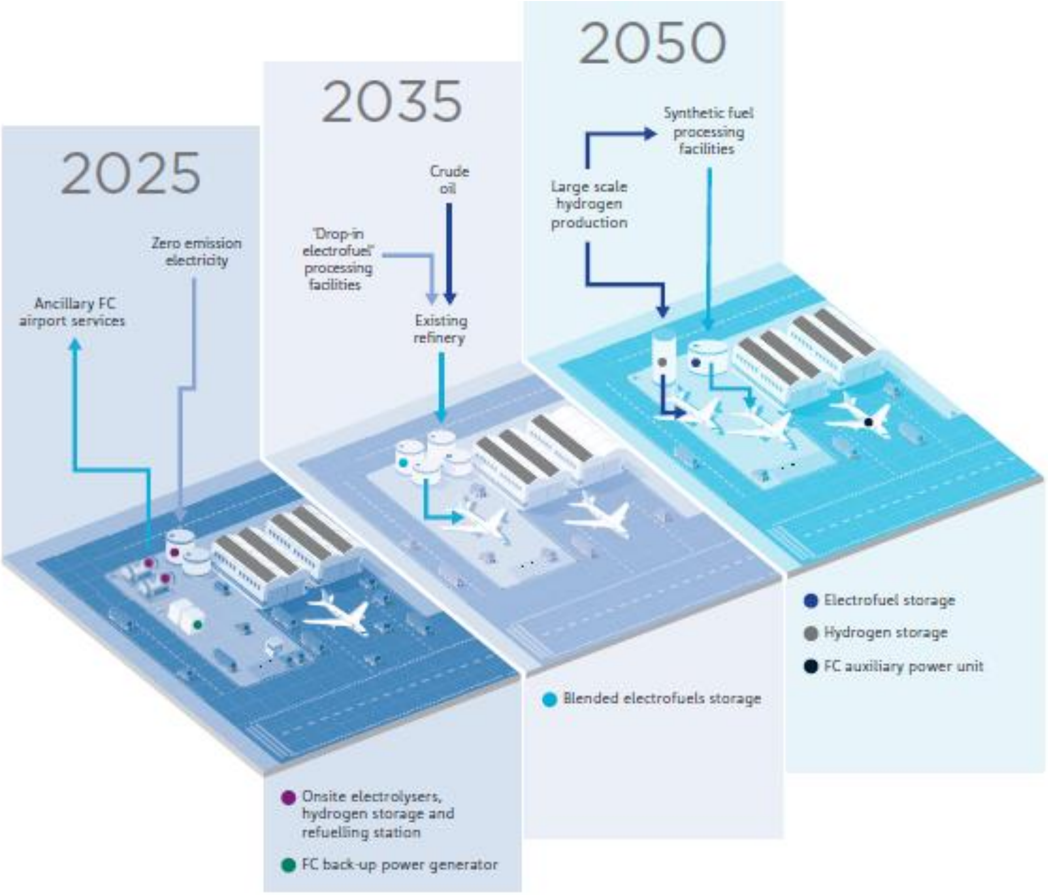
Opportunities for clean hydrogen in aviation
CSIRO, Boeing collaboration

1. *On/adjacent airport*
   H2 for GSE and fuel cell GSE
   Mobility to/from/within airport

2. *Existing infrastructure*
   Green H2 in sustainable fuel production – Bio SAF and PtL SAF

3. *Emerging infrastructure*
   Non-propulsion applications and H2 for propulsion via fuel cell and combustion

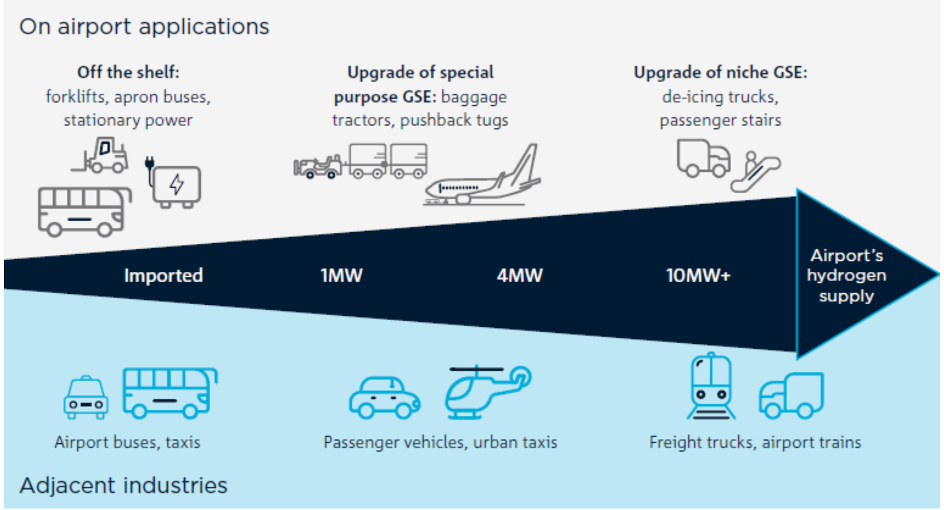


Source: Opportunities for clean hydrogen in aviation. CSIRO. 2020.

On/adjacent airport applications create H2 entry point

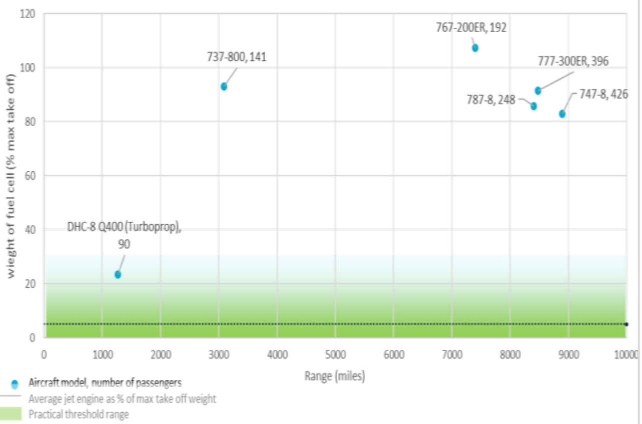
- Significant scale with a lower risk profile by prioritising ‘off-the-shelf’ technologies (e.g. forklifts, cars, buses and stationary power)
- Service adjacent transport industries (e.g. fleet, buses, freight and possibly trains)
  - Multiple public refuelling stations operating at airports such as Tokyo, Gatwick, LAX

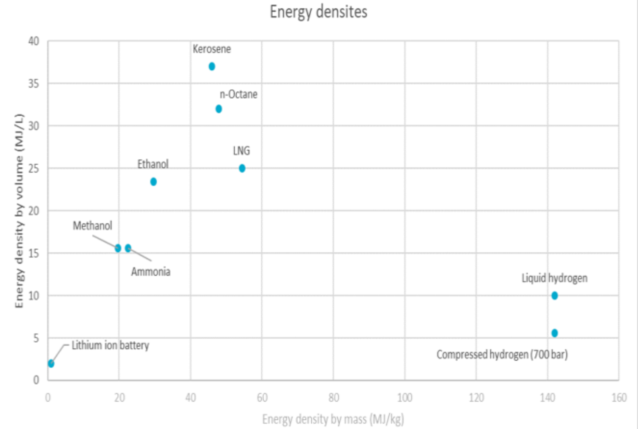
Near term airport applications create potential entry point from which to develop and utilize H2 infrastructure



Source: Opportunities for clean hydrogen in aviation. CSIRO. 2020.

Emerging Infrastructure: Hydrogen for propulsion





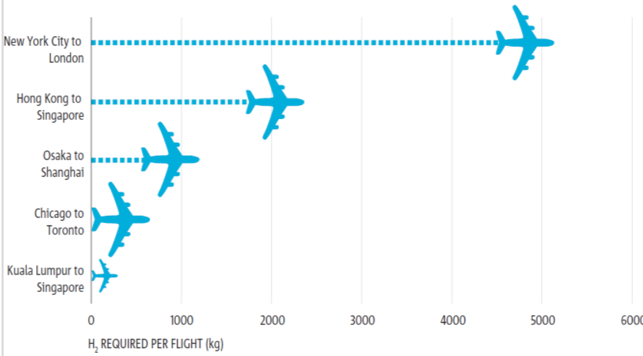


Figure 24. Quantities of hydrogen required for most travelled flight paths[189]

Hydrogen fuel cells

- Significant potential for hydrogen fuel cells (for propulsion) to disrupt the current turboprop market, i.e. shorter haul flights up to 1000 miles and 100 passengers
- Unlikely to provide economical solutions for long distance flights with heavy payloads that currently rely on the use of traditional jet engines

Hydrogen augmented fuels

- Hydrogen-augmented fuels such as ammonia and methanol (i.e. non-drop-in electrofuels) require less extensive changes to airplane and engine design
- With the exception of LNG, have poorer energy densities compared to kerosene which limits competitiveness for long haul travel

Hydrogen for combustion

- Cryogenic hydrogen has a superior energy density by mass compared with kerosene and produces no CO2 emissions upon combustion (other challenges include NOx and contrails)
- Aside from challenges relating to storage and handling, the primary obstacle stems from its poor volumetric density

Source: Opportunities for clean hydrogen in aviation. CSIRO. 2020.

ATAG Waypoint 2050 technology assessment

- Electric & hydrogen initial commercial market entry in regional markets in 2030's, short haul markets in 2040's
- Medium and long haul markets assessed to require hydrocarbon fuel over long term

An indicative overview of where low- and zero-carbon energy could be deployed in commercial aviation

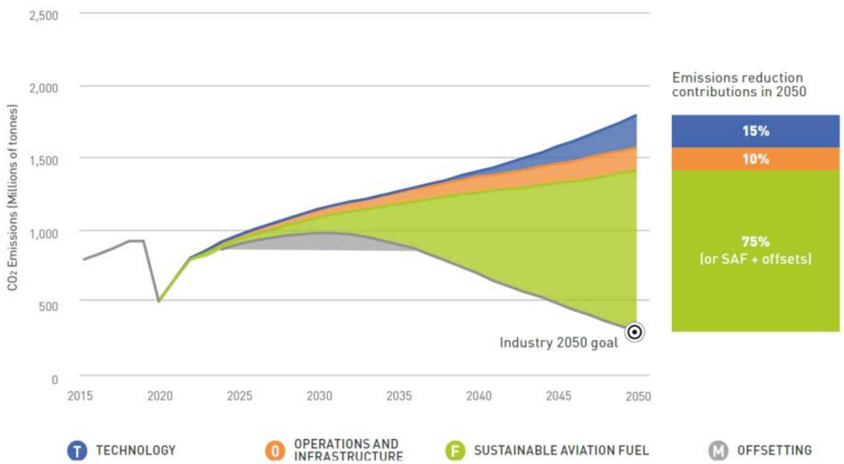
	2020	2025	2030	2035	2040	2045	2050
Commuter » 9-50 seats » <60 minute flights » <1% of industry CO_2	SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF	Electric and/or SAF
Regional » 50-100 seats » 30-90 minute flights » ~3% of industry CO_2	SAF	SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF	Electric or Hydrogen fuel cell and/or SAF
Short haul » 100-150 seats » 45-120 minute flights » ~24% of industry CO_2	SAF	SAF	SAF	SAF	Electric or Hydrogen combustion and/or SAF	Electric or Hydrogen combustion and/or SAF	Electric or Hydrogen combustion and/or SAF
Medium haul » 100-150 seats » 60-150 minute flights » ~43% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF	SAF Potentially some Hydrogen
Long haul » 250+ seats » 150+ minute flights » ~30% of industry CO_2	SAF	SAF	SAF	SAF	SAF	SAF	SAF

Source: ATAG Waypoint 2050 Report

ATAG Waypoint 2050: Electric and hydrogen technologies have the potential to reduce required SAF production by up to 100+ Mt of SAF

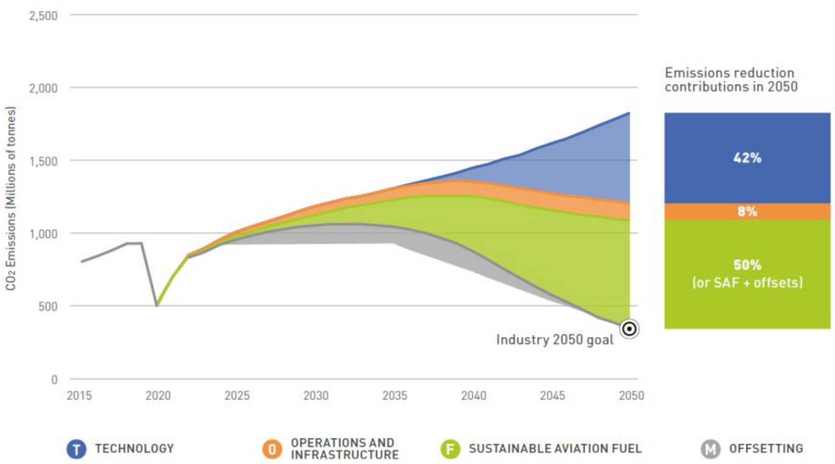
New conventional technology (Scenario 1)

350 — 450 Mt (440 — 570 billion litres) of SAF



Aspirational and aggressive electric and hydrogen development (Scenario 3)

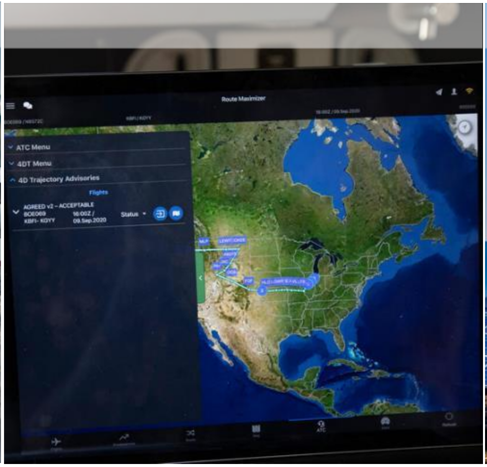
235 — 340 Mt (290 — 420 billion litres) of SAF



Source: ATAG Waypoint 2050 Report

The path to 2050: bigger solutions for a smaller footprint

Airline Fleet Replacement



Network Operational Efficiency

Renewable Energy Transition

Future Airplane Technology

Summary

- Addressing climate change and transitioning aviation to renewable energy is a tremendous challenge
- Success requires aviation system level strategies – with a wide solution space
- The emergence of green hydrogen can contribute in multiple ways – airports, fuels, airplanes
- Scaling up sustainable aviation fuels (SAF) is essential in all forecasted scenarios

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