

Sustainable Air Transport

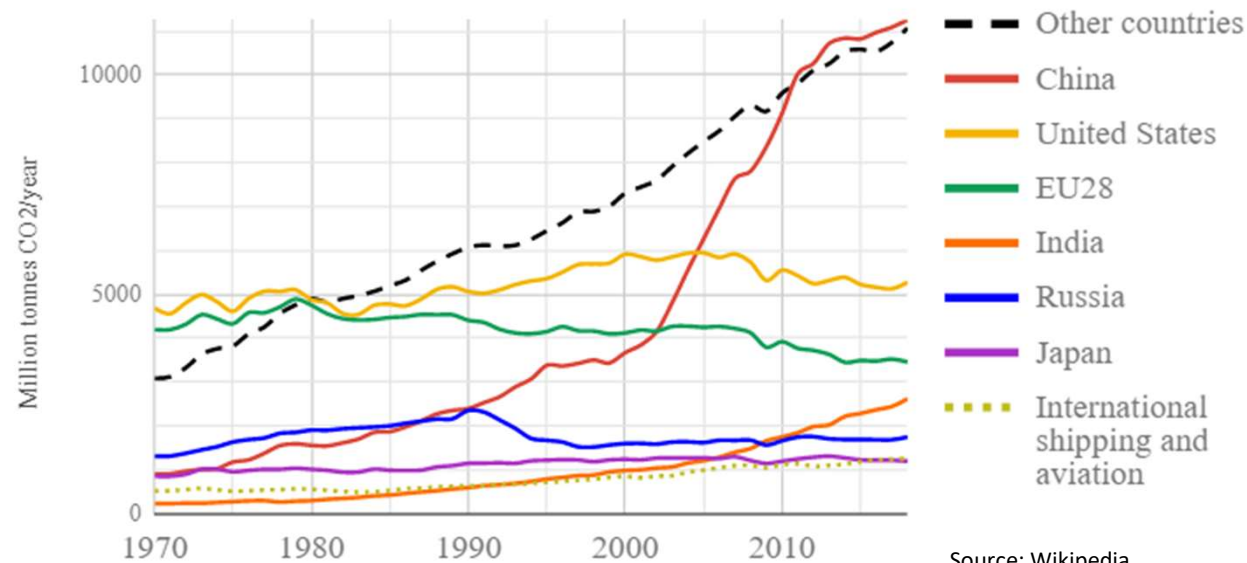
DIFFERENT ALTERNATIVES TO REDUCE AIR TRANSPORT EMISSIONS

Agenda

- Is there a CO2 problem?
- What about electric or electric-hybrid as solutions?
- Hydrogen as aviation fuel solution?
- Hydrogen challenges and possibilities

Is there a CO2 problem?

World fossil carbon dioxide emission 1970-2018



Is the CO₂ problem an air transport problem?

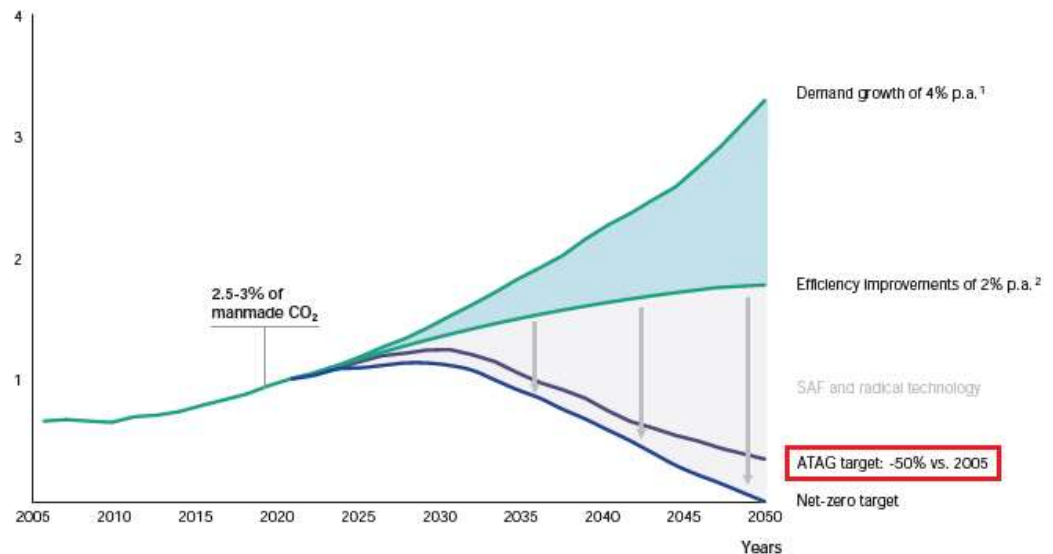
Air transport's part of CO₂ emissions are increasing

The aviation community (ATAG, IATA) has committed a reduction to 50% of 2005 CO₂ levels by 2050

- The present initiatives will not get us there
- Electric and Hybrid airliners will not get us there
 - Explained why on the next slides
- Remains replacing the CO₂ producing Jet fuel with other fuels
 - SAF (bio or synthetic aviation fuel) will be a part solution, used for long haul flights
 - SAF cannot be produced in enough quantities to replace the bulk of Jet fuel, hydrogen can

Projection of CO₂ emissions from aviation

Gt CO₂ emissions from aviation
Does not include compensation schemes



1. Assumption based on growth projections from ATAG, IATA, ICCT, WWF, UN
2. ICAO ambition incl. efficiency improvements in aircraft technology, operations and infrastructure

Source: EU

Are electric or electric-hybrid solutions?

Electric works for cars as these have a 5%-7% efficiency

- Cars use 5%-7% of the energy in the fuel
- Then it's not hard to find more efficient solutions

Airline engines have 40% to 50% efficiency

Jet fuel has 12kWh/kg energy content, Flight certified batteries systems 0.15kWh/kg

- Battery energy for a flight weigh **80 times** as much as Jet fuel
- The weight is constant during the flight, fuel weight declines with 80%
- This kills all battery based flying vehicles except UAMs

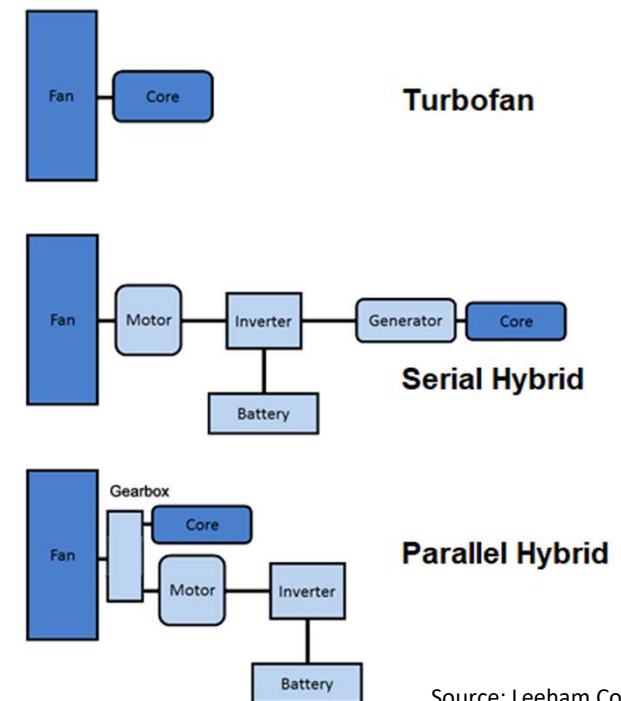
Are electric or hybrid solutions? 2(3)

Hybrid airliners are possible

- The parallel hybrid has the best potential
- But it's increased complexity for no gain

The weight of the battery kills their efficiency, no matter what solution is chosen

Embraer Commercial CEO A. Meijer said last month re. a new Embraer turboprop:
“To add a hybrid-electric powertrain – even one delivering as little as 5-10% of the total requirement – would increase operating costs by 15%.”



Source: Leeham Co.

Are electric or hybrid solutions? 3(3)

- Putting a starter generator on the high or low spool of a turbofan to assist with spool acceleration-deceleration works
 - But calling it a hybrid is stretching the truth
- It's been investigated for decades and hasn't been called a hybrid all this time
 - Changing this now is pure marketing



Source: Rolls-Royce

Hydrogen as aviation fuel solution?

Hydrogen is the Universe's most common substance

- It's non-toxic and produces no CO₂ when burned

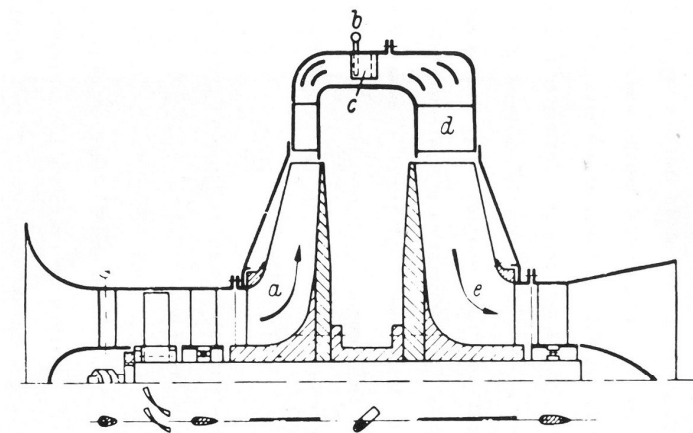
Hydrogen fueled the World's first jet engine

- Von Ohain's first jet engine ran on hydrogen
- It's easy to convert a gas turbine to hydrogen

It has three times the energy per kilo of Jet fuel (which is good) and four times the volume (which is less good)

It's less dangerous than Jet fuel as it doesn't spread like leaking kerosene

- It's non-toxic and is quickly absorbed by the atmosphere = no sanitation after leaks
- It burns straight up from a leak if ignited in the presence of oxygen



RADIAL TURBOJET (He S-1)
WITH HYDROGEN
(Built in 1936; tested in April 1937)

Radius of rotor - 1'

Thrust - 250# Source: Wikipedia

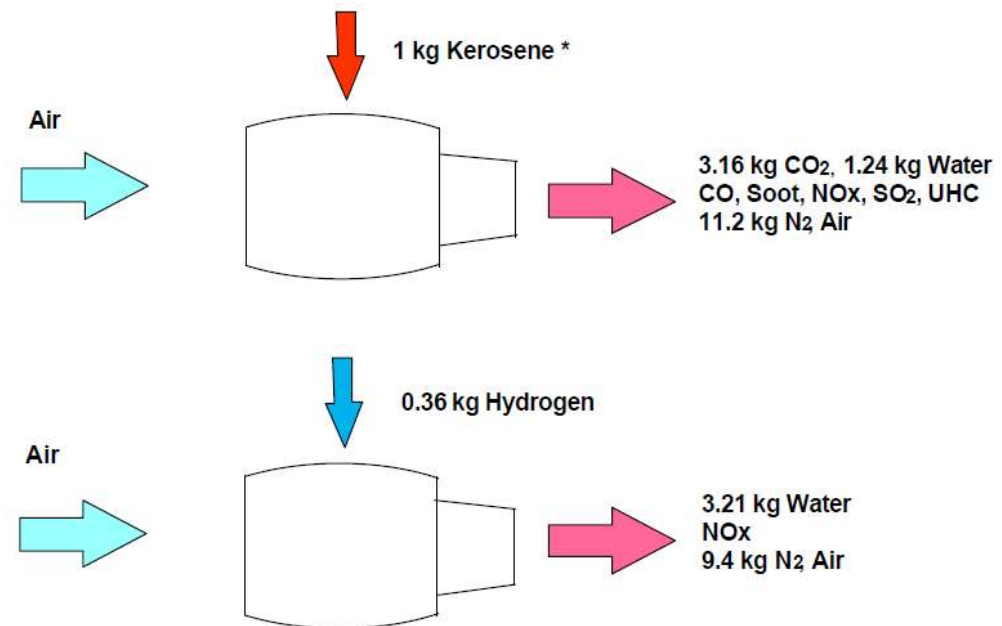
Hydrogen has very low emissions

Hydrogen when combusted in a gas turbine produces H₂O instead of CO₂

- It's easy to convert a turbofan to run on hydrogen
 - It runs better and cleaner
 - No CO₂ emissions
 - The H₂O emission forms larger crystals, making the contrails less problematic
 - NO_x emissions are about 20% of today's Jet fuel turbofans

Hydrogen-fueled airliners would solve our green house gas emission problems

Emissions (*Fuel masses of equal energy content)



Source: Airbus Cryoplane study

Hydrogen can transport energy

Hydrogen is an energy transport vehicle

- Today's production is from Carbon based gas
 - This doesn't solve the CO₂ problem

Green hydrogen production through hydrolysis of water is increasing

- It's 100% emission free if the energy is green
- But it's very energy consuming

The Sun supplies an abundance of low-cost green energy that we don't use

- 1kW/m² in the deserts and oceans on a clear day
- We haven't captured it as we can't store and transport it
- Hydrogen is an efficient store and transport method for energy

The hydrogen economy is about green energy that's stored and transported

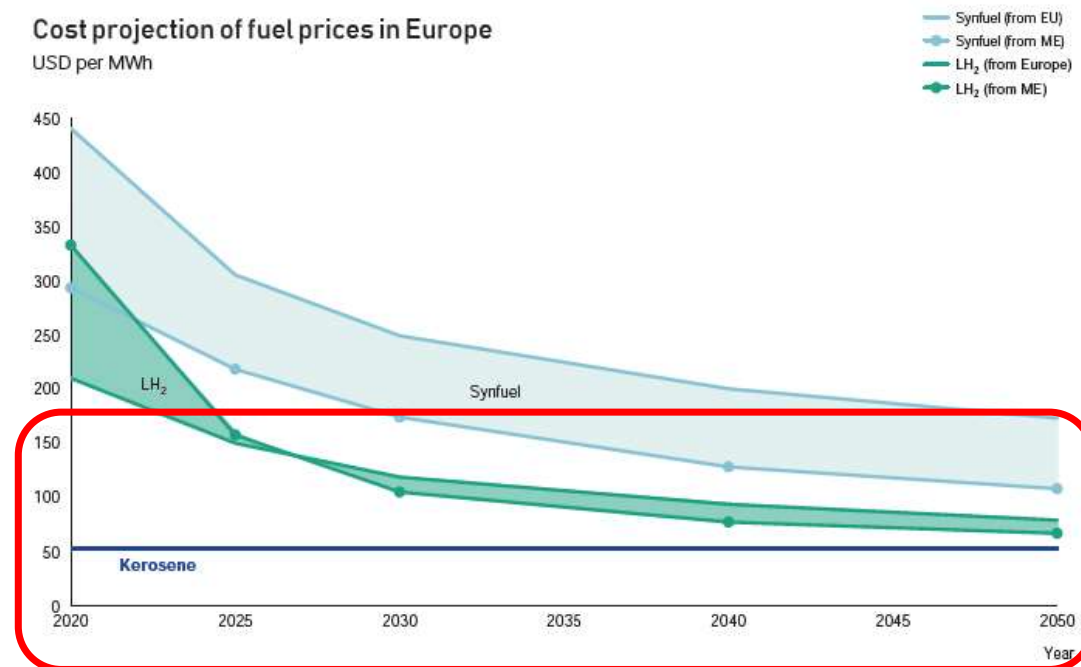


Hydrogen production and price

Hydrogen, as a new fuel will be more expensive initially

- Its eco-system is building (early days still)
- Today's production is from Carbon-based gas
 - This doesn't solve the CO₂ problem
 - Green production through hydrolysis of water is increasing
 - But it's energy consuming
- A green eco system builds on capturing low-cost energy in remote places and transporting it through hydrogen
 - Hydrogen production through electrolysis can be very local
 - Transportation of hydrogen is well developed
 - EU's gas network can be converted to mix-in of hydrogen from low percentage to 100%

Cost projection of fuel prices in Europe
USD per MWh



Source: EU

A hydrogen airliner

First hydrogen airliner flew in 1988, Tu-155

- A joint Airbus and Tupolev project
- Proved the easy conversion of a turbofan to hydrogen

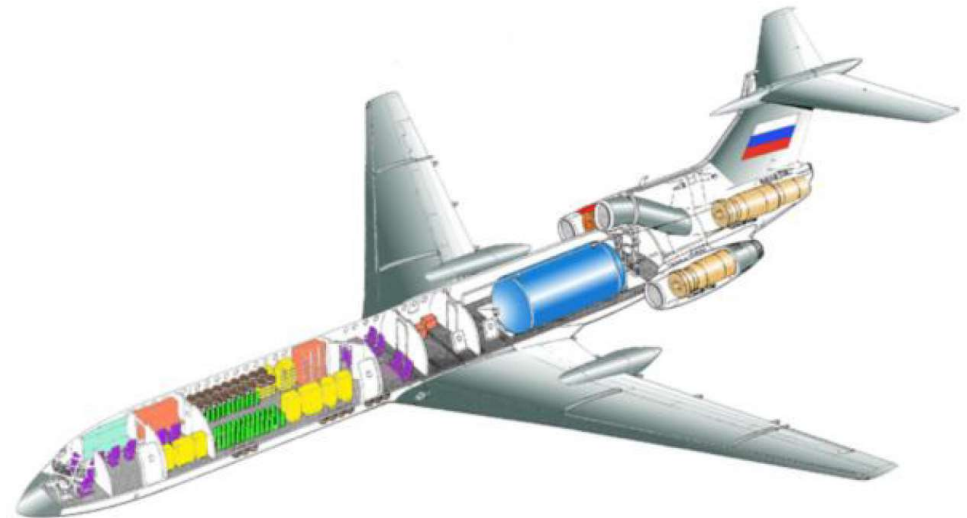
The tanks storage of H₂ is the biggest problem

- It's four times the volume when in liquid form
- It requires -253°C LH₂ temp
- H₂ also embrittles materials

These problems are known and solved by the launcher industry

The work from now on will focus the tank problem

- Converting the engines is a small problem in comparison



Source: Wikipedia

The hydrogen airliner tank

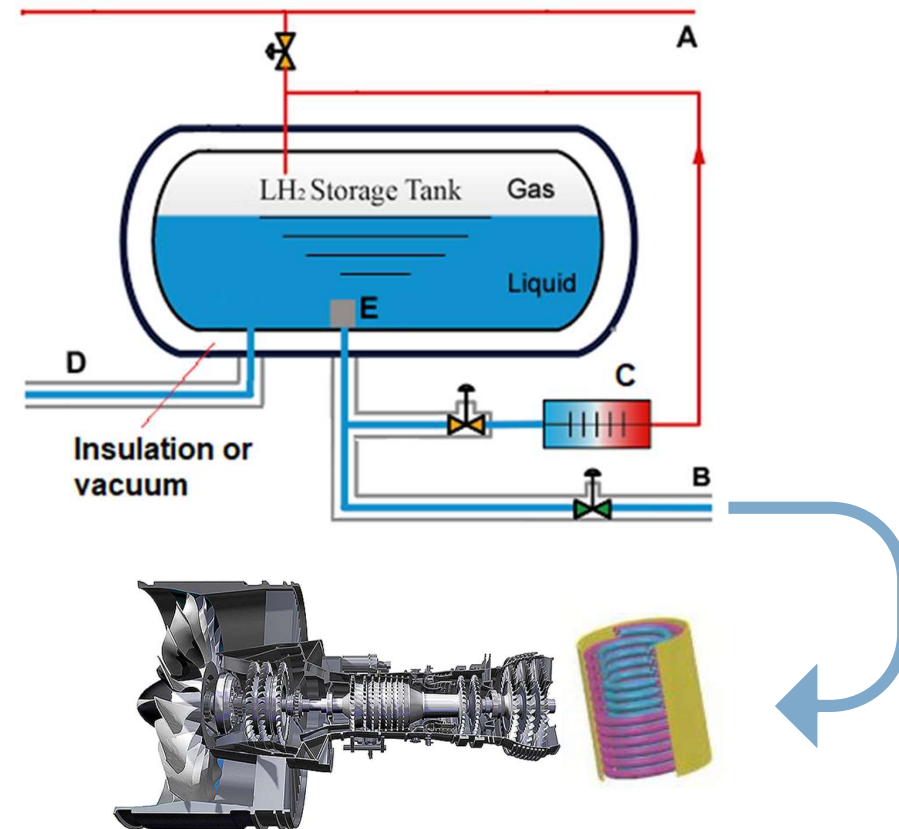
The tank stores the LH₂ at -253°C

- Any LH₂ that goes above this temperature boils to gas, lowering the LH₂ temp. in the process
- Surplus H₂ gas can be used in a fuel cell that replaces the APU feed through A
- Any additional H₂ to the fuel cell is through C

Tanking LH₂ is through trucks and an isolated pipe system (D)

Fuel to the engines is transported as LH₂ at B

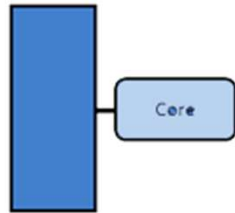
- The H₂ is converted to gas before entering the engine combustors in a tailpipe heat exchanger



Source: Leeham Co.

The hydrogen airliner propulsion

Propeller,
Propfan or
Fan



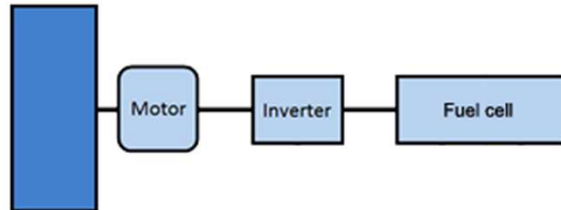
A320 size 165 seater

Gas turbine core

- 55% efficiency, 4t

Regional jet

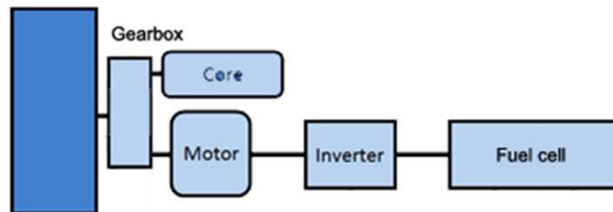
45% eff. 1.2t



Serial fuel cell + motor

- 55% efficiency, 20t

53% eff. 3.2t

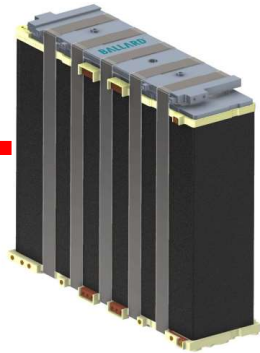


Parallel hybrid fuel cell + motor + gas turbine
• 55% efficiency, 11.5t
not proposed

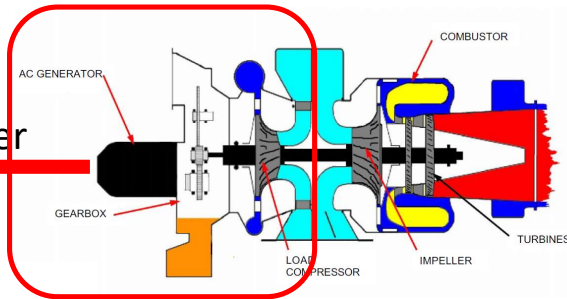
Source: Leeham Co.

The hydrogen airliner APU

Electric power



Electric power



The **Auxiliary Power Unit** function suits the fuel cell:

- It delivers electric power, which is what's needed for the aircraft's systems
- It's efficiency is double that of the gas turbine APU at the same installed weight:
 - ~40% compared with <20% for the classical APU.
- It can use the boil-off H₂ from the hydrogen tank.
- It enables an elegant “more electric” system architecture for the aircraft.

Source: Leeham Co.

The Airbus ZEROe concepts

The Airbus ZEROe concepts shows the research direction for Airbus:

- All use hydrogen as fuel
- All use converted gas turbine engines
- The replacement of the APU with a fuel cell is researched
- The tube and wing jet and turboprop has the LH₂ tank in the rear

Airbus is driving several technology projects already

Expect a hydrogen demonstrator at Paris Air Show 2027

Commercial jet EIS by 2035



Source: Airbus

